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Panel 7 – Mechanical and Industrial Engineering

Research Assessment Exercise (RAE) 2021, self-evaluation

Coordinator: Prof. Lihui Wang
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Organisation

Organisation schedule

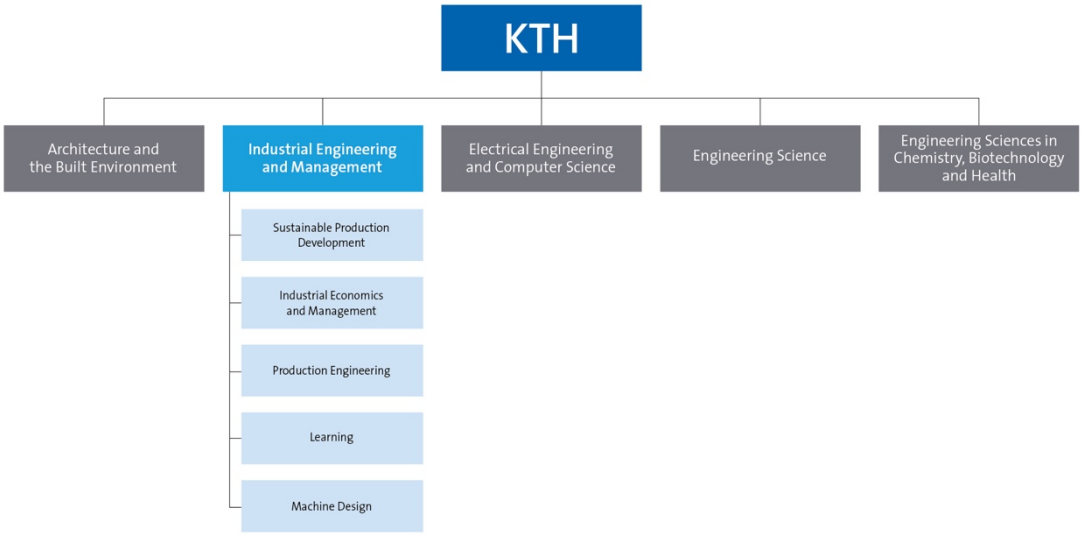

Figure 1: Panel's position in KTH's organisation

Involved units

School of Industrial Engineering and Management
Head of School: Prof. Pär Jönsson

- **Department of Sustainable Production Development (HPU)** Webpage
  Head of Department: Prof. Magnus Wiktorsson
    - **Industrial dependability**, Prof. Andreas Archenti
    - **Production logistics**, Prof. Magnus Wiktorsson
    - **Production management**, Prof. Monica Bellgran
- **Department of Industrial Economics and Management (INDEK)** Webpage
  Head of Department: Prof. Cali Nuur
    - **Management & Technology**, Assoc. Prof. Lars Uppvall
    - **Sustainability, Ind. Dynamics & Entrepreneurship**, Assoc. Prof. Frauke Urban
    - **Accounting, Finance, Economics and Organization**, Assoc. Prof. Gustav Martinsson
- **Department of Production Engineering (IIP)** Webpage
  Head of Department: Prof. Mauro Onori
    - **Digital Smart Production**, Assist. Prof. Antonio Maffei

  - **Manufacturing & Metrology Systems**, Assoc. Prof. Daniel Tesfamariam Semere
  - **Sustainable Production Systems**, Prof. Lihui Wang

- **Department of Learning in Engineering Sciences (LES)** Webpage
  Head of Department: Prof. Arnold Pears
  - **Division of Digital Learning**, Morgan Mickelsson
  - **Division of Language and Communication**, Assoc. Prof Rebecca Hincks
  - **Division of Learning in STEM**, Prof. Lars Geschwind
  - **The House of Science**, Assoc. Prof. Cecilia Kozma

- **Department of Machine Design (MMK)** Webpage
  Head of Department: Assoc. Prof. Martin Edin Grimheden
  - **System and Component Design**, Prof. Sergei Glavatskih
  - **Internal Combustion Engines**, Assoc. Prof. Andreas Cronhjort
  - **Mechatronics and Embedded Systems**, Assoc. Prof. Martin Edin Grimheden
  - **Integrated Product Development and Design**, Dr. Susanne Nilsson

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Part A: Introduction of panel

1. Description of the research field of the departments included in the research panel

Founded in 1827, KTH Royal Institute of Technology in Stockholm is one of Europe's leading technical and engineering universities, with students, researchers and faculty from around the world. Gathering more than 13,000 full-time undergraduates, over 1,700 PhD students and approximately 3,600 full-time employees, KTH is Sweden's largest technical university. As shown in Figure 1, KTH is subdivided in five schools. Panel 7 includes five out of seven departments within the School of Industrial Engineering and Management (ITM). Each department is described in a self-evaluation (Part B).

2. Description of the self-evaluation process for the research panel

The Coordinators for Panel 7 have worked together with the Heads of the five departments. The Coordinator is also the liaison to the RAE 2020 Team led by KTH Vice President for Research. The Panel 7 team maintains regular meetings to discuss the progress and issues related to departmental self-evaluations. Seminars at the school and department level have been used to raise awareness and improve the reports.

3. Identified research panel synergies

In response to recommendations in RAE 2012, the ITM school overarching Research Initiative on Sustainable industry and society (IRIS), an internally funded, interdepartmental research integration effort, was launched in 2019 as a component of the *ITM Development Plan*, 2018-2023:

> *"... to lead the transition towards a zero-emission, adaptable industry for a sustainable society characterized by new product and service designs, new materials, new business models, sustainable energy systems, recycling, reuse and remanufacture."*

The IRIS initiative responds to the challenges and opportunities formed by ongoing technological shifts and by the sustainability crisis. This response uses and directs new technological capabilities including digitalisation to address sustainability. New multidisciplinary collaboration is required since the challenges go beyond what individual departments and academic disciplines can handle. See Figure 2.

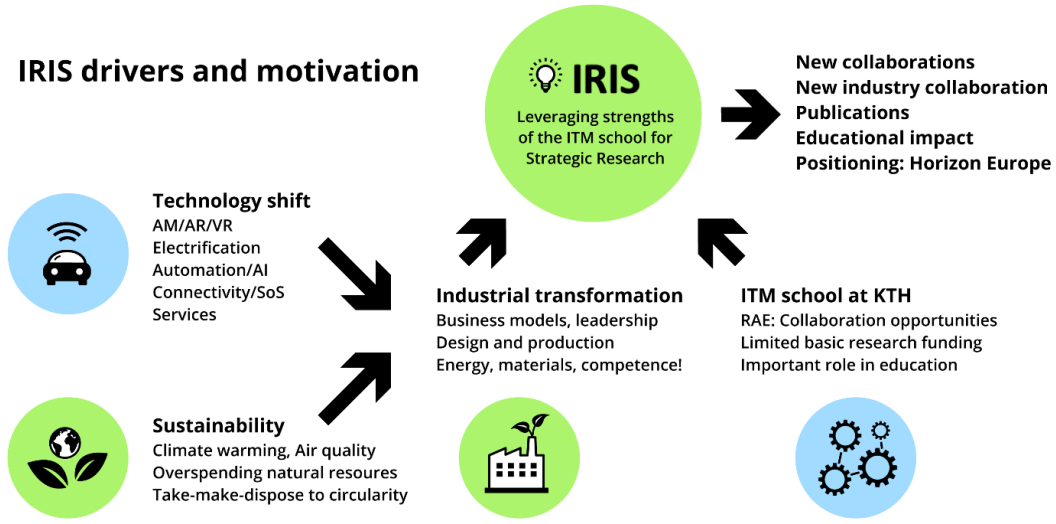


Figure 2. The IRIS initiative – drivers, motivation, and expected results

The ITM school and the five departments are well positioned to address these challenges given their strengths in relevant fields including materials, design, manufacturing, energy, business models, leadership, learning/education, systems engineering and in applied areas of digitalisation. RAE 2012

was a strong incentive for the ITM school in formulating the IRIS initiative. In particular, the need to systematically address collaboration between the involved disciplines and departments was highlighted. The following are representative quotes from the RAE 2012 reviewers:

- *"The strategic opportunity for KTH to use its current competence and enthusiasm for sustainability is being lost through allowing a dis-integrated drift of separate actions and plans."*

- *"Providing incentives and environments for enhancing internal collaboration within KTH"*

RAE 2012 also emphasized the need to focus on breakthrough topics including those involving multidisciplinary, and digital and real systems, i.e. cyber-physical systems. As elaborated in the ITM Development Plan, IRIS encompasses the following four areas:

- Industrial transformation through sustainable digitalisation

- Integrated mechanics, components and materials design, including additive manufacturing

- Sustainable energy systems, infrastructure and business

- Innovation and entrepreneurship ecosystems and infrastructure

The current plan for IRIS encompasses 2020 through 2023, with a budget of about 20 MSEK/year. Started in 2019, initial work involved assigning coordinators and reference groups per area, and initiating a strong, involved and open faculty debate to engage and anchor the initiative in a collaborative spirit. Actions include formulating IRIS cross-department projects, appointing 12 postdoc positions, engaging faculty to work part time in IRIS (as a kind of internal sabbatical), inviting visiting scholars, organising a seminar series and planning strategic infrastructure investments. The new postdoc program will be used first for the IRIS postdocs and then continued within the ITM school.

In addition, IRIS involves strategic collaboration, as follows:

- A dialogue with the KTH *platforms* and in particular a close collaboration with the recently formed platform on Industrial Transformation.

- A dialogue with industrial partners, initially through the ITM school Strategic Council.

- Coordination meetings between all ITM hosted centres and centre-like initiatives, especially the circular economy initiative.

- Collaboration with other schools, by leveraging existing collaboration through the centres. As an example, we can mention the excellent collaboration with the EECS school through the ICES centre (existing) and the new Vinnova competence centre on Trustworthy Edge Computing Systems and Applications (led by ITM and with close EECS collaboration).

In summary, IRIS represents a direct response to the RAE 2012 evaluation and a new type of strategic and integrative initiative at KTH. It fertilises the research synergies across the five departments involved in Panel 7.

Part B: Report for each department

Department of Sustainable Production Development

Self-evaluation
Head of Department: Professor Magnus Wiktorsson

Included research groups:

Research group of Industrial Dependability
Research group of Production Logistics
Research group of Production Management

Department of Sustainable Production Development (HPU)

1. Overall analysis and conclusion; strengths and development areas

a. Limited SWOT-analysis

The department of Sustainable Production Development (HPU) is located at KTH Södertälje, as the first KTH department on site. HPU could be considered a Research Startup, starting recruiting faculty in 2016-2017, even though KTH has had education activities in Södertälje for more than 30 years. The close-down of AstraZeneca R&D in Södertälje was the starting point for a joint initiative in 2014 between the Swedish government, KTH, Scania, AstraZeneca and Södertälje city, resulting in the launch of an expansion in education and an establishment of research. At the new facilities in Södertälje, inaugurated in January 2018, KTH develops research and education for sustainable production and industries of the future. A new faculty has been recruited with three new professors in place 2018, followed by the recruitment of researchers and PhD students. The HPU research is under heavy expansion and as of March 2021, a total of 30 researchers and PhD students are engaged within three research groups, whereof 25 are employed at the HPU department. Summarising the current strengths and weaknesses of the young research activities at the department of Sustainable Production Development gives the following bulleted list, in order of magnitude:

	Strengths	Weaknesses
Research	1. A relevant and up-to-date theme for the department. A common topic on sustainable production, with three focused research groups defined in collaboration with industry, and close proximity and engagement of industrial partners. 2. Entrepreneurial and impact-focused senior research leadership, where the three professors and main part of the staff have industrial working experience. New staff with a focus on expansion and industry collaboration.	1. So far, only smaller contributions to the body of scientific knowledge due to the early phase of the department's research engagement history. 2. First phase of acquiring external funding schemes, mainly relying on a few funding organisations. 3. First phase in terms of research collaboration. Relying on individual contacts at senior research level.
Organisation	1. A strong industrial and societal engagement, manifested in cash and in-kind support to the department's research positions and activities, as well as structured and continuous strategic and operational dialogues with partners. 2. Modern and attractive facilities in a new KTH-campus for education and research, located close to industrial partners. 3. Strong links between education and research; building upon new under-graduate and masters programmes.	1. Unbalanced proportion between senior staff and PhD students/postdocs. The expansion is still relying on a few senior researchers. 2. Immature in internal research and research education processes as well as infrastructure establishment and lack of support. 3. Ad hoc interfaces to other departments and initiatives within ITM and KTH as a whole.

b. Summary statement on contributions of department on impact, infrastructure and sustainable development

Summarising the strengths and weaknesses above, gives the five development areas at HPU:

- Creating a balanced research team comprising a good combination of senior and junior researchers, gender balanced and diverse, and continue to build on the inclusive culture that characterizes HPU.
- Expand the internal ITM and KTH collaboration within current teams as well as new areas of bioproduction/pharma and industrial analytics.
- Further establish research and research education processes and structures in order to prepare for own PhD program starting 2024.
- Continue to leverage upon the strong industrial commitment and relevant research theme, while also broadening the offer at KTH Södertälje within lifelong learning.
- Build a stable funding base from KTH as well as different funding agencies for future research projects, both on national and European level.

The following contributions from HPU to the three cross-panel subjects are identified:

Impact. The HPU department relies upon a close industrial collaboration in Sweden's most manufacturing-intense city. Södertälje is the municipality with the highest proportion of manufacturing value add per capita in all of Sweden (responsible for ~10 % of Swedish export). Impact on industry as well as on society are key reasons for KTH to exist in Södertälje. Industry impact is created by: (1) Students educated in close interaction with industry, gaining relevant and up-to-date education of relevance for the industry. (2) Mobility of staff and students between industry and KTH. (3) Research projects and research education co-produced between industry and KTH, enabling fast industrial adoption. (4) Professional education, both to large companies and SMEs. Societal impact is created by: (1) Local campus presence. (2) Broader recruitments, attracting more diverse groups of students than traditionally to KTH. (3) Reskill- and upskill activities to a wider set of individuals than explicitly from the two large companies of Scania and AstraZeneca. (4) Contribution to the forming Södertälje as knowledge city, supporting the brand and increasing the Stockholm-Södertälje region's attractiveness for manufacturing industry. (5) Supporting the growing emphasis on Stockholm-Mälardalen as a strong Swedish industry region of international importance.

Infrastructure. The establishment of research at KTH Södertälje is to be considered an infrastructural initiative with a purpose to build an academic knowledge environment in symbiosis with industry and society. The research profile of HPU is, therefore, based on close proximity to the world-leading manufacturing facilities of Scania CV and AstraZeneca as well SMEs, and the collaboration with the infrastructure of KTH LeanCenter and Södertälje Science Park. Södertälje Science Park is a physical environment with a consolidated strategy in focusing on "Sustainable Production" and the ambition to contribute to the area on a national basis in this first expansion phase. On a practical level, the research infrastructure within HPU is developed in close collaboration with our industry partners. After the inauguration of the new campus in January 2018, Scania for one year moved their Smart Factory Lab to KTH Södertälje campus, with a highlight when demonstrating the research infrastructure and the new campus to His Majesty the King in May 2018. The labs at HPU currently include a lean training arena, a production logistics lab, a digital twin lab, a prototyping lab, a product design studio, and education labs for physics, chemistry, measurement and electronics. The prototyping lab is coordinated with Södertälje Science Park and the initiative Open Prototyping Södertälje.

Sustainable development. The research at HPU is targeting the renewal and transformation of industrial production based on sustainability and digitalisation. The department is anchored within sustainability in the context of industrial production system development, change and operations, addressing the UN sustainable development goals 9, 12 and 13. Changes made in the way production systems are developed and managed has impact on, and is impacted by changes occurring in adjacent or connected infrastructure (e.g. transport). Incremental improvements and innovative solutions

within the production systems can reduce the environmental impact of industrial activities on both society and planet. All in all, the essence of KTH's research within sustainable production system development is to enhance technology and behaviour for responsible, sustainable and resilient industrial production. In addition, the HPU research team sets out to integrate research results in education on all levels, creating a "built-in-feature" of sustainability within all students at campus by e.g. dissemination of research into different courses. Given the indirect consequences of the ongoing virus pandemic, the emphasis on supply chains, production flexibility and ability to quickly adapt to new circumstances will most likely increase within manufacturing industry, implying the need for new knowledge, initiatives and competence that could be supported from HPU. HPU can in this respect act gateway for ITM and other schools at KTH.

2. Research profile

a. General information of the department

The department of Sustainable Production Development (HPU) is one of seven departments within the school of Industrial Engineering and Management (ITM) at KTH. HPU offers courses to eight education programmes at KTH: three preparatory engineering programmes, two bachelor programmes (180 ECTS), one integrated bachelor and teacher's program (270 ECTS), one integrated bachelor and master's program (Civilingenjör, 300 ECTS) and one master's program (120 ECTS). HPU also host the KTH LeanCentre. By March 2021 the department involves 47 employed staff, and one colleague from another KTH department. In addition, six persons are formally affiliated to HPU's research activities from other organisations as adjunct professors or industrial PhD students. Another additional 13 staff from administration, IT, library and communication is situated at KTH Södertälje, adding up to a total of 67 individuals participating in the research and education environment, with 30 involved in research. Figure HPU-1 shows the status on January 1, 2020.

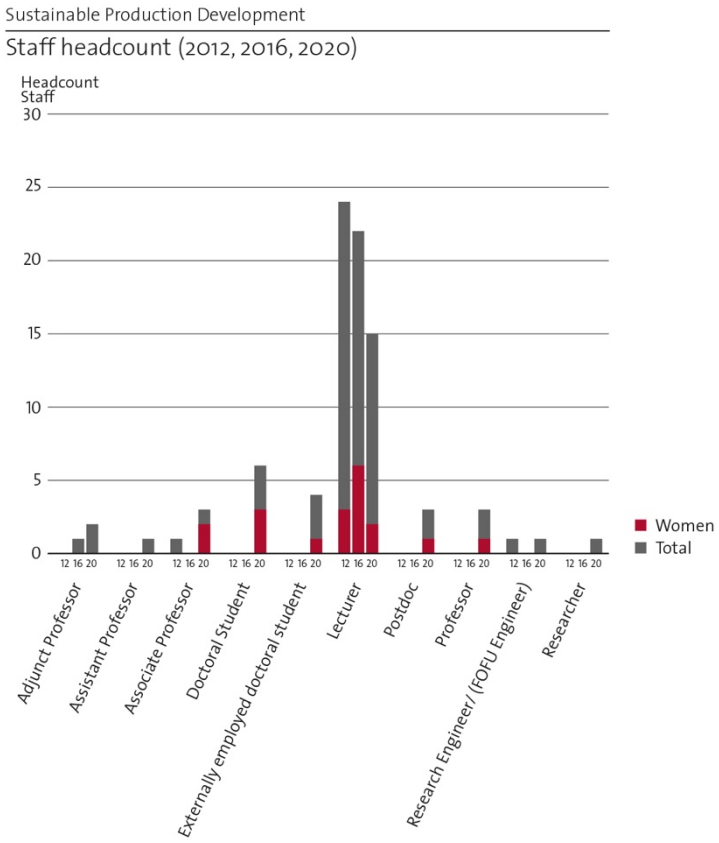


Figure HPU-1. HPU staff by category, on 1 Jan 2012, 1 Jan 2016 and 1 Jan 2020.

Due to the wide span of education activities, from general preparatory engineering programmes to subject-specific master's program, the department have lecturers in a wide set of areas (adjunkter), that is, non-tenure-track teaching faculty on permanent positions, as well as tenure-track faculty and researchers specifically within production, still kept together as one entity (divided into three units). This organisation supports the integration between research/knowledge development and education/dissemination of knowledge. See more on www.kth.se/hpu.

The research activities within the department are organised in three research groups:

Industrial dependability. Led by prof. Andreas Archenti (50% at HPU and 50% at IIP department), joining HPU in May 2018, this research group is under development. As of March 2021, the group consist of one professor (50%), one full time researcher, two part-time researchers, one postdoc and one PhD student. In addition, one researcher from IIP department is engaged in the research group.

Production logistics. Led by prof. Magnus Wiktorsson, joining HPU in November 2017 (since April 2018 Head of department at HPU on 50%). As of March 2021, the group consist of one professor, one associate professor (80%), one assistant professor, two postdocs, two KTH-employed PhD students, two industrial PhD students (Scania and RISE) and one research engineer.

Production management. Led by prof. Monica Bellgran, joining HPU in September 2017 (since April 2018 Director of KTH research platform Industrial Transformation on 40%). As of March 2021, the group consists of one professor, one associate professor, one guest professor (20%), one researcher, three KTH-employed PhD students and two industrial PhD students (AstraZeneca and Scania).

In addition, the department includes one associate professor (50%), two adjunct professors (20%) and one affiliated researcher (docent) (10%), all linked to the general topic of sustainable production and KTH LeanCentre. The research and PhD education within HPU have strong interaction with especially IIP and INDEK departments by shared staff, projects and PhD education.

b. Central research questions and themes, knowledge gaps addressed, main research activities

HPU conducts research and education with the scope to improve sustainability of future manufacturing industries. The research activities are rooted in a close relationship between the *development* and *operation* of production and logistics systems, and conducted within the context of *digitalization* and *sustainability* (including circular economy). Research at the department is performed in close relationship with other universities and large, world-leading manufacturing companies and SMEs, as well as the infrastructure of KTH's LeanCentre and Södertälje Science Park. The research at HPU is organised in three research groups:

Industrial dependability. The strategic research in industrial dependability for operation and maintenance focuses on a wide variety of application areas from aerospace and nuclear industries to automotive and pharmaceutical industry. The demand for dependable and high precision systems is driven by the need to achieve technological and sustainable goals. The technical goals of the research are related to improving the understanding of mechanical and physical characteristics in relation to the physical properties of the components, improving the operational performance and safety of systems working in e.g. harsh environments, and the integration of information and communication technologies ICT to implement sustainable manufacturing systems. Economic concerns include increasing equipment utilization and reducing the design and production costs as well as keeping the products flexible and adaptable. A joint economic and environmental goal is the reduction of re-work to increase sustainability. In this context, research activities on industrial dependability are directed to three focus areas:

- Advanced machinery and their subsystems operational capability and performance.

- Industrial analytics for prognostics and health management of manufacturing assets. Combination of data-driven with knowledge-based for a hybrid physics-based analytics approaches to e.g. understand root-cause failures and predict errors before they occur.

- Data-driven solutions for decision-making and increased manufacturing performance.

Example of our particular interest in the area of dependability applied in maintenance and operation is to bridge the gap between research in quality of manufactured components, capability of machinery and planning and executing maintenance activities. The direct benefits for society are the realization of prescriptive maintenance activities, which reduces the cost, energy and material requirements of manufacturing of products.

Production logistics. The flow of goods and information in a manufacturing facility is often key to an effective and efficient production system. However, production logistics are undergoing major changes driven by pervasive digitization as well as environmentally sustainable production. Our research are in part concerned with how new material flows for manufacturing can enable a more sustainable industry and consumption, but also with how comprehensive digitalization of development and operating processes change the terms of production logistics. Cyber-physical systems and digital representation of the production logistic system are key areas for this. This work relates to how complex socio-technical systems can be described and predicted. The challenge in the field is often to balance many competing aspects to achieve an economically, socially and ecologically sustainable production system. The group focuses on three areas:

- Analytical applications based on a digital representation of the production logistic system. Applications for visualization, evaluation, management and development.

- Circularity for sustainable production. Production logistic flows that create resource efficiency. Development and improvement tools.

- Production logistics visibility. Transparency upstream and downstream, real-time information and multi-criteria models for operation and development.

Production management. The industrial production area is broad, multidisciplinary and encompasses management aspects of relevance to producing industry. Our research in production management focuses primarily on the development and operation of production systems and concerns how to best organize and control different aspects of any given structure – the factory premises, machinery, materials, products and people – to be able to produce products in a more efficient and sustainable manner. The research activities in the production management research group can be characterised to fall in the categories of:

- Production management and strategy, focusing on different aspects of lean production like corporate lean management and lean & digitalization, production localization and change management.

- Industrialization & scale up, dealing with the process of industrializing a new product, going from prototype to volume production and including established companies as well as start-ups.

- Resource efficient operations, where the focus is on create stable processes by efficient and digital deviation handling, as well as on research questions on the environmental part of sustainability including circular economy.

Organized this way, the group aspires to impact on the future of sustainable production by addressing issues at different levels of the production organization and decision making structure, improving preconditions for more efficient development and operations of lean and green production systems. The research is conducted in close collaboration with producing companies, both large companies like AstraZeneca and Scania, as well as SMEs and start-ups.

c. Contributions to the advancement of the state of the art within the research fields of the department

The researchers at HPU are engaged in advancing state-of-the-art in sustainable production through active engagement in the discourse with new insights and perspectives, challenging the "traditional" viewpoints of decision making in production. The researchers have started publishing on theoretical and conceptual developments via conferences and, though limited yet, journal publications. Empirical analysis is also advancing in the unit with collective efforts of the senior and young research colleagues, and in collaboration with external partners from universities, industry and institutes. Senior research members are also active in peer-review processes, examinations of theses etc. in the research field where they exchange critical reflections in the international research front. Each research group has weekly PULS-meetings to monitor progress, and regular research seminars discussing own and others papers, research proposals etc. More specific contributions are presented according to each of the three research groups:

Industrial dependability. Core foundation for implementation of the research of industrial dependability are strongly related to integration of applied science and related information and communication technologies (ICT) in precision engineering for maintenance and manufacturing. It provides a large variety of tools for modelling of processes and measurement systems, statistical data analysis and evaluation of machinery, processes and measurement uncertainties. Design and development of new identification and measurement technologies for prognostics and health management for smart manufacturing systems will require extensive simulations and optimization procedures as well as inverse methods for interpretation of indirect measurements. Mathematics and statistics play a crucial role in the implementation and extension of guidelines regarding measurement and model uncertainty and key comparisons.

One example of developments that goes beyond the state of the art is the introduction of sensor-based metrology for online identification of advanced manufacturing machinery characteristics. The dependability and accuracy of machine tools and industrial robots is affected largely by the behaviour of the system's axes (e.g. joints and links) and their error sources. In this research work a novel methodology using circular inertial measurements quantifies changes in squareness between two axes of linear motion, see Figure HPU-2.

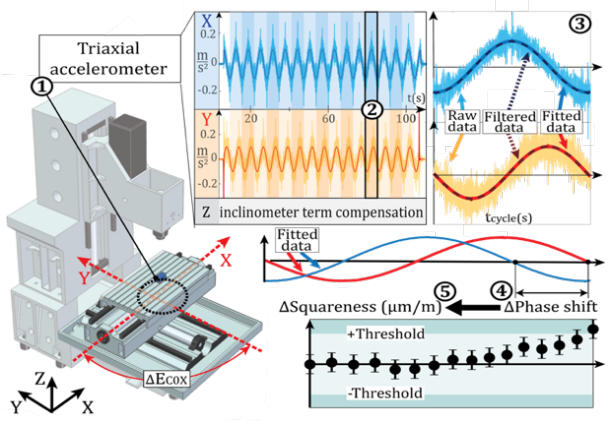


Figure HPU-2: Schematic view of the introduced IMU-based circular test method for monitoring changes of squareness indicating steps 1 to 5.

Results revealed that the new methodology is able to identify squareness values with acceptable test uncertainty ratio verified with traditional measurement methods. The work supports the integration of sensors into machine tools and industrial robots in order to reach higher levels of measurement automation.

Production logistics. Our research has a wider perspective on efficiency in production logistics, towards sustainability, and how comprehensive digitalization of development and operating processes can change the terms of production logistics. Cyber-physical systems and digital representation of the production logistic system illustrated in Fig HPU-3. are in focus. The research activities and contributions are driven by research projects, where the starting point in 2017 was the 22 MSEK project DigiLog. In DigiLog, a combination of a physical and a virtual test bed makes it possible to export and import collected data from actuators and sensors, and thereby identify possible improvements at process (information and material flow), organisational (layouts and operational issues) levels as well as on how digitalisation technologies can support the human in executing the daily task. The digital twin opens for experimenting with new ways of processing, analysing and using the collected data (both simulation model & physical lab) for improved planning, optimisation of running processes and for maintenance purpose. Following this development, the 3 M€ project C-PALS (Cyber-Physical Assembly and Logistics System) target offerings and software solutions for smart assembly and production logistics. The consortium of manufacturing companies, technology providers, IT companies and universities in Sweden and Republic of Korea contribute to the development and validation of four generic offerings: (1) Integrated platform and cloud services, (2) Manufacturing big data management system, (3) Real time location services, (4) Industrial-grade connectivity solution for IoT, as well as the development of four specific use-cases: (5) Smart Quality Control System, (6) Smart Production Control System, (7) AGV control system and (8) Production logistic centre control system. C-PALS includes staff from IIP and was in 2019 appointed as a Eureka SMART Success Story. Building on these larger projects, the 10 Mkr project LOVIS – Production Logistics Visibility target instruments for transparency across intra- and inter-site, SMART PM targets technologies for real-time data collection of manual operations, HUPMOBILE targets simulation solutions for production logistics, SCARCE II is a new initiative for further testbed development and EXPLAIN a new project on AI application in logistics. Two of the projects – LOVIS and C-PALS - were by the Royal Swedish Academy of Engineering Sciences (IVA) appointed as within the 50 most important research projects in Sweden 2021. The set of contribution areas are illustrated in Figure HPU-3.

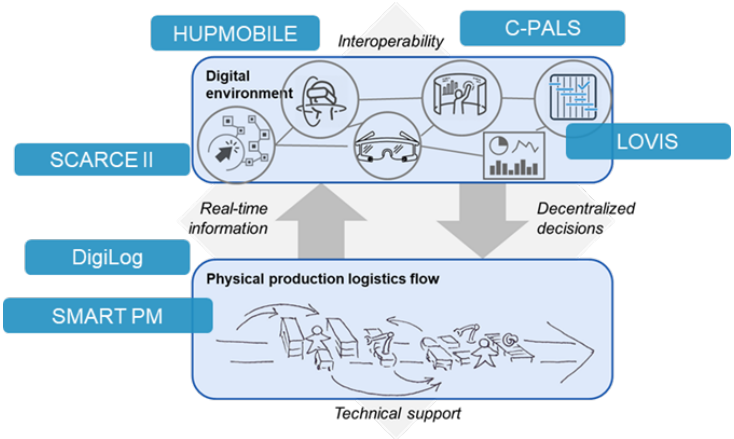


Figure HPU-3: Targeting decentralised cyber-physical system for production logistics

Production management. The research team sets out to advance state-of-the-art through: Expanding the theory on the subarea of *production management and strategy* by (a) focusing aspects related to deployment strategies and tactics in corporate lean management in collaboration with AstraZeneca, by (b) creating new knowledge on the evolution of lean production and how it interacts with e.g. concepts like agile in collaboration with Scania, by (c) dealing with issues on how

digitalization could be used within a lean context for the purpose of production management, partly as part of the mentioned regional project FORDONSDALEN. Furthermore, within the sub-area of *industrialization & scale up*, focus is put on (d) the industrialization process within large corporations and how the design and acquisition of production equipment could be made in a lean and green way in collaboration with AstraZeneca, (e) on the new area of how hardware start-ups could scale up and start production in collaboration with Södertälje Science Park, startups and suppliers (Production Angels) and (f) in a new co-operation project where AI is integrated in the industrialization of a new greenfield plant in the medical sector (Alistair). In the final subarea; *resource efficient operations*, we set out to (g) expand State-of-the-art on the operations level dealing with means for efficient handling of deviations (like digital solutions) as part of the ASPIRE project with Chalmers, RISE and 5 companies by (h) creating means to reduce the environmental impact from production through *Green Kaizen* as part of the LEDA GRÖNT project together with a large number of partners, and by (i) methods for increasing circularity in the factory.

Two major research themes that could be emphasized as specifically important with respect to collaboration with, and impact on industry are *Green Kaizen*, which is a set of tools and practices supporting environmental improvements (today a global standard at Scania and AstraZeneca), and *Production Angels*, where start-ups with physical products are supported by a gradually evolving concept comprising coaching, education & training, digital matchmaking and networking. This initiative is developed and run by KTH and Södertälje Science Park, and has already created high ROI through new supplier-startup businesses. Planning is made for a national scale-up of the initiative.

Organized as described above, the group aspires to increase the understanding and knowledge of different production management strategies, supporting the creation of the future sustainable factory by addressing relevant issues of the production organization and decision making structure.

d. Quality and quantity of contributions to the body of scientific knowledge

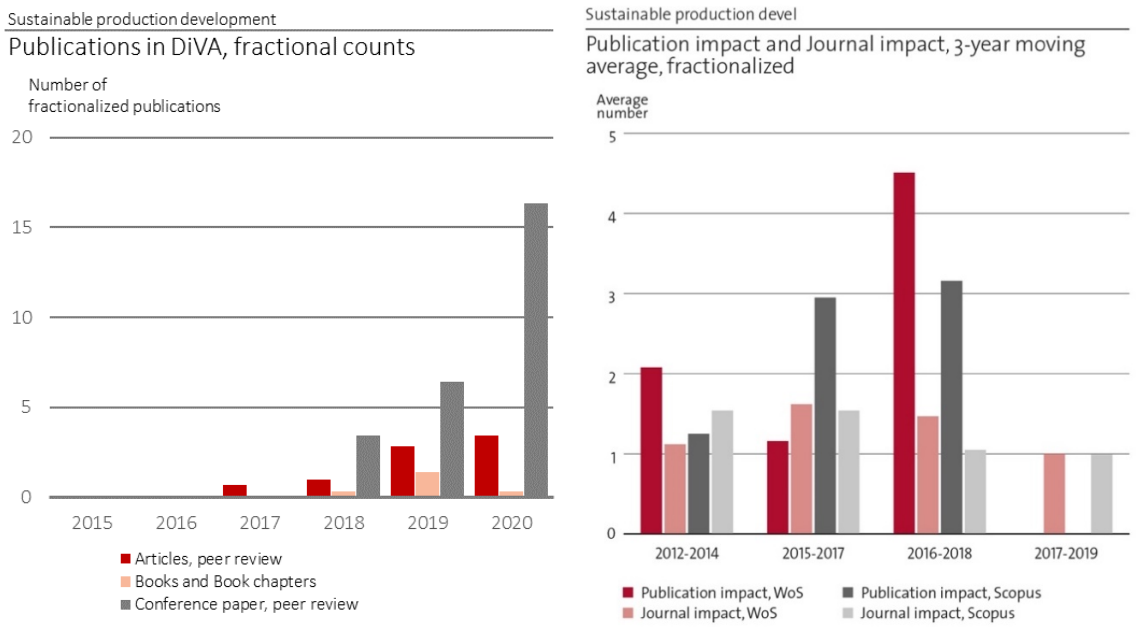


Figure HPU-4. (a) Journal and conference publications, (b) publication impacts.

The department is young in terms of research contributions, starting to build the research faculty in late 2017. The focus during 2018-2020 has been on recruitment, infrastructure establishment, external funding and education/research alignment. Hence, the department shows a startup-bibliometric

performance (10,1 for all publications in fractional count in 2019). Notably, the impact is very high, although based on small data (Fig 4b). In the initial period during 2018-2020, the number of conference papers have been substantial, in order to establish area and presence (Fig 4a). However, we can see a good trend into 2020 and 2021, with a fast increasing number of manuscripts in the revision process for journal publication. Some key publications from HPU during 2018 – 2021:

M. Kurdve and M. Bellgran, "Green lean operationalisation of the circular economy concept on production shop floor level," *Journal of Cleaner Production*, vol. 278, 2021.

S. E. Birkie and P. Trucco, "Do not expect others do what you should! Supply chain complexity and mitigation of the ripple effect of disruptions," *International Journal of Logistics Management*, vol. 31, no. 1, pp. 123-144, 2020.

Baalsrud Hauge, J., Zafarzadeh, M., Jeong, Y., Li, Y., Khilji, W. A., & Wiktorsson, M. (2020). Employing digital twins within production logistics. In *IEEE International Conference on Engineering, Technology and Innovation*, ICE/ITMC 2020.

Wolf, Á., Troll, P., Romeder-Finger, S., Archenti, A., Széll, K., Galambos, P., "A Benchmark of Popular Indoor 3D Reconstruction Technologies: Comparison of ARCore and RTAB-Map", *MDPI Electronics, Computational Cybernetics*, 9(12), 2091; 2020

Johansson, G., E. Sundin and M. Wiktorsson. *Sustainable Manufacturing*. Studentlitteratur. 2019.

Flores-Garcia E., Bruch J., Wiktorsson M., Jackson M. "Decision-making approaches in process innovations: an explorative case study," *Journal of Manufacturing Technology Management*, 2019.

Szipka, K., A. Archenti, G. W. Vogl, A. Donmez, "Identification of machine tool squareness errors via inertial measurements," *CIRP Annals – Manufacturing Technology*, vol 68, Issue 1, pp. 547-550, 2019

Vogl, G. W., N. J. Jameson, A. Archenti, K. Szipka, A. Donmez "Root-cause analysis of wear-induced error motion changes of machine tool linear axes," *International Journal of Machine Tools and Manufacture*, vol. 143, pp. 38-48, 2019

Zafarzadeh, M., M. Wiktorsson, J. Baalsrud Hauge, Y. Jeong. "Data-Driven Production Logistics - An Industrial Case Study on Potential and Challenges," *Smart and Sustainable Manufacturing Systems*, vol. 3, no. 1, s. 53-78, 2019.

e. Engagement in national and international research collaboration within academia and its outcomes

The researchers at HPU are actively engaged in national and international research collaboration of different kind. To demonstrate some examples:

- Continuously presentation, participation and peer-review of conference papers in EurOMA, APMS (organised by IFIP w.g. 5.7), CIRP, euspen, Swedish Production Symposium (SPS), ISL, ICE/ITMC (IEEE) and WinterSim.

- HPU is represented in CIRP - the international Academy of Production Engineering and euspen - The European Society for Precision Engineering and Nanotechnology, and activities are well in line with work ongoing in scientific technical committees.

- The three professors at HPU are active in the presidium of the Swedish Production Academy, as well as within the National Manufacturing Cluster (former FFI cluster).

- The researchers were active in the Lean Forum conference held at Södertälje 2019, and organised the PLAN research conference at KTH Södertälje campus October 2020. PLAN is the largest community within logistics in the Nordic countries.

- HPU co-chaired euspen's 14th International Conference and Exhibition on Laser Metrology, Coordinate Measuring Machine and Machine Tool Performance, (LAMDAMAP 2021).

- HPU is partner within the HELIX Excellence Centre together with LiTH, KTH Flemingsberg and many industrial partners. The existing running 14 externally funded research projects includes collaboration with some 40-50 industrial and academic partners worldwide.

- HPU is represented in internal KTH research and education initiatives and centres like DMMS, SFO Digital Future, Platform for Industrial Transformation, ITM/IRIS etc.

- HPU is represented in the steering and council groups of VINNOVA SIP Production 2030, the (Governmentally appointed) Delegation for Circular Economy, in the Royal Academy of Engineering Sciences (IVA), the European Society for Precision Engineering and Nanotechnology (euspen) council, and The United Nations Centre for Trade Facilitation and Electronic Business (UN/CEFACT).

- University collaborations include: Chalmers, Uppsala University, Mälardalen University, Jönköping University, Lund University, Luleå University of Technology, NTNU (NO), Seoul National University (ROK), Sungkyunkwan University (ROK), Tohoku University (JP), University of Tokyo (JP), Technische Universität Berlin (DE), Budapest University of Technology and Economics (HU), Aalto university (FI), Riga Technical University (LT), Tampere TK University of Applied Sciences (ES), Lahti University of Applied Sciences (FI). In addition, research institutes and similar collaborations include: NIST (US), BIBA (DE), RISE, Södertälje Science Park AB, Fraunhofer-Chalmers Centre, Odette, SIQ.

- The research projects run and participated in by HPU include some 25 small and large manufacturing companies (e.g. Scania, AstraZeneca, Ericsson, Marcus Komponenter, Modig, Dexta, MainlyAI, H&D Wireless), as well as public collaborators (e.g. Södertälje City, City of Gdynia, City of Hamburg, City of Riga, City of Tallinn, City of Turku, Region Stockholm)

- One of the senior researchers at HPU has a dual position at KTH and BIBA – Bremer Institut für Produktion und Logistik GmbH, also active in the European Technology Platform ALICE. HPU researchers have participated in EU applications by invitation with many different European actors (e.g. SIMO, researcher mobility), and was actively part of the application work for EIT KIC Manufacturing (no funding, but assessed as No.2). HPU researcher is active in the funded EIT KIC Urban Mobility. HPU is also part in shortlisted EDIH application.

f. Follow up from previous evaluations

The department was not part of previous RAE at KTH.

3. Viability

a. Funding; internal and external

The research activities at HPU was part of the joint initiative from the Swedish government, KTH, Scania, AstraZeneca and Södertälje city, launched in 2014. In 2020 the government allocated an annual budget of 10 MSEK for research, Scania 3 MSEK, AstraZeneca 1 MSEK and Södertälje city 3 MSEK. This is the base for the department on which external funding have been applied. During 2018-2020 the growing research team have been successful in attracting external funds, primarily from VINNOVA, but also EU, Wallenberg foundation and Tillväxtverket and others.

Critical factors for the future are to:

- Ensure continued support from all partners in the initiative: The Swedish government, KTH, Scania, AstraZeneca and Södertälje city.

- Further increase the attracted external funds for research, expanding to national and international sources.

Currently, the department is an education-intense department. The total turnover 2020 was 72 MSEK, whereof 25,5 MSEK related to research (Fig HPU-5). Given an aim of 50/50 between research and education, and that education is planned to expand for the coming years with four new education programmes having courses from the department, the research is to expand. The aim is a total budget of approx. 100 MSEK, whereof 50 MSEK in research. The additional funds need to be a mix of additional allocated basic funds as well as external funding.

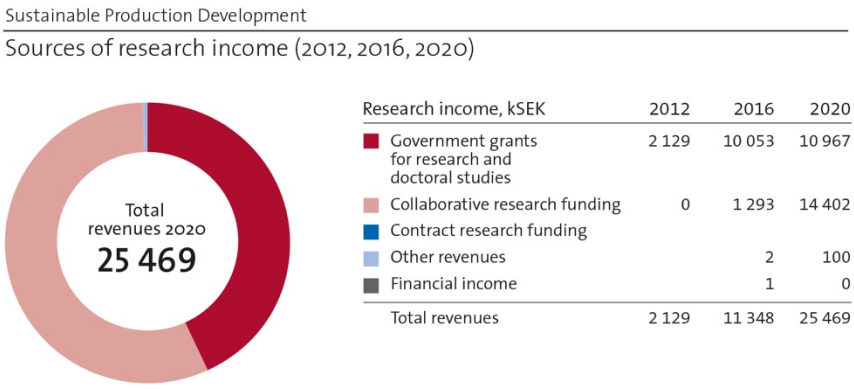


Figure HPU-5. HPU research income 2020 with a fast growing rate of external funding (56% 2020).

b. Academic culture

The department is currently establishing an academic culture. As the research teams grow, we have established following fora for building an academic culture:

Professor collegium: Gathering the entire set of professors (three full professors, two adjunct professors and one visiting professor) for regular strategic discussions. The core team of the three full professors also meet regularly planning research development. A **Supervisory collegium** with supervisors and unit managers meeting twice a year. **HPU research seminars:** Seminars once every fourth week, gathering the entire research group at the department. **Research team meetings** for each of the three research groups: Industrial dependability, Production Logistics and Production Management. Meetings every week or every second week (depending on group), managing the ongoing projects, publications, applications and lab developments. **Project steering groups and meetings** within each of the (as of March 2021) 14 ongoing research projects, with external funding and industrial partners. **Industry/academy research meetings:** Puls-meetings every month where key persons from KTH, AstraZeneca and Scania meet. Strategic research seminars 2-4 times/year with the partners above. In addition to these research driven fora, are research recruitments, outcome and budget discussed at the department's management meetings and the unit's work place meetings.

c. Current faculty situation

The faculty dedicated to research is expanding, starting from zero just five years ago. The proportion of the staff involved in research are increasing steadily: 36% (2018), 41% (2019) and 45% (2020). The research faculty is led by three professors (two men and one woman), whereof one is head of department on 50%, one is employed at IIP department on 50% and one is heading the KTH research platform on Industrial transformation on 40%. Hence, full professor capacity is only 160%. The faculty further consists of three associate professors, one on full time, one on 80% and one on 50%, as well as one assistant professor. HPU has one visiting professor on 20%, two adjunct professors on 20% each

and one researcher (docent) on 10%. Three groups are formed including postdocs, researchers, PhD students and research engineers. Adding up to a total of 30 engaged persons (all status March 2021).

d. Recruitment strategies

The short term plan is to establish three robust research groups, each one consisting of at least one professor, two associate professors and one assistant professor. These would then keep a running set of postdocs, PhD students and research engineers, adding up to some 12-15 persons in each group. The PhD industry-cooperation is based on a "trefoil-strategy", building a thematic PhD student team within each of the research groups, comprising one PhD student from each partner (KTH, Scania and AstraZeneca). The new positions for PhD students and Postdocs has attracted highly qualified applicants, especially given being a completely new research campus.

To develop a sound balance in the research groups, recruitments of senior researchers are needed and under way (associate and assistant professors). Furthermore, the current staff is relatively young but lacks an even gender balance. Measures in recruitments of female researchers are prioritised. The recruitment process for PhD studentships and postdoc positions has been rigorously set to ensure highest potential quality of the candidates. This includes a three step progressive evaluation (documentation screening, interview, and finally an assessment centre) in which multiple evaluators are involved in each step.

e. Infrastructure and facilities

The department is located in a spacious new building in central Södertälje with new labs, office spaces and innovative education infrastructure. It is co-located with Södertälje Science Park and is situated next door to the head office and manufacturing plant of AstraZeneca, and close to the head office and major manufacturing sites of Scania CV. Södertälje is a key manufacturing node in Sweden with over 22,000 employees within manufacturing industry.

The new campus also includes KTH's LeanCentre with its lean training centre (pedal car factory), offering skills development programs and knowledge networks for industrial practitioners. The research projects run at the department concern the renewal of industrial production practice set by digitalisation initiatives and sustainability requirements. Hence, the establishment of digital and physical labs for future production and logistics is a key function in the department. During 2018-2020 the labs and infrastructure for research have been started up. The first major research project run by the department (DigiLog) was a demonstrator research project, leading to the build-up of an integrated physical and digital environment for production logistics. The specific focus on real time data, digital twin capability and analytic application for the two groups on Production logistics as well as Industrial dependability, implies further investments on equipment, connectivity, data storage solutions and analytic platforms. Still, the close proximity and intense collaboration with industry is a major feature of this new campus and its research and education activities. This leads to a joint perspective of what to invest in at KTH and what to use at the companies. For instance, research activities are run at Scania's Smart Factory Lab located at Scania's site. Good relations within ITM as well as with Mälardalen University and Uppsala University also brings future collaboration opportunities regarding manufacturing lab resources in the greater Stockholm–Mälardalen Region.

4. Strategies and organisation

a. Goals for development 5–10 years ahead

The vision for HPU is to create a strong academic environment within Sustainable Production, which in an innovative way initiates, co-produces and disseminates cutting edge knowledge that is necessary to secure the future of the Swedish manufacturing industry, while contributing to climate change and social development. The first 6-year period in this endeavour (2014 – 2020) has mainly been about building up a department including education as well as research, with a regional focus. In the ramp-up

to 2025, we start from this regional base, but now intend to become a national Node for Sustainable Production. For the coming 5-10 years, we set out to achieve the following:

- A strengthened research environment and eco-system as part of the National Node for Sustainable Production, hereby contributing to industry's transformation to a circular and fossil-free production. In addition to the three teams, further research and postgraduate education will be established in the areas of digitization and analytics for sustainability, bio/pharma production, as well as industrialization of circular material flows.

- A strategic investment in lifelong learning to support industry change. KTH Södertälje has long worked with professional education on lean production, which we have the ambition to strengthen and broaden to offer education that supports the industrial transformation. KTH Södertälje with its industrial proximity has an important role to play here.

- A strong social responsibility through education modules and internship opportunities that enable rapid integration into the Swedish labour market. In the environment around Södertälje there are great opportunities for broader recruitment. Through Södertälje Science Park, an open infrastructure is created for education and research through community collaboration.

Specifically, adding to the further establishment of three robust research groups within Industrial dependability, Production logistics and Production management, two additional research themes are envisioned on a longer perspective:

- Ongoing planning for a Professor chair within Bio Production, with the focus of production engineering and management of new pharma products (of how to build and operate the production systems, i.e. not how to develop and produce the chemistry of the products). This is a collaboration between the Transformation platform and the CBH and ITM schools.

- A research group on Digitalisation and analytics for sustainable production, which build upon the integration of the digital technology and data applied on the industrialization of circular material flows and sustainable manufacturing.

b. Congruence with university-level goals for "A leading KTH" as set out in KTH´s "Development Plan 2018-23" (page 5)

HPU is actively working towards application-oriented research that is deepened by curiosity-driven basic research and interdisciplinary collaboration. The development of a leading education and research practice within sustainable production is based on a leading and unique industry-academic collaboration practice, as well as supported by active participation in the KTH platform Industrial Transformation, ITM collaboration with especially IIP, INDEK and MMK, and collaboration development efforts within biobased production with CBH school. HPU is also active in the ITM strategic effort **IRIS**. By active involvement focus areas and joint positions, this is a key instrument for a joint strong ITM development.

The research is further characterized by digitalisation, sustainable development, internationalization, and gender equality. **Digitalisation** is supported by the new practices and infrastructure in education and research where KTH and the department invests in digitalisation as an important element of collaboration with industry and society. Digitalisation is a corner stone in the knowledge development towards sustainable production. **Sustainability** is at the heart of the HPU department. In research as well as education, sustainability is a core value for developing future multidisciplinary knowledge. **Internationalisation** efforts are still under development. So far the international aspects rely on individual efforts with key countries being Germany and South Korea. The new international master's

program is also an instrument in this. **Equality** is supported by an active and gender-aware management with an even distribution of women and men.

c. Leadership structure and collegial structure

The department is organised in three units. One unit includes some of the lecturers as well as the two research groups on Industrial Dependability and Production management. A second unit includes the rest of the lecturers and the research group on Production Logistics. The third unit is the Lean Center, providing professional education and life long learning within lean production and leadership. The department is headed by one of the professors and the two larger units are headed by two lecturers, while LeanCenter is managed by a centre director. The research activities within the department are coordinated by one of the professors, and education activities are coordinated by a director of studies. These six persons are included in the department management group, together with a business controller & head of administration at KTH Södertälje, as well as a communicator for KTH Södertälje. Elements in the collegial structure is in part described in section 3b, including the Professor collegium, Supervisory collegium, Research teams and HPU research seminars.

d. Strategies for high quality

The strategies for high quality are currently being implemented. As we set the research culture and practice of HPU, we have a unique chance of implementing these strategies. The strategies include: (1) publication strategies including open-access principles, targeted journals (such as CIRP Annals, IJMM, IJPR, IJTM, JOM, IJOPM, JCLP etc) and internal kaizen steps towards final manuscript, (2) community engagement and conference participation with selected and specified international (CIRP, EurOMA, IFIP) and national communities (SPA, PLAN, LeanForum etc), (3) industrial-academic dissemination and quality assurance processes and fora where research under development is commented and constructively criticised by colleagues and experts, (4) structured PhD and postdoc processes with QA gates and improvement cycles internally by research seminars and presentations. For PhD students this will require close collaboration with the doctoral programmes of IIP and Indek.

5. Interaction between research and teaching at all three levels (BSc, MSc, PhD) of education

KTH's activity in Södertälje started in 1987, and emphasised during the first 30 years preparatory education, undergraduate programs in Swedish and one-year master programs. By the effort initiated in 2014, and new education programs launched and research staff hired since 2016, HPU has expanded to a full academic environment with BSc, MSc and PhD teaching as well as research.

The department has courses within eight education programs. We run some 80 courses every year, with a total volume of 709 ECTS annually. 10 of these courses are on MSc level in English, covering 109 ECTS, the rest of courses on BSc and preparatory level and in Swedish. During 2012 – 2020 the department has examined a total number of 616 student thesis, whereof 462 on BSc level, 135 on MSc level (one year) and 19 on MSc level (two year). As of March 2021, the department has 10 PhD students, enrolled in two different doctorate programs.

The development and implementation of the new master's program Sustainable Production Development is closely linked and mapping the focus of the research groups in the department. Research results have been used in lectures and seminar sessions in courses; course project tasks so far are as closely related to issues of research interest in the department as possible. This is also the direction currently adopted in the CDIO course in the Master's program.

The PhD students in the department are for now enrolled in either IIP or INDEK departments' doctorate programmes. With the growing number of supervisors, doctoral students as well as the research and academic culture developing in the department, it is expected that HPU will start to run its own PhD programme by 2023. In this direction, all PhD candidates are required to perform a structured state of the art (SOTA) review in their field, in relation to HPU research focus. In addition to

the benefit of the SOTA for the PhD student's own development, the aim is to develop PhD courses at the department (currently we have two), and in developing courses for second and first cycles.

It is also worth mentioning the textbooks developed by professors at the department. Some examples on self-authored textbooks used in education at all levels:

- *Sustainable Manufacturing* by Johansson, Sundin and Wiktorsson, 2019 (Studentlitteratur)
- *Production Development: Design and Operation of Production Systems* by Bellgran and Säfsten, 2009 (Springer)
- *Produktionsutveckling: Utveckling och drift av produktionssystem* by Bellgran and Säfsten, 2005 (Studentlitteratur)
- Book chapters, such as *Accuracy and Performance Analysis of Machine Tools* by Archenti and Laspas, 2019 (Springer)

6. Impact and engagement in society

a. Relevance of research to society at large

The logic of having HPU situated at KTH Södertälje is to keep relevance to society. It relies upon a close industrial collaboration in Sweden's most manufacturing-intense city, as well as keeping a local presence for student recruitment and competence development. The research is conducted in co-production with industry, where knowledge from all organisations is synthesised and analysed jointly, for scientific and industrial benefits.

A new initiative in the production eco-system of Södertälje was inaugurated as part of the grand opening of Science week 2021; the **National Node for Sustainable Production (SuPr)**, funded by VINNOVA, Region Stockholm, and the partners HPU/KTH, Scania, AstraZeneca, Södertälje Municipality. The node is managed by Södertälje Science Park AB in joint co-operation with the partners and will facilitate and initiate activities and projects that enhances sustainable production. HPU also participates in KTH's research platform **Industrial Transformation** which sets out to visualize and initiate research that supports industry's transformation for climate and competitiveness. The HPU professor Monica Bellgran is the Director of the Platform (see more on KTH webpage). The platform is managing KTH's part in the **Fordonsdalen** project together with Region Stockholm, with the task to strengthen the automotive industry in the Stockholm – Mälardalen region (the largest export sector in Sweden, with 31 % of the employees working in the East coast region).

b. Research dissemination beyond academia

The two world-class companies (Scania and AstraZeneca) with more than 22 000 employees, as well as a number of SMEs and start-ups, next door to KTH, forms the basis for the strong knowledge environment in Södertälje. In this context, the view of 'knowledge dissemination from academia to industry' is not fully relevant. The underlying philosophy of the research within sustainable production development at HPU is to conduct joint knowledge development and co-production of research, including both knowledge-intense industries and academia.

In addition to the jointly created knowledge within the industry-academia co-operation, HPU and its industrial partners undertake a set of actions to reach a wider audience like next generation students, as well as the citizens with large common organised events like the Södertälje Science Week. The 3rd Annual Science Week 2021 was a three-day long conference, executed with Bonnier News and 32 partners and broadcast for 27 hours on the di.se TV-channel (see www.scienceweek.se) where researchers from HPU participated actively in many seminars, videos and panels. The event was a success and the broadcasting link was clicked on nearly 1,5 million times over the three days. Science Week helps build a national brand for sustainable production in Södertälje. Measuring the impact, we see increasing number of participants of Science Week and higher awareness of KTH Södertälje. These

jointly undertaken activities have also created an increased awareness of the relevance and the competitive advantage the development of sustainable production will have on citizens' quality of life.

The interactive knowledge flow between academia and industry is critical and key for the future success of this effort. The strategies for mutual communication of research results are realised by: (1) Joint research projects conducting joint co-production of research, including staff from academia as well as industry. (2) Individuals that cross borders between academia, industry and society. This includes industrial PhD students, adjunct professors, efforts for affiliated staff and to encourage mobility for KTH-employed researchers and PhD students. (3) Continuous knowledge exchange between industry and academia based on the research projects, the research groups and the department as a whole. (4) Joint publications with industrial and academic contributions. (5) Public events such Science week, Tekla festival, Young researchers competition, and visit programs for upper secondary school students.

c. Sustainability and the United Nations' Sustainable Development Goals (SDG)

Sustainability is at the core of the department's research and teaching activities. In a broad sustainability definition, 80-100% of HPU research relate to sustainability. All research projects in the department comprise in some way at least one of SDG 9 (industry, innovation and infrastructure), 12 (responsible consumption and production) and 13 (climate change). SDG 9 is targeted by upgrading infrastructure and retrofitting industries to make them sustainable, with increasingly efficient use of resources and greater adoption of clean and environmentally sound technologies and industrial processes. SDG 12 is targeted by manufacturing contributing to the circular economy (CE) based on a life-cycle perspective of the product and by introducing new business models that contribute to reducing the number of products produced and consumed. SDG 13 is targeted by decreasing manufacturing's carbon emission, but also contribute to sustainable manufacturing of less carbon-emitting products as well as efficient industrialisation of a circular economy with less carbon emissions. For example, the projects Leda Grönt, Green kaizen, Operational readiness are immediately and directly linked with SDGs 12 and 13. Having an educational offer being closely related to our research activities means that we have a high emphasis on course level ILOs to explicitly reflect knowledge, skills and attitudes in line with the sustainable development goals.

d. Structure for increased impact

The vision of HPU is to be a leader in sustainable production with the goal of creating a positive social and industrial impact through education and research. We are forming a dynamic, innovative and creative enterprise driven by curiosity and a goal-oriented desire to realize a brighter future. The ambition is to create a meeting place for learning, research and innovation between different actors, disciplines, sectors and organizations.

We recognise that impact has academic, economic and societal elements. Academic impact concerns the impact from excellent research to scientific advancements across and within disciplines, including advances in understanding, method, theory and application. Economic and societal impact concerns impacts from excellent research to society and the economy, beneficial to individuals, companies and organisations. To plan and create the foundation for impact, this ambition is embodied in the hiring criteria of staff, in the formation of research projects, in the establishment of research leadership forms and roles, as well as in mobility schemes across industry and academia. Industrial experience is of importance during recruitment, as well as dissemination interest and academic experience. HPU research is managed in close collaboration with key industrial stakeholders, and projects are jointly formed for impact beyond the immediate academic contributions in order to increase the competitiveness of the Swedish production industries, while increasing the general awareness of the relevance of sustainable production as a competitive (and not only cost) factor.

The main reason for KTH to operate and invest in a campus in Södertälje is to create impact. See specific impact cases with academic, economic and societal elements in the Appendix.

7. Other

Specifics that the department wishes to mention and describe

We want to, once again, emphasise the research start-up character of the department of Sustainable Production Development, located at KTH Södertälje. The focus during 2018-2020 has been on recruitment, infrastructure establishment, external funding and education/research alignment. It is a challenging task to establish and starting to give courses in five new started undergraduate and master's programs (now adding up to courses in eight education programs) while simultaneously starting up and establishing three research groups in a new campus, with all investments, recruitments and external funding needed. The department is small and a lot of administrative efforts are put on staff in order to develop and manage the department, and its educational and research engagement within KTH. In addition, the combination of a challenging student recruitment situation for KTH Södertälje (leading to income challenges) and high costs for the new campus (allocated on the department), puts the department in a challenging economic situation. Still, we feel confident of the strengths mentioned: the relevant and up-to-date theme for the department, the close proximity and strong engagement of industrial partners, the modern and attractive facilities, and the entrepreneurial and impact-focused senior research leadership, and feel proud of the results shown so far. We see that the far-sighted focus that KTH and partners chose for the new department (sustainable production) a number of years ago, now are even more in focus and how we gradually and in collaboration with many actors build new structures, skills and knowledge to contribute to the industrial transformation that is critical to achieving the objectives of the Paris Agreement.

Department of Industrial Economics and Management

Self-evaluation
Head of Department: Professor Cali Nuur
RAE coordinator: Matti Kaulio (Head of Department 2016-2020)

Included divisions:

Division of Management & Technology
Division of Sustainability, Ind. Dynamics & Entrepreneurship
Division of Accounting, Finance, Economics and Organization

Department of Industrial Economics and Management (INDEK)

1. Overall analysis and conclusion; strengths and development areas

a. Limited SWOT-analysis

The Department stems from 1912 when the first special teacher, Erik Forsberg, in what later became the subject of Industrial Management (Swe: "industriell ekonomi och organisation") was hired at KTH. At that time, industry argued for the need of engineers who had a broader competence than mathematics, science and engineering only. In those early days teaching included cost accounting, costing techniques, and commercial law, as well as time and motion studies, job design, and operations management. At the department, the first Swedish text book in field was published 1916, the first Swedish chaired Professor was installed 1939, and the first Swedish Doctorate in Industrial Engineering and Management was convened at the department in 1972.

Today, the Department of Industrial Economics and Management (INDEK) covers a broad spectrum of academic subjects revolving around the management of technology, engineering, and technology-based businesses. INDEK pursues research at the interface where technology meets management.

INDEK has an ambition to be one of the most prominent departments of its field in Europe, conducting high-class academic teaching and vibrant research on relevant issues for contemporary, and future, engineers. Examples of prominent benchmarks among our European sister departments include, DTU Management at Technical University of Denmark; Industrial Engineering and Management at Aalto University; School of Management at Politecnico di Milano; Department of Management, Technology and Economics at ETH Zürich; and School of Management at TU Munich.

Table INDEK-1. Bulleted list, in order of magnitude.

	Strengths	Weaknesses
Research	1. Relevant research for individuals, companies and society in large. Research is often framed in thematic challenges and approached inter-disciplinary. Example of current challenges are circular economy, sustainable transition, simultaneous business and technology innovations, gender and equality in organisations, growth and innovation policy, etc. The relevance of the department's research is illustrated in the large number of impact cases, see section 6. 2. Large width of publications and extensive international collaborations. During the last years INDEK has increased its Web of Science (WoS) publications, its international co-authorship and its ranking. 3. Competent and motivated faculty with broad disciplinary and methodological	1. *Size*. INDEK's faculty is spread over a broad number of sub-disciplines, leading to a situation of un-critical mass. Although measures have been taken to focus on INDEK's core competence, there still remain challenges as processes for recruiting faculty is a tedious endeavour that takes time. 2. Although INDEK has a broad width of research and publications, the share of highly cited and influential papers is relatively small. However, recent trends point to a huge leap with a number of papers gaining "highly cited" status in the WOS. 3. One of the research streams at INDEK is applied economics which is currently conducted in different schools at KTH including ABE and Mathematics. A potential exists if

	plurarity and with an extensive international network. 4. Excellent integration between research and education, especially at the graduate level. Based on own research, several professors publish award winning textbooks in key areas of Industrial Management which later are used in teaching. Own empirically grounded case studies and articles are used in teaching. 5. INDEK has successfully built-up research in areas, which represent major current societal challenges such as sustainability and digitalisation. As these challenges are complex and include both technology and business aspects, the department of industrial economics and management has the potential to lead the development of these areas.	these environments where more integrated. 4. Research funding for PhD students is a challenge. Typically, funding for research is granted in three years periods, a timeframe that not cover a four-year PhD student project.
Organisation	1. Demonstrated capability of improvements and repeated radical change. From 2010 to 2019, INDEK has transformed from a domestic academic environment, publishing mainly Swedish monographies, to an international academic environment, recruiting internationally and publishing articles in journals indexed in the Web of Science. 2. Extensive and successful PhD education. The European Doctorate in Industrial Management (EDIM) programme, an EU financed PHD school together with POLIMI (Italy) and UPM (Spain) has generated many and very competent PhDs who now are working worldwide. In addition, alumni from INDEK's PhD programmes have been recruited to universities such as Uppsala University, Uppsala and Mälardalen University College and have become academic leaders and senior faculty. 3. Responsible for one of Sweden's most popular engineering educations, the Industrial Engineering and Management programme (Civilingenjör industriell ekonomi).	1. Research is often conducted on individual basis, often by associate professors who teach >50%. The primary motivation for them is promotion. Large structured research programmes managed by a designated principal investigator are rare. 2. ITM School in general and INDEK in particular have very low basic funding from the university compared to other departments at KTH. This restricts the possibilities for growth of research, both internally and externally funded. 3. Very high overhead costs at KTH for externally funded research. This in not only a financial issue, it has also (de)motivational aspects. This weakness was also highlighted in the 2012 RAE.

	Recruiting students in competition to medical Schools (Karolinska Institute) and Stockholm School of Economics. 4. New matrix organisation, which aims to focus the department's research on larger project and initiatives, increase faculty's time on research and create a dynamic environment for academic entrepreneurship.	

Development Areas:

- Growth. The single most important factor that will improve INDEK's performance is to grow in terms of number of faculties. A goal is to increase the number of faculty by 100% to 2030.
- Receive large and long-term research projects both in the core areas of the departments of operations management, innovation and digital and in sustainability transition.
- Continue strengthening the strategic partnership with the Scandinavian Academy of Industrial Engineering and Management (SCAIEM) and other academies in Europe and worldwide.
- Continue developing our PhD program and increase the number of PhD candidates admitted every year Continue developing our PhD program and increase the number of PhD candidates admitted every year.
- Create a new platform for research on applied economics, which integrates INDEK and faculty from the ABE school.

b. Summary statement on contributions of department on impact, infrastructure and sustainable development

INDEK is the leading Industrial economics and management department in Sweden and one of the leading ones in Scandinavia. In focus for INDEK is to conduct research in the intersection where management and economics meet science and technology. The current societal challenges of sustainable and digital transformation are both in the centre or INDEKs competence area and INDEK intend to continue make impact in both the core areas of INDEK as well as related to those areas.

2. Research profile

a. General information of the department

INDEK is a full-range Industrial economics and management department, in an Engineering School (ITM School) at a Science University (KTH). By full range, we argue that the department covers all (sub)disciplines that are included in our educational programmes. By an Engineering School, we refer to the fact that the ITM school is strongly grounded in prototyping and experimental engineering sciences. By a Science University we refer to that KTH is one of Sweden's research institutions which all have larger turnover devoted to research than education.

As mentioned in the introduction, INDEK is currently organized as a matrix comprising of three (3) units. The units are: Management & Technology (MT), Sustainability, Industrial Dynamics and Entrepreneurship (SIDE) and Accounting, Finance, Economics and Organization(AFEO)

In addition to the nits, there are currently two research streams, which cuts across the Units are established: Sustainability Forum and Diginomics. Both these streams are "loosely" organized around

faculty with specific interest in sustainability and/or digitalization issues. The intention with this matrix organisation was to create larger research streams, which could generate larger project and programs. The Covid-19 situation has, however, delayed the full implementation of the research streams as a component and compliment of the line organisation.

In addition, two specific initiatives the Software Development Academy (SDA) and European Doctorate in Industrial Management (EDIM) are organised under the Head of Department.

b. Central research questions and themes, knowledge gaps addressed, main research activities

Industrial economics and management research do not have a given structure of its research in the same way as for example a Business School. The reasons are found both in the history of the subject and in the operative context. From a historical perspective, production economics has been a core area since the birth of the subject. Project management, commercialization issues related to technology and industrial dynamics was later added as these areas represent key challenges faced by engineers in managerial positions. Currently, industrial economics and management has developed and includes most of the sub-areas found at a Business School, however, with a tech dimension included. In addition, industrial economics and management departments are embedded in a technical university, with both the opportunities and limitations thereof. On the opportunity side, we find a large possibility and potential to cooperate with different science and technology departments. A consequence of this embeddedness is that a typical industrial economics and management department ranking-wise do not only contribute to the subjects of Management and/or Business Administration, something that is the case for INDEK. To encourage this cross-disciplinary interaction, in a time when ranking is key, and to exploit the opportunities that exists, in particular in relation to the large challenges of sustainability and digitalization is therefore a strategic question for INDEK.

In this report, we have chosen to present INDEK's research, as well as the selected papers, in relation to the three levels of Macro, Meso and Micro-level.

- **Macro.** This level addresses economics of innovations and growth, mainly based on economic theories. Databases and data sets, collected and refined during several years is one important foundation for this research.

- **Meso.** This level addresses sectoral and technological transformation, innovations, eco-systems, sustainability, energy management, regional development, and technology diffusion are example of topics addressed.

- **Micro.** This level addresses management research from a variety of perspectives such as human factors, operations and supply chain management, project management, organizational leadership, technology, innovation and R&D management, gender studies and change, health care management, IT management and entrepreneurial processes.

c. Contributions to the advancement of the state of the art within the research fields of the department

INDEK is advancing state of the art and state of the science, for example, through:

- Research, speeches and debate articles related to the cashless-society
- Research, speeches and debate articles related to innovation policy, growth and how to fight Covid-19
- Research, change initiatives and training related to gender and equality
- Development of new training methods for re-skilling of newcomers to become programmers
- Research on sustainable transition and systemic innovation

d. Quality and quantity of contributions to the body of scientific knowledge

INDEK contributes to KTH's ranking in the fields of management, economics and environmental sciences. In ARWU, KTH[1] is now ranked 200-300 (2019) in Management and 151-200 (2019) in Economics. In 2018 KTH climbed one level in the field of Management (from 300-400 to 200-300).

INDEK has made a significant improvement in terms of type, style and target of its publications. Figure INDEK-1 shows the number of publications during 2012-2019. For WoS and Scopus coverage and international co-publication, see Figure INDEK-2.

Figure INDEK-1. Publications in journals and conferences.

[1] Note that this is the ranking of KTH. The rank for Management is mainly based on INDEK's performance, while the rank for Economics is an aggregate of contributions from INDEK, ABE and Applied mathematics.

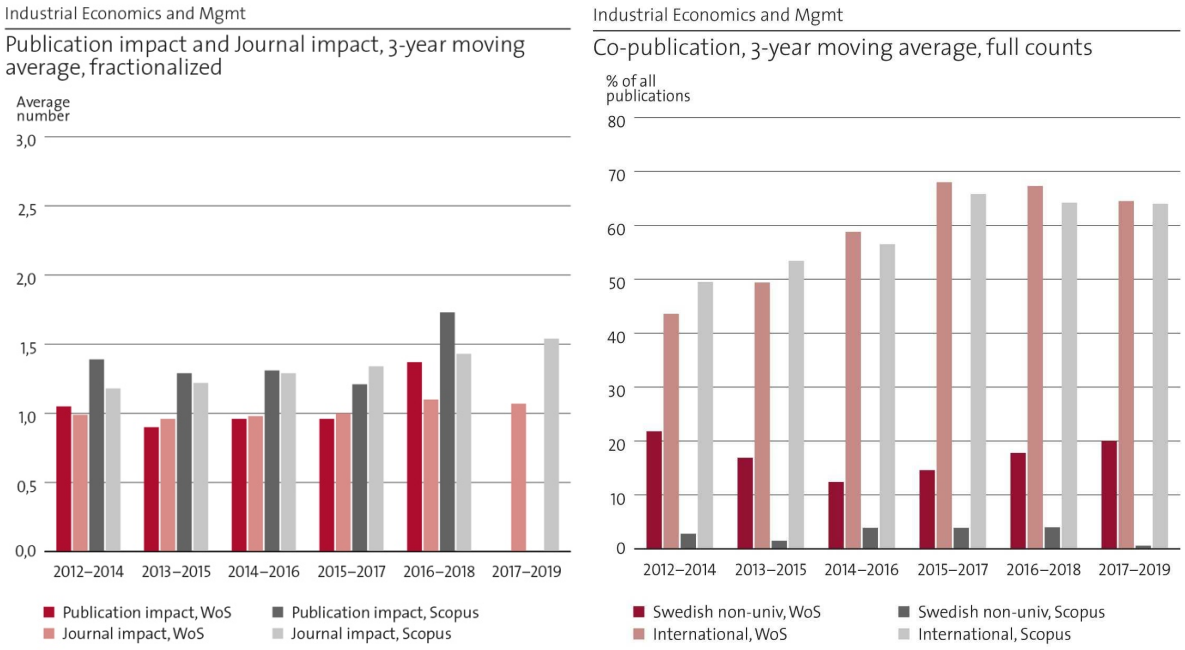


Figure INDEK-2. (a) Publication impact and (b) Co-publication.

Discussion at the department (although limited due to the Covid-19 situation), resulted in a selection of the following nine (9) papers which represent the departments research output during the evaluation period. The papers are selected based on several criteria. They represent research conducted at the department by its faculty, they have high number of citations in Web of Science (WOS), they represent the diversity of topics researched at INDEK, they represent established as well as younger faculty's production, they represent both male and female researchers, and they span over the whole evaluation period (2012-2019).

Micro-level:

1. Lindgren, M., Packendorff, J., & Sergi, V. (2014). Thrilled by the discourse, suffering through the experience: Emotions in project-based work. *Human relations*, 67(11), 1383-1412. (WOS: 37)

2. Dabhilkar, M., Birkie, S. E., & Kaulio, M. (2016). Supply-side resilience as practice bundles: a critical incident study. *International Journal of Operations & Production Management*. (WOS: 30)

3. Holgersson, C. (2013). Recruiting managing directors: doing homosociality. *Gender, Work & Organization*, 20(4), 454-466. (WOS:58)

Meso-level:

4. Tongur, S., & Engwall, M. (2014). The business model dilemma of technology shifts. *Technovation*, *34*(9), 525-535. (WO: 88)

5. Korhonen, J., Nuur, C., Feldmann, A., & Birkie, S. E. (2018). Circular economy as an essentially contested concept. *Journal of Cleaner Production*, *175*, 544-552. (WOS: 197)

6. Karakaya, E., Nuur, C., & Assbring, L. (2018). Potential transitions in the iron and steel industry in Sweden: Towards a hydrogen-based future? *Journal of Cleaner Production*, *195*, 651-663 (WOS: 26).

Macro-level:

7. Brown, J. R., Martinsson, G., & Petersen, B. C. (2013). Law, stock markets, and innovation. *The Journal of Finance*, *68*(4), 1517-1549. (WOS: 103).

8. Perkmann, M., Tartari, V., McKelvey, M., Autio, E., Broström, A., D'Este, P., ... & Krabel, S. (2013). Academic engagement and commercialisation: A review of the literature on university–industry relations. *Research Policy*, *42*(2), 423-442. (WOS: 838)

9. Baltzopoulos, A., Braunerhjelm, P and Tikounides, I. 2016 "Spin-offs: Why Geography Matters", *Journal of Economic Geography*, 16, 273-303. (WOS: 12)

e. Engagement in national and international research collaboration within academia and its outcomes

INDEK has a number strategic agreement and is partner in several centres, partnerships and collaborations.

Strategic Partner	Area of Collaboration
Stockholm School of Entrepreneurship (SSES)	INDEK is the Hub for KTH in this initiative aimed at developing entrepreneurial skills among students in the Stockholm region. SSES is mainly funded by Erling Persson foundation (H&M).
Swedish holm House of Finance (SHoF)	SHoF is managed by the Stockholm School of Economics and provides an independent platform for dialogue, open to everyone with an interest in finance. SHoF has a very strong focus on excellent academic research.
European Doctorate in Industrial Management (EDIM)	The EDIM PhD research programme is a European funded project with KTH, UPM and POLIMI as partners. All in all ,34 PhD students has been enrolled and the project is currently closing down, however, the collaboration with UPM and POLIM remains.
Gubkin Oil and Gas University (GOGU)	KTH has at Rector level a teacher and PhD exchange agreement with GOGU. Currently three PhD students are enrolled in this exchange programme.
Integrated Transport Research Lab (ITRL)	ITRL is a research centre at KTH sponsored by Ericsson and Scania. INDEK is engaged in research project and supervision of PhD students.

INDEK is also an active partner mediating research within the ITM School's departments.

Department at ITM	Area of Collaboration
Energy Technology	Ongoing shared research projects Shared supervision of PhD students
Learning in Engineering Science	Shared associate professor in learning, gender and change
Machine Design	Circular Economy imitative Shared supervision of PhD students

Material Science	Circular Economy imitative Shared supervision of PhD students
Production Engineering	Research applications and joint research projects
Sustainable Production Development	4 PhD students at this department follow INDEK's PhD programme Development of the academic environment

On individual level, researchers at INDEK have extensive collaboration with colleagues around the world. The papers selected as representative for the departments research (see Section 2d) illustrates some of the department's international collaborations.

f. Follow up from previous evaluations

From the 2012 RAE assessment INDEK received the following feedback.

- *Proposes that the UoA carries out an intermediary research evaluation, e.g. after two years, when significant changes have taken place.*

Research monitoring and evaluation has been a prioritized issue for INDEK's management team during the whole evaluation period. The goal during this period has been to reach a stable and significant quantity of articles, (see section 2d). In addition, several measures have been taken to "raise high-low", (see further section 4d). A measurable outcome of these efforts is that INDEK now has taken a place on the ranking lists. INDEK has also examined the existing publication channels (i.e. most frequent journal), with the aim of being more strategic in the selection of target journals. Yet another measure taken is that faculty now is recruited internationally primarily on research merits, in contrary to earlier years when teaching was prioritized.

- *The UoA could be a bit more focused in its research and maybe merge some of the divisions. To reach a leading position the UoA should focus on publishing more journal papers, in good journals. The UoA would consider creating incentives for its staff for journal publishing.*

See comments above. INDEK has recently re-organized with the above-mentioned purpose. In addition, two new research platforms have been created: sustainability and digital transformation.

- *A huge opportunity for the UoA, not to replace the current research agenda, but to complement it, is to focus on the growth of service dominant logic in the world just outside the home base of the UoA. As the business models of manufacturing companies have started to leverage the installed base of their products, inherently the services associated with the installed base (design, installation, financing, maintenance, operation, managed services, financial services, recycling) start to grow. Beyond the installed based related applications, as 60%+ of GDP is coming from the services, the industrial engineering knowledge will be needed in all kinds of services.*

Given the structure of Swedish industry, iNDEK needs to keep up a high level of competence related to manufacturing industry. Nevertheless, new business logics and new industries have been added to the "application portfolio" such as digitalization, sustainability, utilities, health care and transport related challenges which now have become central parts in INDEK's research, (see for example 6d Impact cases).

- *Encourage some more basic thinking about phenomena and critical social issues and apply more theory-based approach to enhance disruptions in the status quo in industry.*

Having secured the capability of paper publication, the two research streams sustainability and digital transformation addresses the request for phenomenon/challenge-driven research.

- *As the ambition level of the UoA has increased drastically, the UoA will encounter challenges to recruit top talents to fulfil the mission of the UoA. These talents also need proper induction and training in research methods and scientific writing. INDEK has been successful in attracting very good candidates. Onboarding of them is so far a partly neglected area.*

- *Consider to enhance its cross departmental collaboration within the school and also across different schools, in particular what comes to entrepreneurship and sustainability challenges. There could also be pace to extend collaboration and specialisation between KTH INDEK and the business schools in Stockholm area.*

INDEK has been successful in recruiting faculty and PhD candidates on an international market. One explanation to this is that INDEK and KTH has a good reputation. Another explanation is that Stockholm is an attractive city for foreigners. Nevertheless, onboarding has not yet been a prioritized area. The recent re-organization makes onboarding easier, but this issue needs re-newed attention, especially in the light of an increased focus on short term positions such as Post-docs.

INDEK has maybe the largest engagement with other departments in the ITM School. This fact has been hidden, as it has not had strategic implications for neither the school nor the department until the launch of IRIS.

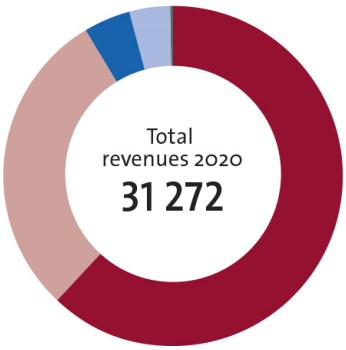
3. Viability

a. Funding; internal and external

INDEK has a turnover of approx. 100 MSEK. Related to the financial structure of the department, it is important to notice that much of INDEK's operations (still) are designated to education. During 2011-2019 the EDIM programme represented a major engagement for INDEK. Currently, INDEK is in the phase of transformation to an operative model, building upon the experiences from EDIM (i.e. increased international collaboration), but without the funding (see below). This explains the drop in external financing the last year(s).

Industrial Economics and Management

Sources of research income (2012, 2016, 2020)



Research income, kSEK	2012	2016	2020
Government grants for research and doctoral studies	20 177	19 980	19 408
Collaborative research funding	23 078	19 910	9 254
Contract research funding	492	2 124	1 310
Other revenues	2 035	1 323	1 299
Financial income	215	2	2
Total revenues	45 997	43 339	31 272

Figure INDEK-3. Research income.

The research budget of the Department has during the evaluation period been in the interval 30-40 MSEK, which is approx. 30-40% of the turnover of the Department. This figure includes basic funding received from KTH centrally. The decline in external funding 2018-2019 is to a large extent explained by the termination of the EDIM programme. New research applications, some of which has been granted, has been launched in order to cope with this situation.

For both 2020 and 2021, INDEK has received an extra performance-related funding based on publication output in 2020, as it is assessed as the top performer at the ITM School in terms of increasing its research output.

INDEK has also initiated fundraising activities targeting basic funding for new professorship in Sustainable Innovation and Entrepreneurship.

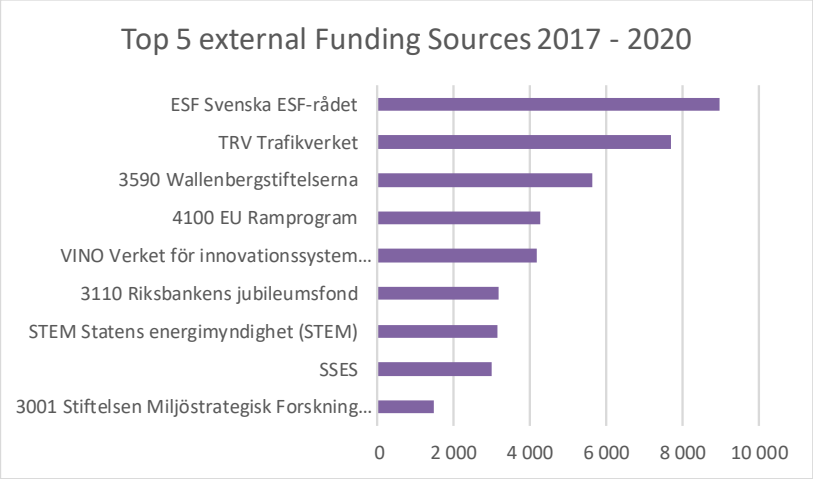


Figure INDEK-4. The Top 5 external funding sources, 2017-2020 (in Swedish).

In top of the external funding of the department is ESF (European Social Fund). This funding is related to the Software Development Academy, see further Impact Cases. Basic research funds are received from Wallenberg foundation, Riksbankens jubileumsfond and Stiftelsen Miljöstrategisk Forskning. As large part of INDEK's research is thematic and challenge-oriented it is not surprising that TRV (The Swedish Transport Administration), VINNOVA (The Swedish National Innovation Agency) and STEM (Swedish Energy Agency) are other main funding sources for the Department. SSES refers to Stockholm School of Entrepreneurship, a cooperation where INDEK is a key partner. The aim of SSES is to develop entrepreneurship in the Stockholm region. Another source of funding that currently is growing is funding from the different EIT:s. In addition to the above mentioned, the IRIS initiative will add 4 MSEK/year in research resources to INDEK intended for Post-docs. INDEK has also started to be active in becoming home Post-docs via Wallander scholarships. Wallander Post-doc grants are personal (they are not visible in INDEK's budget) with a duration of three years and nominated by an institution. INDEK's goal is to have at least three fully financed Wallander scholars at the department. Currently, INDEK hosts two Wallander Scholars.

b. Academic culture

During its history, INDEK has passed through four major phases.

- Foundation phase: Although INDEK has a more than 100-year history at KTH, the department was founded in 1972. During that time Professor Albert Danielsson led the department with a clear ambition to bridge technology and management. This was for example done by PhD students who studied both management and a specific area of technology.

- Conglomerate of one-professors' unit phase: INDEK grow and additional professors and units where merged with INDEK. Unit of Work Science, Unit of Skill and Technology, Unit of Accounting, Unit of Gender and Organisation and Unit of Economics became all part of INDEK. Later KTH decided that all these, once freestanding subject organised around one professor should be integrated in the larger subject Industrial Economics and Management. During this period most research was published as monographs in Swedish.

- Internationalisation phase: In 2011 INDEK received funding for the EDIM programme. 34 international PhD students became suddenly part of INDEK. During a few years INDEK changed from a domestic national institution to become an international academic environment. INDEK increased international publication significantly during this period. The EDIM programme was then followed up by increased recruitment of international faculty as a strategy to establish the international environment.

- Current phase: With the EDIM programme finished, new measures have been taken in order to cope with this new situation. The IRIS Post-doc initiative is one important activity that will add research capacity to the department. The new organisation, which aims to make a clear separation between education and research thereby fostering cross-functional research streams is another. Also initiatives which aims to make education more efficient and teaching tasks transparent, are implemented.

On an overall level, INDEK have not had a strong seminar culture. Before the re-organisation, research was mainly discussed in each (small) unit. Occasionally, external speakers were also engaged although this varied across the units.

The faculty assembly was a place for intense discussions on research. During a few years this assembly lost focus and addressed only administrative issues, however, recently there is a renewed interest in the academic debate also.

Currently, with the new organisation in place, the ambition is to create cross-unit topic areas, or research streams, where the department can accumulate strength in specific areas. Due to the Covid-19 situation, this process has been delayed, however, the IRIS initiative will result in four new major research streams.

In relation to PhD students, the academic discourse is maintained both by supervision team as the main arena for supervision, and three formal seminars defining the progress of the PhD student's research. These seminars are: Thesis proposal (6 months to 1 year after start), mid-term seminar (2 years after thesis proposal) and final seminar (6 months-1 year before defence).

Another important area is conferences. Conferences are often a focus point for research and a first intermediate step before submission to a journal. Often several persons attend the same conference leading making it an important component for the academic debate at the department. Finally, worth mentioning is that INDEK hosted the 2019 Scandinavian Academy of Industrial Engineering and Management (SCAIEM) conference. This conference has developed from being a mainly education-oriented conference to now be a full conference where education, research and impact matters are discussed.

c. Current faculty situation

The department has currently:

- 8 professors of which 6 are full time at the department. 2 are women.
- 18 associate professors, of which 6 are women.
- 2 assistant professors, both are men.
- 2 lecturers, both are men.
- 9 researchers, of which two are women.
- 1 visiting professor, who is a man.
- 5 post-docs, of which 3 are women (not included in Figure INDEK-3).

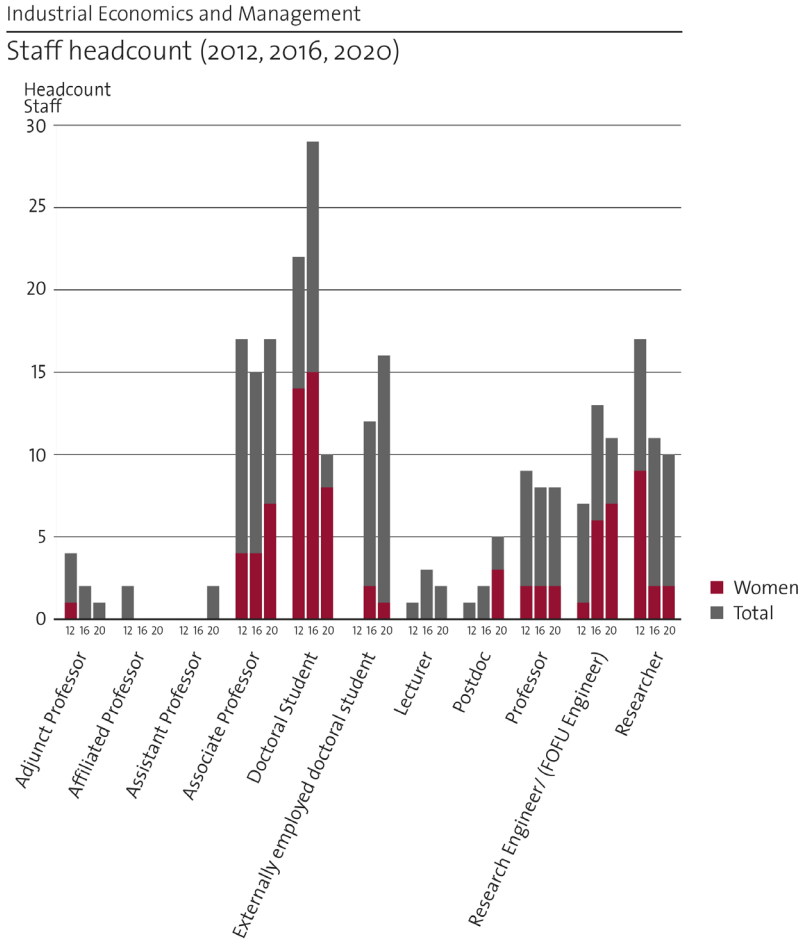


Figure INDEK-5. Staff categories.

Not surprisingly, the faculty is dominated by associate professors. In this category, the gender balance and the future promotions to professors is satisfactory. INDEK expects at least three (3) women to be promoted to professors within three years. In all the other categories, and in particular at assistant professor level, increased activities are needed in order to attract women.

However, as mentioned in this report, INDEK is too small in terms of critical mass of research. In order to improve, growth is necessary – and then growth should be done on individual basis where INDEK has the opportunity to pick strong candidates. INDEK has passed through a phase of merges.

d. Recruitment strategies

The faculty is nowadays recruited on research merits rather than teaching merits as earlier. Positions are formulated as bridging management-technology issues. Examples of recently opened positions are Associate professor in marketing with specialisation in e-commerce or Associate professor in management of sustainable energy systems.

During the last years INDEK has increased its international recruitment and currently the faculty is composed be people with origin from Sweden, Germany, Greece, Italy, Iran, Russia, Somalia, Turkey and USA. Recruiting women to faculty positions is a prioritised task.

After the termination of EDIM, INDEK has been successful in recruiting new PhD students. Since 2018, five (5) new in-house PhD students and two (2) industrial PhD students have been recruited. Of these,

are five women and two men. Worth noting is that the new rules for industrial PhD students state that it is a time limited position of 8 years with 50% research. This increased focus on academic research of Industrial PhD students is very promising.

INDEK has very limited experience of working with Post-docs. The IRIS initiative is therefore very promising as it adds research volume and a "new" category of faculty.

e. Infrastructure and facilities

INDEK is a management and innovation department and as such the infrastructure is limited to software and databases. In particular, to maintain, update and add new data to existing economic databases is crucial for INDEK. Databases are also accessed via the department's alliance with Swedish House of Finance (SHoF) which hold a number of important databases.

To keep the databases internationally competitive approx. 1 MSEK/ year is needed including license fees, purchase of new complementary data and management of the database.

4. Strategies and organisation

a. Goals for development 5–10 years ahead

- Growth. INDEK aims to grow by 100% (in terms of no. of faculty) until 2030. The largest part of this growth shall be related to research. The new organisation, which emphasises larger research projects/programmes, is one mean to reach this goal. Technology-based entrepreneurship and digitalisation are prioritised areas.

- Platform/Hub for technology-based entrepreneurship at KTH. INDEK has the ambition to grow in this area and exploit the link to SSES.

- Creation of a platform for Economics research at KTH including INDEK and the School of Architecture and Built Environment (ABE-school).

- To increase the departments as well as the faculties external communication.

b. Congruence with university-level goals for "A leading KTH" as set out in KTH´s "Development Plan 2018-23" (page 5)

"A leading KTH - Development Plan 2018-23" states the three areas of Leading Education, Leading Research and Leading Collaboration as pillars for KTH's strategic development. In addition to these three pillars, seven "elements" or prioritised areas should be leading the strategic development of KTH. These elements are: an integrated KTH, a visible KTH, an open KTH, a KTH for a more digitalised world, a KTH for a more sustainable world, a KTH in a global world, and an equal-opportunities KTH.

INDEK is embracing these goals in several ways. INDEK hosts one of Sweden's most popular educational programmes, INDEK is improving the quality and quantity of research, INDEK is a department integrated within the ITM-school and as well as collaborates with other departments at other schools. INDEK is visible in news and through the publication of books and academic papers, INDEK is engaged in research related to digital transformation as well as has a strong research footprint related to environmental sustainability. INDEK sends out many students to study abroad programmes, receives many international students and recruits internationally and has numerous international collaborations. INDEK has a fairly good gender balance and is continuously working on improving it.

c. Leadership structure and collegial structure

INDEK has, as mentioned earlier, a line organisation with Head of Department, Vice Head of Department, Three (3) Unit Managers, a Director of Studies, A Director of Third Cycle Studies and a Controller. These positions form the management team (MT) of INDEK. In parallel, INDEK has several forums for faculty participation.

- The professors' assembly is a new arena created in 2019. The idea with this arena was to balance the line organisation and to take a larger academic responsibility for the department's future development. This arena should also be responsible for quality issues of dissertations.

- The teachers' assembly is led by the Director of Studies. This assembly is responsible for Education affairs and is run in a collegial manner.

- The Supervisors' assembly is led by the Director of Third Cycle Studies. This assembly discusses PhD related issues. In the near future this assembly will be given an increased role for discussing the department's general research strategy. Both main and co-supervisors are invited to this assembly.

APT (ArbetsPlatsTräff). APT is included in the Swedish labour law and is mandatory for all employees. APT's are organised by the first line manager (Unit Managers). An APT is an arena for dialogue between employer and employees as well as a forum for interaction between members of the unit.

INDEK Development Meetings were created as department assembly, mainly for information purpose. The venue is led by the Head of Department and typically held once a month before the APT. With this sequence, it is secured that all faculty gets the same information at the same time. In addition, the upcoming issues and challenges can then be discussed at the APT.

In parallel to these fora research collaborations and assemblies take place.

d. Strategies for high quality

The main strategy for improving research quality at INDEK has been to "raise high-low". The concept of "raise high-low" is borrowed from athletics, a sport where it is important to perform evenly, but on a high level. This means to increase the lowest level of research output continuously, but different means. Transferred to the academic setting at INDEK, this means that focus is sat on continuously aiming for publications in high ranked journals (Web of Science) which is the academically recognized repository of KTH. To implement this strategy, INDEK defined in 2016 a measure for research output for each faculty member stating that the output should be >1.0 Pfrac WoS during a 3-year period (sliding 3-year). The measurement was not ambitions, but it should be seen in relation to other measure taken. It was formulated in this way in order to increase team work (Pfrac), to focus on Web of Science publications, and to create a general research culture at the department. To increase internal information, two TV monitors in the entrance of INDEK's building was installed which display news and recent publications authored by the faculty as a way to create recognition for achievements. INDEK has also a designated mail for distributing newly published articles to the whole faculty.

5. Interaction between research and teaching at all three levels (BSc, MSc, PhD) of education

Interaction between research and undergraduate teaching is strong at INDEK. Professors develop and publish award winning text books such as Professor Anna Wahl's "Det ordnar sig" and Professor Mats Engwall and colleagues "Modern Industrial Management".

Interaction between research and Master level teaching is strong at INDEK. The majority of courses at Master level are taught by faculty and they often include elements of own research.

Interaction between research and PhD teaching at INDEK is currently limited. During the past years, focus has been on scheduling and delivering the mandatory courses in the programme. The management team of INDEK has budgeted 500 KSEK annually, at the disposition to the Director of Third Cycle Studies to initiative PhD courses. This is an issue that the Department currently is working on.

6. Impact and engagement in society

a. Relevance of research to society at large

The challenges of digital transformation, sustainable transformation, equality and equal treatment in society and organisations, the cashless society, the future of work and the organisation of knowledge workers, business models and systemic innovations, the future of the university are some examples of society challenges addressed by INDEK researchers. The outcome of these research areas is relevant for a large number of stakeholders stretching from the individual private person, via managers in organisations to policy makers.

INDEK has a mixed experience of shared industry-academic positions. In some cases (energy), it is very successful. In others (digitalisation), it has not fulfilled the expectations. Also, the experience of industrial PhD's is mixed.

b. Research dissemination beyond academia

INDEK takes part in the public debate through several channels: is an active source of dissemination.

News coverage (newspaper and TV): Prof. Pontus Braunerhjelm contributes often to the ongoing economic debate, most recently in relation to the Corona crisis. Assoc. Professor Niklas Arvidson is an expert commentator in media in relation to the emerging cash less society.

Speeches and presentations: A large number of faculty hold speeches in different settings such as research assemblies and executive education.

c. Sustainability and the United Nations' Sustainable Development Goals (SDG)

INDEK addresses SDG goals no.:

- GOAL 3: Good Health and Well-being – by investigations into management and economics of health care organisations. These findings are important as they contribute to increased quality and cost-efficiency of health care.
- GOAL 4: Quality Education – by offering a number of MOOC's and continuously improving the quality of education.
- GOAL 5: Gender Equality – by engagement of INDEK faculty in KTH's central equality initiatives.
- GOAL 6: Clean Water and Sanitation – by running projects related to digitalization and the management of water utilities
- GOAL 7: Affordable and Clean Energy – by investigating the invention and innovation of new technologies such a photovoltaic cell, new steel making and carbon-capture technologies which aims contribute to CO_2 neutrality.
- GOAL 8: Decent Work and Economic Growth – by investigations of the future of work and re-skilling approaches as well as policy-oriented research related to the policy of innovation and growth.
- GOAL 9: Industry, Innovation and Infrastructure – by conducting extensive research related to both innovation and entrepreneurship, and management of innovation in utilities.
- GOAL 10: Reduced Inequality – No specific Actions.

- GOAL 11: Sustainable Cities and Communities – by engaging in the EIT Urban Mobility.
- GOAL 12: Responsible Consumption and Production – by striving for a CO_2 neutral industrial ecosystem 2050.
- GOAL 13: Climate Action – by conducting extensive research related to circular economy, sustainable transformation, management of sustainable energy systems and green economics.
- GOAL 14: Life Below Water – No activity.
- GOAL 15: Life on Land – No activity.
- GOAL 16: Peace and Justice Strong Institutions – No activity.
- GOAL 17: Partnerships to achieve the Goal – by engaging in international networks related to several of the areas above.

INDEK has during the last 5 years invested in the areas of circular economy, sustainable transition and management, economics of sustainable energy systems and green economics. Together these areas represent approx. 20% of the research volume measured in journal articles at INDEK. The investment in these areas represents a strategy of linking management research tighter to technological challenges. This strategy is also manifested in recruitment where several new positions have had a similar combination. In addition, based on these investments, INDEK is also a central partner in the MSc Program in Energy and Environmental Sciences.

d. Structure for increased impact

Apart from the above-mentioned initiatives, the department has limited processes and procedures for increasing engagement in society. Previously KTH Executive School was one channel for impact, but since the ITM school has restricted avocation how this channel should be used is unclear.

The following impact cases were prepared by INDEK, of which the three in bold are presented in the Appendix. The list shows INDEK's large spectrum of impact. The selected ones illustrate three areas of different focus. The first case illustrates a reach impact case as this case has gained great attention and the researcher (Niklas Arvidsson) is working close to Swedish financial institutions. The second case, VR, presented by Britta Forsberg, illustrates how new technology can impact both research and training in the field of management. Finally, the case on gender equality by Charlotte Holgersson illustrates a firm-specific impact case, with a potential of broader generalization.

- **Building a cashless society in Sweden - Niklas Arvidsson**
- **VR - Britta Forsberg**
- **Ripple effects in gender equality work - Charlotte Holgersson**
- Software Development Academy (SDA), a high impact reskilling program - Mattias Wiggberg
- Business Models for Electric Road Systems - Mats Engwall
- High Capacity Transports: Temporary organizing and collaboration in networks involving larger variety of industrial actors - Anna Jerbrant
- Safety management in SAS (Scandinavian Airline Systems), Pernilla Ulfvengren
- Sustainable aviation, Pernilla Ulfvengren
- World leader in development of CDR through BECCS, Fabian Levihn

7. Other

Specifics that the department wishes to mention and describe

Evaluating INDEK's research is impossible without considering the very large educational assignment it provides. As department, INDEK is small. Nevertheless, it runs approx. 100 courses, of which more than 15 have over 100 students, and one 1000 students. INDEK is responsible for the integrated Bachelor and Master programme in Industrial Engineering and Management (Civilingenjör I) which is one of Sweden's most popular engineering programmes. In parallel to this program INDEK runs a

Master in Industrial Management (targeted non-I students) and a 1-year Master in Entrepreneurship currently being up-dated to a full 2-year Master in Technology-based Entrepreneurship. In addition, INDEK also offers doctorate education in its a PhD program in Industrial Management.

All in all, INDEK, faculty need to fill seven (5) managerial positions (Head of Department, vice Head of Department, three unit managers, two directors of studies and five (5) program directorships (3 Master programme director, 1 bachelor programme directors and 1 PhD program director). Accordingly, a total of 13 part-time administrative positions are needed to manage the department and its educational engagement. Hence, approximately one third of the faculty are engaged in administrative assignments.

The research output of INDEK needs to be seen in relation to this dominant educational assignment. As stated in this report, INDEK has a potential to grow and to an even larger extent continue to KTH's research output. To do so there are two important factors that need to be in place. First, INDEK is in need of substantial increase of basic funding which can be used to increase the external funding. Thereby, the financial structure could be shifted so that research activities would have a higher priority. Second, as stated in the 2012 RAE, KTH centrally need to reduce overhead of external funding.

Finally, we would like to highlight an interesting observation of strategic importance for KTH (and maybe also other technical universities). The table below can be found in a new book about technical universities, co-authord by Anders Broström. Notheworthy is that many of the world's best "technical universities" (top 100 in the world) are also top performers in social sciences. The table shows to the left ranking in QS global subject ranking (top-25). To the right ranking for the same universities in the category of social sciences is displayed. The point is that stars such as MIT, ETH, Nanyang and Imperial College are performing world class in both areas.

E&T Rank	University	Country	SS Rank
1	Massachusetts Institute of Technology	United States	5*
2	Stanford University	United States	5*
3	University of Cambridge	United Kingdom	4
4	ETH Zurich	Switzerland	66
5	Nanyang Technological University	Singapore	29
6	Imperial College London	United Kingdom	49
7	National University of Singapore	Singapore	7
8	The University of Tokyo	Japan	13
9	University of Oxford	United Kingdom	3
10	Tsinghua University	China	39
11	University of California, Berkeley	United States	9
12	EPFL	Switzerland	-
13	Harvard University	United States	1
14	Tokyo Institute of Technology	Japan	213
15	Korea Advanced Institute of Science & Technology	South Korea	73
16	Seoul National University	South Korea	21
17	Politecnico Milano	Italy	99
18	The Hong Kong University of Science and Technology	Hong Kong	24
19	National Taiwan University	Taiwan	37
20	Peking University	China	26
21	Kyoto University	Japan	45
22	Delft University of Technology	Netherlands	194
22	University of Malaya	Malaysia	45
24	Georgia Institute of Technology	United States	213
25	Technical University of Munich	Germany	202

* Tied ranking position

KTH is today in the top 100 in engineering science in this subject ranking, but in 366th place in social sciences. Not bad, given the conditions, but the ambitions should be higher.

Department of Production Engineering

Self-evaluation
Head of Department: Prof. Mauro Onori

Included divisions:

Digital Smart Production
Manufacturing & Metrology Systems
Sustainable Production Systems

Department of Production Engineering (IIP)

1. Overall Analysis and Conclusion; Strengths and Development Areas

a. Limited SWOT analysis

	Strengths	Weaknesses
Research	1. Leads the SFO (govt. funded strategic research area) XPRES, an initiative for excellence in production research, allowing IIP to pursue basic research and support faculty development. 2. A driving force and leader of the Circular Economy paradigm. Led the CE@KTH initiative that coordinates research across four KTH schools. 3. The three main research areas lead to focused, high-impact outcomes: 5 EC success stories in 6 years. 4. Created Units focused on research in manufacturing engineering education. A large European network and projects investigating pedagogical development. 5. IIP researchers are active in editorials for number of well-known journals and publications in the field.	1. The research relies heavily on external funding, which does not support infrastructural investments. The internal funding is limited compared to the outstanding research outcomes. 2. Basic research has a limited opportunity for funding. 3. Insufficient participation in the Swedish Production Academy, the national organisation for scholars in Production science, due to retirements and lack of Swedish speaking faculty. 4. Poor gender balance. IIP has reacted to this and now holds a significant number of non-permanently hired female researchers that IIP hopes to recruit as future faculty. 5. The limited staff preclude having a full spectrum of competencies. Significant gaps exist. However, IIP does cooperate through XPRES to fill this gap.
Organisation	1. Only department with a Roadmap & Academic Development Plan. 2. Strong connection to research networks, such as CIRP, EUSPEN, IGC, NRSG, CE100, Swedish Component Manufacturing cluster, Arena for Additive Manufacturing of Metals, etc. 3. Enjoys close ties to local industry through DMMS, XPRES and Powertrain Manufacturing for Heavy Vehicles Application Lab (PMH), a collaboration between KTH and Fraunhofer. 4. Most well integrated management board with several nationalities.	1. Lack of prospect in having Swedish-speaking teachers take over the BSc courses, traditionally in Swedish. 2. Lack of instruments within the tenure track approach that allow young faculty to effectively pursue a career oriented to teaching.

Other things worth mentioning: IIP members are active in the most important international academy for scholars researching in Manufacturing: CIRP, International Academy for Production Engineering. The department has hosted CIRP Design conference in 2016, and CIRP CMS in 2018. IIP holds an open

bid to host the CIRP General Assembly in 2025. IIP has also representatives in the largest and the most prestigious international communities, such as council member in EUSPEN (European Society for Precision Engineering and Nanotechnology), vice-chairman of the STC P group in CIRP, and a research leaders in the Quality team in the IGC (International Grinding Centre). At editorial level IIP has the editor of the Journal of Manufacturing Sciences (JMS), editorial team of Emerald Press and associate editorship in the Precision Engineering Journal (IF 2.685. On the national level IIP has representatives in the Swedish Production Cluster for the Component Manufacturing, Swedish Arena for Additive Manufacturing of Metals, and NRSG (Nordic Residual Stress Group) for non-destructive testing (NDT).

Development areas considered most important:

- *Three main areas of R&D development* The three major R&D areas will be detailed later (see Research Profile): new areas include precision engineering, coopetition/ business models, and data analytics. These areas are currently covered by IIP but are growing in importance.

- *Education*: continue improving of the IIP educational impact through research and development of the IIP pedagogical domain. To be enabled by the XPRES and IRIS ventures, as well as by cooperating with the Learning department (LSE).

- *Gender gap*: the low level of faculty members being women remains a major area of future effort for IIP. Plans have been set with the ITM leadership for how to improve this, including the financing of guest professors.

b. Summary statement on contributions of department on impact, infrastructure and sustainable development

Since the launch of IIP's Roadmap 2040 in 2015, the department has worked almost exclusively on multi-disciplinary projects. It has also widened its collaboration to include several ITM departments and even some from other schools (details later). IIP's infrastructure (machine park, robots, measurement tools) are shared by IIP, MMK, MSE departments, as well as being supportive to KTH Junior ventures such as Formula Student.

All topics at IIP are strongly connected to *sustainability*, from re-usable machines to new business models, circular economy and collaborative robotics. Our roadmap explicitly sets this as one of the two main pillars of all our future work.

2. Research Profile

a. General information about the department

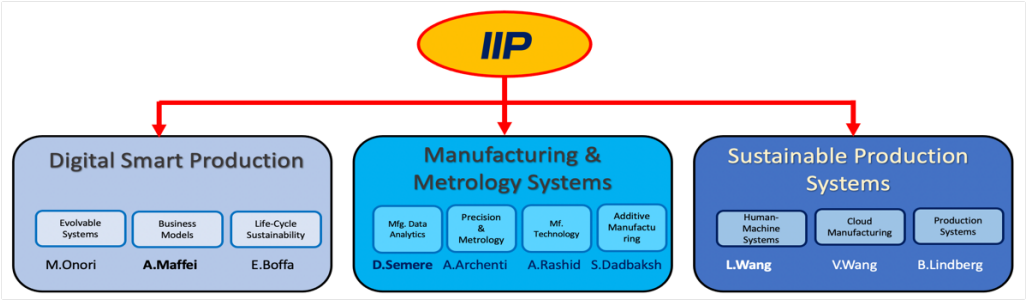


Figure IIP-1. Department structure.

The IIP department, following the RAE 2012 recommendations, carried out a complete re-organisation in 2014. The action took place as a new Head of Department was chosen and the administrative team

changed. The previous IIP consisted of 7 Units each created around a professor. This approach led to several RAE 2012 comments, including:

- Unsynchronised thematic and doubling of research areas
- No structured link between research and education
- Structure was person-dependent which hindered progress of young researchers
- Vague/split departmental identity (no common vision)

The new structure was derived to achieve a set of given improvements:

- The combination of professorships into a single unit creates a natural environment for collaboration, hence enforcing collaborative synergies.
- The combination of adjacent topics allows for strengthening of respective areas.
- A flexible structure is formed, in which young researchers may find a natural inclusion.
- Expansion and/or retirements are easily accounted for.
- More resilient economy as several groups contribute to a single economic unit.

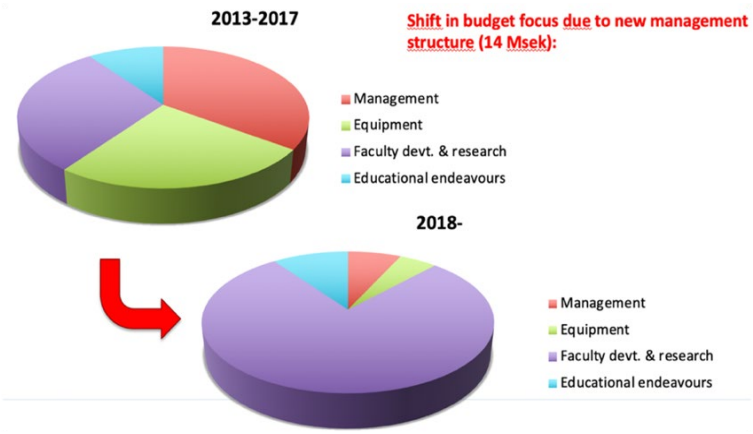


Figure IIP-2. Department budget rebalancing.

This re-organisation of the department was then followed up by a total re-structuring of the XPRES Strategic Research Area: these are large government-sponsored “areas of strategic importance” with an annual funding of 2 M€/year. The XPRES is also vital as it is a collaboration between IIP and Mälardalen Högskolan, Department of Machine Design (KTH), Department of Lightweight Structures (KTH) and SWEREA research institute. The main aspects of the improvement plan (defined by Prof. J. Wikander and Prof. M. Onori), were also discussed with President Gudmundson in May 10, 2015.

In summary, the improvement plan led to a radically new management structure and re-defined subdivision of budget. The new management structure has re-directed funds such that faculty development and basic research come to the fore, whilst the management is kept lean. Financing of educational endeavours has also increased, whilst equipment costs will be kept low in this period due to the large investments during 2013-2017.

b. Central research questions and themes, knowledge gaps addressed, main research activities

Biannual IIP roadmapping exercises are used to analyse, identify and renew the research areas and pinpoint future technologies. Figure IIP-2 shows the current central research topics and the relation to the ITM school and beyond. Digitalisation and sustainability are the two of the most powerful drivers in today’s industry and the IIP synchronisation of these lies at the core of the future plan.

PRIORITY AREA 1 – Autonomous Production Technology: The Autonomous Production Technology research area spans over several TRL levels, combining system technology developments to novel business models, re-usable production systems, design methodologies and more. As this is a ground-breaking area that includes the well-rewarded Evolvable Production Systems (EPS) paradigm, gaps do remain: *IIP would require a greater commitment from the ITM school on EPS, and more efforts should be exerted on autonomous control*. The work on regenerative processes is proceeding well with additive manufacturing, 4D printing and hybrid systems leading the research. EPS is now being tentatively tested in some industrial applications after a series of high-impact European projects (IDEAS, openMOS). This area also collaborates widely with other ITM departments and is the initiator of large ITM initiatives such as additive manufacturing and Cyber-Physical Systems (CPS).

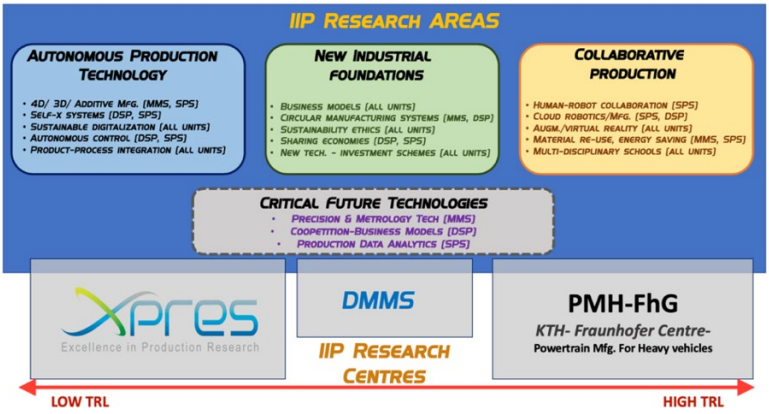


Figure IIP-3. Research areas.

Additive Manufacturing (AM) activities have been recently started at KTH level as a result of the push, efforts and initiatives at MMS division, beginning from 2016. The AM team is closely working with the department of materials engineering (MSE) and the department of machine design (MMK) as well as the department of engineering mechanics at KTH as the members of AM initiative at KTH. This collaboration is to develop AM courses, to guide master theses, to synchronise the research activities and to gain commonly usable AM infrastructure. Further collaboration is taking shape. Several MSc students are working with companies to develop AM at the destination company.

IIoT and CPS, industrial automation and Cyber Physical Systems (CPS) allow the creation of autonomous and cooperative elements and subsystems with the purpose of controlling and optimising production processes. Within IIP the units have been focusing on the infrastructure technologies for the CPS systems including Industrial Internet of Things (IioT), Evolvable Production Systems (EPS), and smart digital platforms. Furthermore, IIP has been developing models and simulations for digital twin prediction/optimisation purposes.

4D Printing – Through collaboration between MMK and IIP, IIP team won a VR (Science Foundation) grant to conduct fundamental research on closed-loop 4D printing with high precision. The lab hosts many pioneering research topics, including precise closed-loop control of 4D printed shape memory polymers, design, control, and fabrication of soft robots made by 3D printing, magnetically stimulated 4D printing, 3D printing for fabricating scaffolds and artificial arteries.

PRIORITY AREA 2 – New Industrial Economies: Transition towards circular economy (CE) by implementing Circular Manufacturing Systems (CMS) has become inevitable to ensure sustainable development. The CE concept has become a major research and educational paradigm as soon as the European Commission declared Circular Economy Action Plan in 2015 as well as the Swedish government identifying circular and bio-based economies as key areas for a sustainable society.

Circular Manufacturing Systems: IIP has prioritised CE as a high agenda for both research and education. Already in 2011 IIP, the Dept. of Production Engineering at KTH, proposed a visionary framework to intentionally design closed-loop systems. To allocate dedicated resources and sustain the research emphasis the department launched the focus area CMS in 2013. Since then IIP has played the role of core knowledge provider to industry, academicians, students and policy makers as well as positioned itself as a major research group in CMS. CMS research mainly focusses on developing new knowledge for industrial transition, methods and tools for CMS implementation and multimethod modelling and simulation to assess different aspects of CMS. In doing so IIP takes a system approach that considers business models, products design, supply chain and information management aspects.

Sharing Economy: Sharing Economy provides new business opportunities by connecting the stakeholders together, namely X2X (Everyone-to-Everything). In the past years, IIP has been taking the important research challenges in Sharing Economy research including:

- Sharing Economy on the Cloud: multiple types of devices, hardware and software can be encapsulated as service packages and shared in a mutual service pool, the Cloud.

- Service Level Agreement for Industry 4.0: Embedded Systems research environment at MDH has been working on moving intelligent parts of a factory into cloud and sharing services among different industrial domains.

- Smart Energy Sharing in Reykjavik and Borkum.

PRIORITY AREA 3 – Collaborative Production: The Collaborative Production research is one of the major research areas combining the flexibility of human, accuracy of robot and intelligence of computing systems. The research is taken across multiple TRLs, including fundamental research on robot control, human-machine interaction (TRL 1-5), and applied case studies of assembly tasks and robot cells (TRL 6-7). The research includes basic theory investigation, EU and national projects and holds a very high success rate (3 EC Success Stories in 4 years). Master, bachelor thesis projects and European student exchanges are also initiated in this area.

Cloud and Edge Computing: the cloud technology provides a pool of resources, including both computing capability and manufacturing tasks that requires minimum local hardware. IIP has been working on the cloud and system engineering research that integrates various manufacturing software and hardware and provides the remote functions with high-efficiency. Additionally, edge computing brings computation and data storage closer to where it is needed, to improve response times and save bandwidth. Combined with cloud technology, the time-critical computing tasks can be performed at the edge nodes on site, and others on the cloud.

HRC Human Robot Collaboration: human-robot collaboration combines the flexibility and intelligence of human together with the accuracy and stability of industrial robot. The SPS team has been working on the HRC topic for years towards the sustainability goals including friendly working environment, lower energy consumption, lower running cost, etc. The Human-Robot Collaboration (HRC) research especially strengthens the gender equality as it provides a uniform working environment, despite the gender, age, and physical conditions of the workers. The collaborative production research connects multiple research disciplines including Robotics, Artificial Intelligence, Human-computer Interaction, System Engineering, Mechanical Engineering, etc.

Production Development in Industry 4.0: Production development is part of the XPRES initiative and collaborates with the IPR environment at MDH. Currently, the group is working towards preparing for and adopting digitalisation and Industry 4.0 technologies and techniques in the context of production development. Within the IIP framework, the group focuses on supporting manufacturing companies in their transition towards Industry 4.0. Some of the ongoing initiatives at the group

includes coordinating production development in international manufacturing networks in times of Industry 4.0, data-driven decision making for production development, digital-twin of factory floor, AI Reasoning, cloud supported maintenance and digitally-enabled process innovation.

Critical Future Technologies:

Precision Engineering: This topic is becoming an integral part of research areas 1 and 3, but is being highlighted due to its recent progress. The demand for high precision systems is driven by the need to achieve technical, economic and environmental goals. Technical goals are related to improving the mechanical and physical characteristics related to the physical properties of the components, improving operational performance and safety and also aid the integration of ICT to implement CPS. Economic goals aim at reducing the design and production costs as well as keeping the products adaptable. The Precision Engineering team´s primary research activities are:

- Equipment: design and build of precision machines and metrological instruments;
- Industrial metrology: calibration, traceability and uncertainty
- Processes: precision manufacturing processes, surface texturing;
- Parts: dimensional, geometric characteristics and surface finish

The demand for high precision systems is driven by the need to achieve technical, economic and environmental goals. Technical goals are related to: (i) improving the mechanical and physical characteristics related to the physical properties of the components; (ii) improving operational performance and safety of systems and components working in harsh environments; (iii) the integration of Information and Communications Technology (ICT) to implement Cyber Physical Systems (CPS).

Data Analytics: The research in Data Analytics is a critical enabler to the transformation effort of manufacturing. The current projects are using deep learning and reinforcement learning, applied to address cases in prediction and optimisation, variation propagations in manufacturing, anomaly detection, error source identification in manufacturing, condition and asset health monitoring. A doctoral course, MG3915 Disturbance and Variation Analysis in manufacturing systems is being offered for the second time this year. Considering the long-term industrial needs as well as a few more new projects in the pipeline, more PhD students and researcher will join the research to strengthen the research activity in the area. Currently plans to build a test-bed are underway.

c. Contributions to the advancement of the state of the art within the research fields of the department

All the research areas detailed earlier have attained awards from the European Commission and beyond. IIP is a comparatively small department but has succeeded in obtaining 5 **Success Story** project results at EC level in the past RAE period: PoPJiM (FP7), IDEAS (FP7), CAPP-4-SMEs (FP7), ResCOM (H2020), SYMBIO-TIC (H2020). Beyond these major results, the IIP researchers have scored other awards, such as the Emerald Press Journal Article of the Year (2014, M. Onori), induction into Canadian Academy of Engineering (2019, L. Wang), Elsevier most cited paper (2016, Lieder M., Rashid A.), and JSM/Elsevier Best Paper of the Year 2020 (Wang, Onori % Törngren).

In terms of methodological contributions, IIP has been the main developer of the Evolvable Production Systems (EPS) paradigm, which represents a full methodology for the development of re-usable, self-configuring production systems. IIP has also been an early developer of the Circular Manufacturing Systems framework and methodology, work which has brought IIP high impacts (see later sections) and awards. IIP has also been the source of spin-offs, from MAQ AB to Modular Management AB.

A vital contribution is that the IIP research areas are no longer confined to the individual Units. The roadmapping efforts have produced the above depicted IIP Research Areas as **multi-disciplinary directions in which all units collaborate**. This tactical approach greatly motivates cross-unit work, collaboration and develops holistic methodologies.

d. Quality and quantity of contributions to the body of scientific knowledge

As shown in the figure below, IIP faculty members have maintained high impact during this review period), is now the department with highest publication impact improvement at the school (fig.5-6).

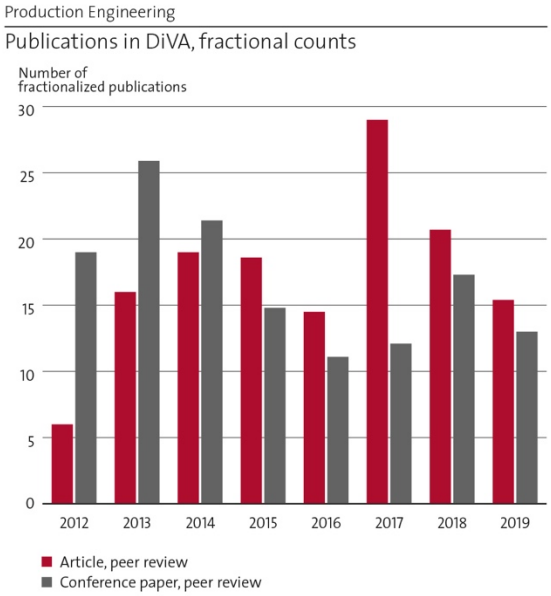


Figure IIP-4. Journal and conference publications.

Scientific impact has increased, with awards being achieved and new young faculty attaining strong publishing records. The latter has been supported by IIP senior members attaining editorial staff status with international journals (Prof. L. Wang, Prof. A. Rashid, Prof. M. Onori, et al.). These changes have brought about an increased cooperation within ITM partners, through joint faculty, projects and publications. The journal impact has therefore grown substantially, both at Scopus and WoS levels. See Figure IIP-5, which also shows co-authoring with external scholars.

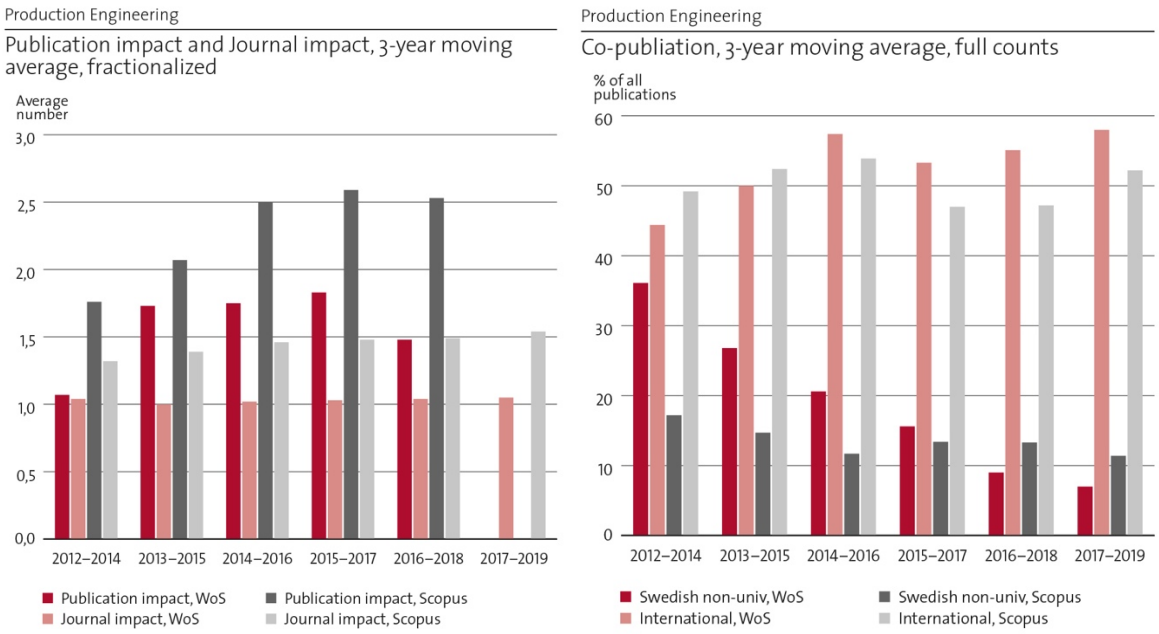


Figure IIP-5. (a) Development of publication impact, WoS and Scopus, and (b) Co-publication with external scholars.

Collaboration with industry is also strong and what is of interest in this period is the broadening of the industrial cooperation to SMEs. This is due to new initiatives at ITM School level which IIP has successfully joined, as well as the growing rate of external funding. The newest ITM initiative, IRIS (Initiative for Res. on Ind. Sustainability) covers four thematic areas and aims at enforcing inter-departmental research: post-docs and new junior faculty will have to work across departments in true multi-disciplinary manner. IIP is present in all four areas and actually coordinates Area 1 on Digitalisation of Industry. Other initiatives in which IIP is involved are Additive Manufacturing and Circular Economy. Note that the department holds one of the 160+ top 2%-citation KTH professors, namely Prof. Lihui Wang (see below). This is noteworthy as KTH has far more citation-friendly topics such as biomedics, computer science and others. IIP authors Lihui & Onori have also been awarded the JMS Best Paper Award 2020 from the Society of Manufacturing Engineering (SME) and Elsevier.

Author	Institute	Country	No.	1st year	Final yr	C-score	subject	Rank	Total no.authors
Wang, Lihui	KTH	swe	349	1993	2020	3,850385	Industrial Eng. & Auto	261	87535

List of main IIP publications (2012-2020):

Onori, M. et al; “The IDEAS project: Plug & produce at shop-floor level”; Assembly Automation 04/2012; 32(2):124-134., DOI:10.1108/01445151211212280; Best Article of 2013 Award; Emerald Press

Akillioglu, H.; Ferreira, J.D.; Onori, M.; “Characterization of continuous precise workload control and analysis of idleness penalty”; Computers & Industrial Engineering 06/2016; 102., DOI:10.1016/j.cie.2016.06.026

Wang, Lihui; Törngren, Martin and Onori, Mauro. "Current status and advancement of cyber-physical systems in manufacturing." Journal of Manufacturing Systems, Vol.37 (2015): 517-527. JMS/Elsevier Best Paper 2020 award

Wang, Lihui. "Machine availability monitoring and machining process planning towards Cloud manufacturing." CIRP Journal of Manufacturing Science and Technology, Vol.6, No.4 (2013).

Wang, Lihui; et al. "Collaborative conceptual design—state of the art and future trends." Computer-Aided Design, Vol.34, No.13 (2002): 981-996.

Lieder M., Rashid A. Towards Circular Economy implementation: A comprehensive review in context of manufacturing industry", Journal of Cleaner Production, Vol.115, (2016): 36–51.

Asif, Farazee M. A.; Lieder, Michael & Rashid, Amir (2016). Multi-method simulation based tool to evaluate economic and environmental performance of circular product systems, Journal of Cleaner Production, 139, 1261-1281.

Dadbakhsh, S., Mertens, R., Hao, L., Van Humbeeck, J. & Kruth, J.-P. (2019). Selective Laser Melting to Manufacture "In Situ" Metal Matrix Composites: A Review. Advanced Engineering Materials, 21(3).

Vogl G.W., Donmez M.A., Archenti A, Diagnostics for geometric performance of machine tool linear axes, CIRP Annals, Volume 65, Issue 1, 2016, Pages 377-380, ISSN 0007-8506, https://doi.org/10.1016/j.cirp.2016.04.117

e. Engagement in national and international research collaboration within academia and its outcomes

The concrete international collaborations are established based on close cooperation around EU and international research projects. These research partners include but not are limited to Fraunhofer IPA (Germany), University of Patras (Greece), Hungarian Academy of Sciences (Hungary), VTT (Finland), Cranfield University (UK), Coventry University (UK), Tsinghua University (China), Strathclyde University (UK), Sungkyunkwan University (Korea), Chalmers University of Technology (Sweden), Ericsson (Sweden), Sandvik Coromant (Sweden), Volvo Group (Sweden), Volvo Cars (Sweden), ABB AB (Sweden), Scania Cv AB (Sweden), Fraunhofer Chalmers Research Centre (Sweden), SWERIM (Sweden), RISE (Sweden), Swedish AM Arena (Sweden) etc.

IIP has also successfully increased the involvement in CIRP during recent years and is an active member of the IEEE/IES section. Other key international communities where IIP will increase their engagement are EurOMA and Design Society. IIP will further increase the international collaboration through visiting professors and international postdoc recruitments, an action well supported by the external financing obtained under 2019 through IRIS and XPRES. International collaborations are also established based on the joint EU projects with overseas contacts, e.g. ReCiPPs, ResCOM, EU CAPP-4-SMEs, SYMBIO-TIC, openMOS, MAESTRO, ICARUS, COMACH, HiCut, etc.. IIP is also representing Sweden in the ISO technical committees that aims to bring forward the CE standard. A list of main IIP partners (Academia) is readily available if required.

f. Follow up from previous evaluations

Recommendations from RAE 2012:

- *IIP Contribution to ITM School Recommendations*

Create a more rational organisation: IIP has contributed substantially to this endeavor by re-organising its own department in 2014 and by being the driving force behind the XPRES re-structuring in 2016. The results have been studied and applied by ITM.

Providing incentives: The ITM School has initiated several incentives to promote collaboration between departments. Several of these incentives have been started by IIP research, such as Additive Manufacturing, Circular Economy and Cyber-Physical Systems. ITM has also launched its IRIS initiative now in which IIP coordinates 2 areas and is present in all four. .

Promote more regular and longer international mobility: IIP is currently engaged in several ERASMUS, MARIE CURIE and CATALY(C)ST schemes to promote faculty mobility. The DimanD project (MC/H2020) currently hosts 2 senior researchers and will exchange personnel across Europe (8 people). Furthermore, the ITM School has initiated a sabbatical initiative to promote mobility.

Work actively in achieving a more equal gender balance: Since 2016 the department has launched active recruitment schemes at Masters level. This has produced 6 new female PhD candidates, leading to the overall number of newly employed PhD students holding a female majority.

Recommend that KTH takes its ethical requirements more seriously: IIP has been a driving force in this respect. It has developed the most comprehensive course on scientific methodology, which includes several actions on ethics.

Production Engineering, IIP; RAE Recommendations

Strengthen developments of the evolvable production system by additional (university) funding: This recommendation has not been followed up by the ITM School. Although both IIP and XPRES have repeatedly highlighted its importance, and practical results have been demonstrated at European level, there still exists a certain level of skepticism on its validity at ITM level.

Continue and permanent adaptation of XPRES roadmap: The IIP/XPRES Roadmap is now in its third evolution and will present the fourth edition by October 2020. The second edition was actually developed in collaboration with **TIETO**, one of Scandinavia's largest consultancy groups. Two of the major R&D trends today, sustainability and digitalisation, remain largely unsynchronised and are now IIP roadmap targets to develop an entirely new paradigm that does combine the two streams.

Process-near measurement technologies: Today, the strategic research in the Precision Engineering, Metrology and Machine Tools (PEM) team focuses on a wide variety of application areas such as systems and components from aerospace and nuclear industries to electronic, medical and optical parts. PEM objectives are also in the agreement with *CIRP STC-P* group.

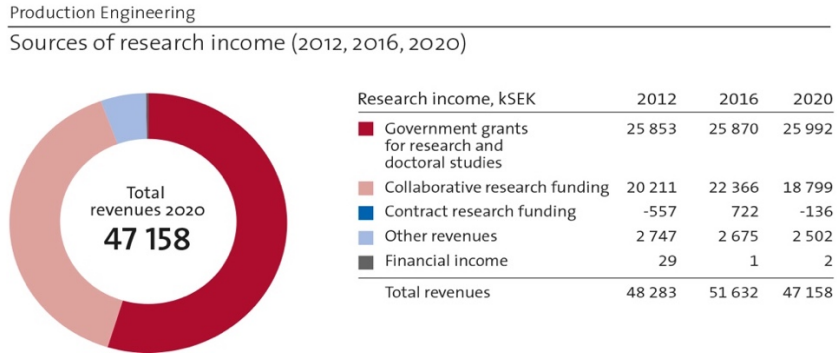
Improve internal collaboration within ITM school: This recommendation has definitely been addressed by the leadership with several new collaboration schemes at ITM level, including Circular Economy (CE@KTH platform), Additive Manufacturing, ITM Roadmapping, and Production Platform Collaboration with HPU Södertälje. This includes the new IRIS (Initiative for Research on Industrial Sustainability) which covers four thematic areas.

Strengthen the journal publications: The figures for the past RAE period have improved. Fortunately, IIP now holds one of the top-cited professors at KTH (L.Wang). In realistic terms, one may clearly see that the improvement is ongoing. The positive aspect is that international publications are increasing and that awards have been won (Elsevier, Emerald Press).

3. Viability

a. Funding; internal and external

The new IIP organisational structure, linked to a well-oiled collaboration, has resulted in a steady increase in acquisition of external funding, through both national (VINNOVA, Vetenskapsrådet, STINT, etc.) and international (H2020, etc.). As of 2020 IIP ranked as the second highest in R&D funding at the ITM School, a substantial achievement when considering it is the smallest department.



Research income, kSEK	2012	2016	2020
Government grants for research and doctoral studies	25 853	25 870	25 992
Collaborative research funding	20 211	22 366	18 799
Contract research funding	-557	722	-136
Other revenues	2 747	2 675	2 502
Financial income	29	1	2
Total revenues	48 283	51 632	47 158

Figure IIP-6. Research income development.

b. Academic culture

Within the IIP research teams, the quality of research is identified as the highest priority for all members. The research group meeting, seminars, and meetings are the most important occasions to discuss the research outcome and plans, thus allowing reviews by the peers and the quality guaranteed. Inter-unit collaboration is also improving with publication-sharing and projects.

Externally, the research outcomes are required to be published on high-quality international journals and conferences, where the external experts and peers review and comment on the outcomes as well. In the public research projects, the external experts and reviewers are also important source of objective feedbacks to guarantee the overall research quality.

c. Current faculty situation

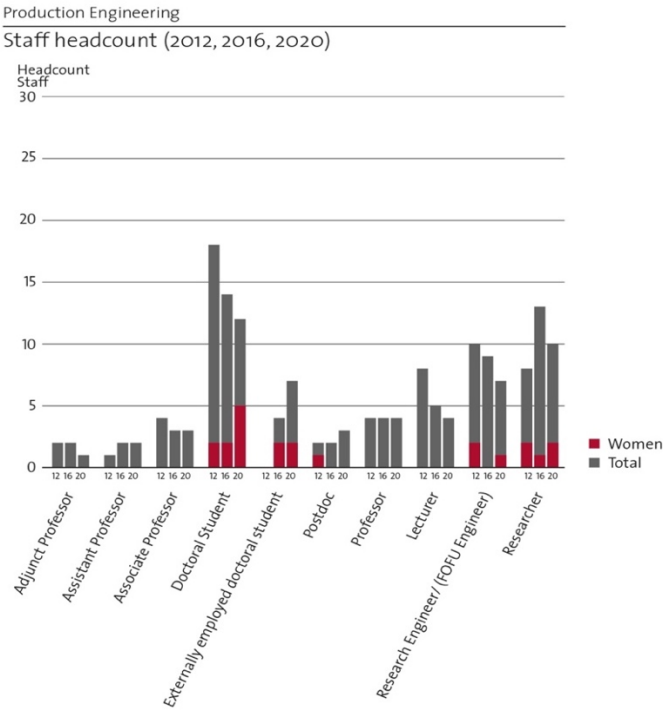


Figure IIP-7. Staff categories.

Due to several retirements, IIP has been undergoing a major generational shift. The faculty is fairly young and the post-doc/researcher numbers are strong, which ensures a sound development.

Another employment area which is being strategically targeted for future faculty is the MSc and PhD students. The recruitment of new PhDs has improved one of IIPs major problems: gender gap. Currently the numbers of women being recruited for PhD positions is on a steady rise, with 2 or 3 of them now approaching possible candidacy to post-doc and/or assistant professorship positions.

IIP has now finally attained one of its intended goals: a substantial increase in new faculty members, with a particular emphasis on young faculty with new skills. This is of fundamental importance as it not only proves that the new management structure is more efficient, but it also consolidates the future of the new subject areas being developed within IIP. See Figure IIP-7.

The IIP research team has a good age distribution from 20s to 60s, across multiple career stages including professor, associate professor, assistant professor, post-docs and doctoral students. The gender equality is critical as the production industry has had a male-dominated tradition in the past. Therefore, faculty development plans have been made for the following 10 years, in which gender equality strategy is included and enforced to establish an environment which is specifically attractive for female researchers.

d. Recruitment strategies

The recruitment of new positions is established based on the research topic objectively. New position descriptions are drafted in a neutral way which can be attractive to both female and male candidates. The requirement procedures strictly follow the KTH's regulations including public advertisement, fixed application period and review committee. When the application distribution is not as equal as expected, the submission deadline is extended. IIP has representatives in the KTH Admissions Board.

The IIP Academic Development Plan follows the natural evolution of senior faculty such that retirements can be replaced in due course and potential topics are duly reinforced: this Plan, which is revised annualy is growth rate aimed and proactive in reacting to new ITM initiatives and aging faculty.

e. Infrastructure and facilities

The MMS (Manufacturing and Metrology Systems) division was purchasing in the last 5 years and is working on the state-of-the-art scientific equipment, machine tools and metrology systems, such as EBM ARCAM A2X 3D metal printer, Stratasys FDM 400mc for plastic components and a small desktop/hybrid FDM printer, Hermle 5-axis machining centre, ABB robotic arms, Sodic Wire EDM, waterjet machine, Zygo NewView7300 White Light Interferometer, Wenzel CMM system, Polytec Scanning Vibrometer, Phenom ProX table-top SEM with EDX system, micro and macro hardness testers from Mitutoyo, Archimedes density measurement kit for AM, HiPIMS multilayer coating system, laser measurement systems, force and vibrations sensors, turning and milling machine tools, and many others. The AM team is also building a large-scale plastic 3D printer. The MMS division has an internal agreement that scientific equipment can be used not only by department faculty, but also by other departments staff from KTH, in order to increase internal collaboration and leverage research activities.

ARCAM A2X TECHNICAL DATA

Model-to-Part accuracy, long range [1]	+/- 0.20 mm (3σ)
Model-to-Part accuracy, short range [1]	+/- 0.13 mm (3σ)
Surface finish (vertical & horizontal) [2]	Ra25/Ra35
Beam power	50–3000 W (continuously variable)
Beam spot size (FWHM)	0.2 mm–1.0 mm (continuously variable)
EB scan speed	up to 8000 m/s
Build rate [2]	55/80 cm³/h (Ti6Al4V)
No. of Beam spots	up to ~100
Vacuum base pressure	<1x10⁻⁴ mbar
Power supply	3 x 400 V, 32 A, 7 kW
Size and weight	1850 x 900 x 2200 mm (W x D x H), 1420 kg
Process computer CAD interface	PC
CAD interface	Standard: STL
Network	Ethernet 10/100/1000
Certification	CE

Figure IIP-8. (a) ARCAM 3D Printing system available at IIP, and (b) Advanced, 5-DOF Machining Centre (Hermle)

However, new investments are necessary to introduce the newest solutions into research and to "push" scientific discoveries forward. The biggest concern of the department is the *source of funding* for the new scientific instruments and the limited space on which they could be located. These needs refer to laser metal deposition/laser cladding equipment as well as a laser powder bed fusion AM machine, *both issues being targeted through the IRIS initiative*. Bringing new AM infrastructure may also require allocation of sophisticated space installations and lab equipment. These could include permanent ventilation, powder storage, suitable electrical powers, vibration dumping floors, gas bottles and regulators, powder vacuum cleaner, etc.

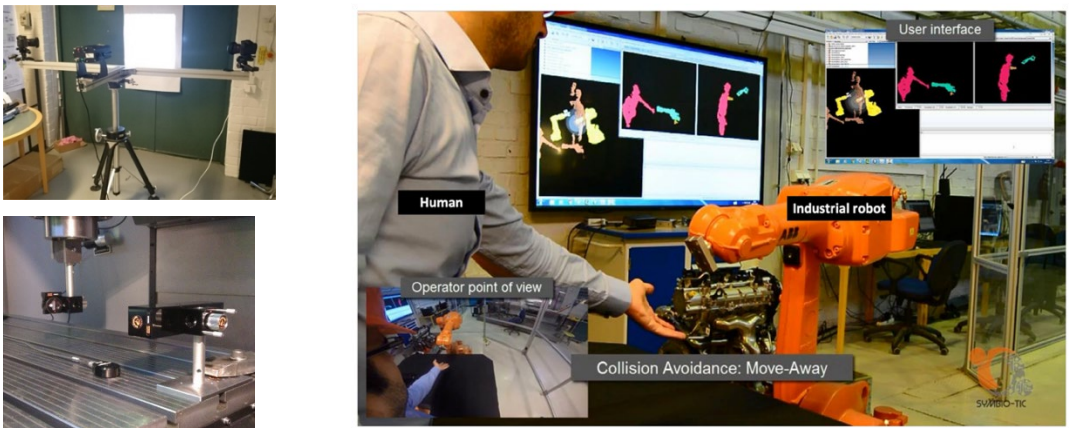


Figure IIP-9. (a) Metrology systems, and (b) Robotics Lab (3 ABB IRBs)

There is also a high demand for lab adaptation for making the controlled measurement environment (temperature and humidity), which is required for many measurement tools. Furthermore, the CMS team is aiming to establish a Circular Economy (CE) Lab with the objective to bring the CE concepts closer to implementation in industry.

The lab will develop ideas for small scale projects to simulate, experiment and implement in collaboration with industries, municipalities and cities (a forum for lifelong learning). For AM, specifically there is a need for additional features to the lab space such as lab infrastructural features: permanent ventilation, powder storage, vibration dumping floors, gas bottles and regulators, etc.

The HRC team has a robotic cell including the major industrial robot models, i.e. ABB, KUKA, and Universal Robots. A private cloud system is also invested to provide the computing power for the HRC and CPS research. In the future, the HRC lab aims to bring the current infrastructure up to date to match the requirements of Industry 4.0/Smart Manufacturing, with 5G machine/robot connectivity, cloud/fog computing power, AI and human intelligence in the loop of smart manufacturing. A state-of-

the-art demo lab equipped with smart sensors and connected by a 5G network with better mobility of robots will be an effective support to both fundamental research and industrial collaborations.

4. Strategies and Organisation

a Goals for development 5-10 years ahead

The long-term vision (2030) was developed on the basis of three fundamental pillars as shown in Figure IIP-10: *technology shift, social empowerment and economic support*. The transformation of industry towards radically new and sustainable production forms will require similar efforts of society and economic structures, hence this approach. This updated vision will form three new Priority Areas. By 2025/2030 IIP will have implemented a way of working in line with the new vision and demonstrated it through pilot industrial examples. This will be achieved through establishing a stable, cross-discipline, cooperation among incumbent and new faculties in an international effort to develop technology for sustainable manufacturing.

Almost all current roadmaps on industrial technology will highlight the need to push for higher digitalisation of industry, set Industry 4.0 as a goal, and work towards "the Internet of Things". What is striking is that the core paradigm for which all these developments are intended, is not described. In fact, it is assumed that all such developments should be directed towards an optimisation of the current mass customisation paradigm. *This paradigm, whether one calls it mass personalisation or mass production represents absolutely no revolution*!

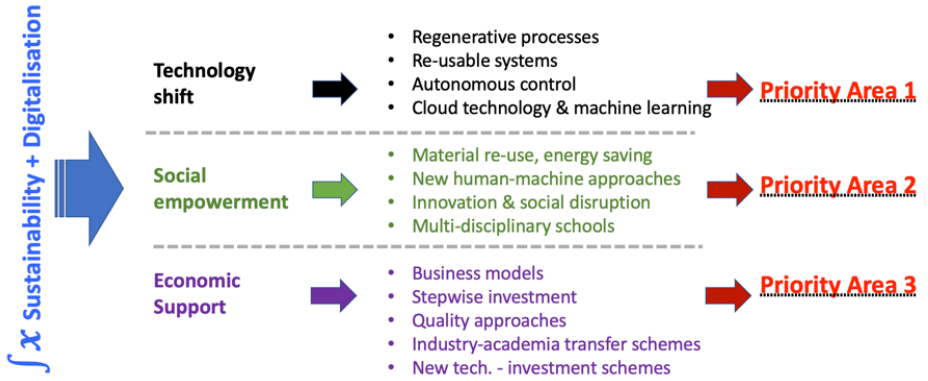


Figure IIP-10. The three fundamental pillars of the long-term vision.

IIP distinguishes itself by proposing an entirely new paradigm for the industry of the future. Instead of treating sustainability and digitalisation as separate objectives, IIP uses both simultaneously to drive all R&D efforts. Projects such as ReCiPPs, MAESTRO, and SYMBIO-TIC are clear examples of such a radical approach: the industrial partners are assisted in changing their business models such that resources are re-used and/or replaced, etc.

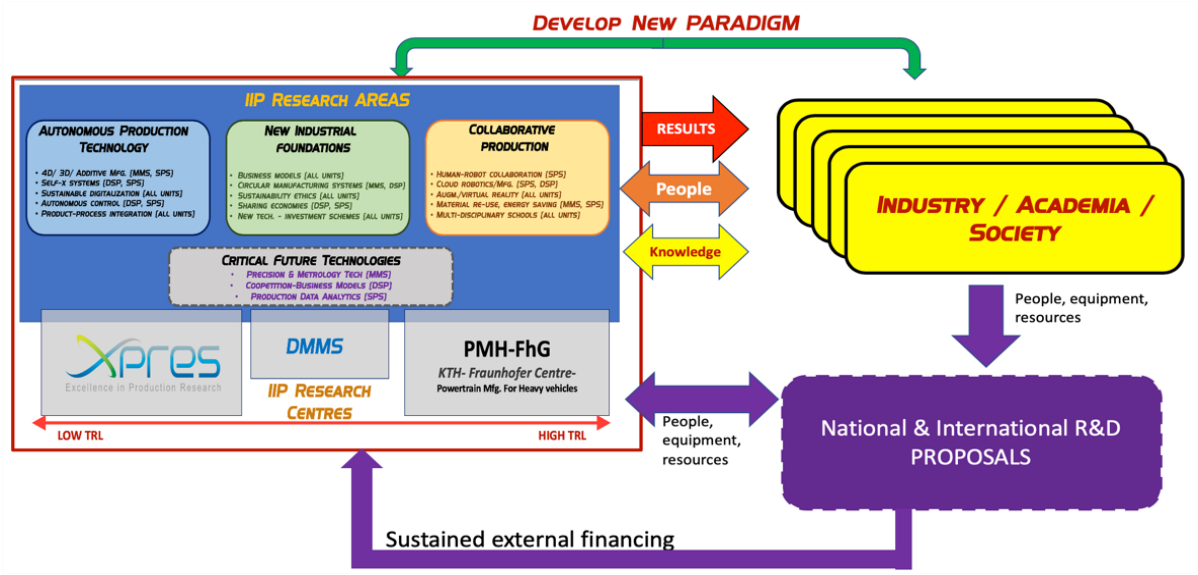


Figure IIP-11. IIP paradigm shift.

Expected goals:

The following goals have been identified in relation to the main KPIs considered for IIP. The goals include efforts in line with the vision:

- New faculty: 6
- External funding: increase 5-20% [SEK]
- Cooperation: broaden impact
- Increase in joined publication: +20%
- Postdoc working across units: 3
- External collaborative project: +10% [mix of project]
- Publication increase total volume 10%
- Quality of publication +50% in WoS/Scopus

List of envisaged milestones:

- 5 Postdocs in collaboration with partners by 2021, at KTH with IRIS support.
- 6 new faculty recruitments planned (1 due to retirement)
- 4-5 new EC projects; H2020 and new Framework Programme
- 20-30% more base funding
- 20% more annual publications, specifically targeting collaborative authorship
- 2 docents, 1 professor + 2 joint research projects at other dept/univ.

The above Goals and Milestones are linked to IIPs new vision to form a New Paradigm for industry that abandons traditional mass-production economics. To enable this, the integrated, inter-unit priority research areas will continue to collaborate beyond their territorial topics with academia, industry and society to achieve this.

b. Congruence with university-level goals for research as set out in “A leading KTH - Development Plan 2018-23” (page 5)

The IIP mission is to define and develop an area of tying business needs to technologies: smart sustainable digitalisation. This entails a well-integrated approach in which Digitalisation and Sustainability are developed hand-in-hand and not as separate objectives. Such an area will

consolidate knowledge and competence in robust, digital and smart production together with manufacturing processes and system technologies, all the while adhering to the KTH and UN sustainability goals.

IIP is active within KTH Sustainability and is also collaborating with VINNOVA to revise how projects are classified in view of future potential. As this topic is at the heart of IIP Vision 2040 (see later), it has also clarified which aspects of the UN agenda for sustainable development it will primarily focus on (see below). IIP has recently taken a leading role in the ITM School endeavour for attaining zero emission industry through the IRIS initiative. With reference to the UN agenda for sustainable development IIP specifically addresses the following goals:

- Goal 4: Quality Education. A specific part of IIP resources is devoted to improving the quality of education both at KTH and beyond. In detail, IIP research results are integrated in the course offer through formulation and implementation of new learning outcomes. In addition to that IIP lab has established itself as integral resource for the learning environment. IIP is constantly updating existing courses and developing new courses to integrate state-of-the-art knowledge. For example, in 2021 IIP Is introducing 3 new master lever courses.

- Goal 9: Industry, Innovation and Infrastructure. IIP research activities focus on promising emerging technologies, within the 4th industrial revolution framework, which are expected to foster innovation for Swedish industry in the vital domain of manufacturing.

- Goal 12: Responsible Consumption and Production. Special attention, throughout all IIP contributions, is devoted to the theme of sustainable industrialisation through circular and sharing economy.

c. Leadership structure and collegial structure

IIP has re-organised its leadership structure, as detailed earlier. The decision to unite several small units into 3 major ones accomplished the interaction objectives, enhanced topical collaboration, and has led to improved holistic approaches. This has also promoted the young faculty development: young faculty is now able to be promoted to full professor without having to wait for retirements, they are catalysed by cross-disciplinary unit discussions and have also formed their own IIP Faculty Club.

The new management structure and efforts of the past years are clearly reaping benefits: IIP is now strongly supported through financing by external projects (national & international), it has a growing network of industrial & academic partners, and has received several awards for its results. In order to firmly establish internationally recognised production research, and IIP as a significant contributor for KTH, the IIP management will further develop the organisational structure in several ways:

- Continue the efforts to attract more, established, foreign and national production researchers.
- Channel applications for higher TRL projects and shift main IIP focus to lower TRL projects.
- Use the lower TRL to develop strategies for higher impact publications.
- Integrate the IIP development plans to those of collaborating university units.
- Establish an industrial reference group to maximize industrial long-term relevance of low TRL projects.
- Maintain and expand the organisational structure to strengthen cooperation with other production research centres/areas.
- Use the roadmap to identify research areas with potential for world class R&D.

d. Strategies for high quality

The IIP Vision and Priority Areas will continue to be monitored and updated through its now established Roadmap. The results will be monitored through an agreed set of KPIs (list available if

required), which the Management Board will discuss and evaluate at regular intervals (3-4 times/year). The international recognition is measured and evaluated by a selection of Key Performance Indicators (KPI) taken from a table which may be made readily available if required.

5. Interaction between Research and Teaching at all three levels (BSc, MSc, PhD) of education

The interaction between research and teaching at IIP has been one of the key improvement areas of the management during the last 8 years. At the time of RAE 2012, IIP was organised according to a traditional KTH approach that separated teachers and researchers. Almost all courses in the first cycle and a majority of courses in the second cycle were given by full-time teachers with a few exceptions of researchers with specific knowledge who dedicated a small amount of their time, never exceeding 30%, to education related activities. This has now been updated with almost all senior faculty actively engaged in education. The main benefit for this is the seamless integration of leading-edge research findings into education, a key factor for success: integrating the 4th industrial revolution and sustainability as presented by the UN agenda.

KTH has been receptive to this and has, several times and through different channels, suggested to shift towards a mixed model. IIP management has adapted to this way of thinking and has started to renew the faculty in this aspect. Examples of actions taken:

- All profiles for newly hired faculty include a mixed set of duty in research and education. This includes three assistant professors and two associate professors. Example: for five full time teachers (lecturers) that have retired in the last 8 years, only one new lecturer has been hired with a profile including 75% teaching, 25% research.

- Most researchers have taken the pedagogical courses to get the formal required pedagogical background: IIP is now well in line with the KTH policy that each faculty should pursue at least 15 credit equivalents of pedagogical education. This had a good impact in raising awareness of the needs related with teaching.

- Beside the new mixed faculty policy, IIP has also worked to stimulate existing lecturers to be involved in research by participating in projects. The most important achievement of IIP in this domain in the last years, is the *creation of a new research area on manufacturing engineering education*. From non-existing activity in this domain, IIP has now a solid publication record in engineering education and is leading European research projects focusing on these issues.

- Another important contribution is a new course of Scientific Methodology that is compulsory for our master students since 2014. The most innovative feature of the new course is that all senior researchers present both their research findings and the research methods they use, thus connecting active research to the student projects. This course is now part of the Swedish Produktion 2030 PhD syllabus.

In 2012 we had courses based on material produced in the 1980s and perfectly valid: this is no longer possible with the current pace of innovation. The new policy has completely renewed educational contents: courses have been upgraded both in content and in the way they are taught. From the formal point of view, the new courses have been designed according to *constructive alignment*: they include clear learning outcomes focused on student expected learnings, a breakdown of teaching and learning activities as well as assessment task, and finally a transparent list of grading criteria.

Another benefit of including researchers in teaching is that they feel more attached to the department and have been motivated to learn Swedish. This in increases cooperation among faculty and between faculty and students. An example of integration between research and education at IIP is in the domain of cooperation with industry in national research projects. IIP researchers often use master

thesis projects as tools to advance knowledge when cooperating with our industrial partners. Results from Bachelor and Master theses are often an integral part of national projects contribution and are, in most cases, defined together with industrial R&D colleagues. This has the positive effect of strengthening IIP ties to industry, and to leading edge applied research. Finally, a separate section must be devoted to third cycle education. This is linked to research in several ways:

- We have several industrial PhDs whose experience in industry is often translated into course material or company visits for our students and joint definition of master theses.
- The third cycle courses at IIP include an explicit element of research where they are required to publish or scientifically communicate the output of their activity throughout the course.
- Third cycle courses are often used as base to launch similar master courses. Examples: assembly technology, digital factories, circular manufacturing systems, additive manufacturing, and cloud manufacturing (in early development stages).
- PhD students who show interest for education are often involved as teaching assistants in their domain of expertise.

6. Impact and Engagement in Society

a. Relevance of research to society at large

The **Collaborative Production** has significant impact to the society at large in multiple perspectives beyond academia. First, it brings advanced production technologies, e.g. Cyber-Physical Systems, Cloud, Artificial Intelligence, Human-Robot Collaboration, to industry directly via collaborative projects, such as EU CAPP-4-SMEs. Moreover, based on the connectivity and intelligence of the production network, it is also beneficial for decision makers to understand material flows and conduct high-level policies accordingly. For example, the cloud-based data system provides the battery import and export statistics between different countries, leading governments to be prepared for future battery wastes and plan for recycling solutions (EU GREENet project). Additionally, the Human-Robot Collaboration approach offers a uniformed working environment despite the gender, age, and physical conditions (e.g. EU SYMBIO-TIC project). Note that both CAPP-4-SMEs project and EU SYMBIO-TIC project are rated as **success stories** by the EC.

Circular manufacturing systems (CMS), in the context of **circular economy** mainly addresses manufacturing industry, students, academicians and policy makers. Through several EU and nationally funded projects the CMS team at IIP has directly supported number of Original Equipment Manufacturers (OEMs) in exploring and implementing CMS as well as several SMEs in developing methods and tools that are necessary for implementing CMS. Furthermore, CMS has been a main theme for B.Sc. thesis since several years and the team is successfully running a PhD course on CE for last two years. CMS is also new research area developed at IIP, which is now an active topic for PhD research under production engineering program.

The **Digital Smart Production** (DSP) unit conducts research in the domain of integration of cutting edge IT technologies in the manufacturing domain to attain the goal of autonomous production systems. Different aspects of the industrial automation control systems are investigated targeting “plug and produce”: self-organisation, self-learning and dynamic workload control are some outstanding examples. DSP researchers work in close cooperation with Swedish and international companies and are active in the areas of digital factory with emphasis on the assembly process and system design. The technical dimension is coupled with the strategic one through the concept of business models, that is at the core of the original DSP perspective. Finally, DSP is an important contributor to active standardisation efforts for both organisational and information related dimension.

Additive manufacturing is a progressive technology that is influencing society rather directly. For example, during the COVID 19 crisis, IIP contributed to help the hospitals by providing spare parts at

the shortest time. IIP also joined in another project with colleagues from engineering mechanics department (KTH MoveAbility Lab) to develop posture aids to help the recovery of COVID patients.

b. Research dissemination beyond academia

The research dissemination has been taken through multiple channels. For instance, introductory videos have been produced and published on YouTube to share the research outcomes with the general public (EU CAPP-4-SMEs Project and EU SYMBIO-TIC Project). Meanwhile, public events and workshops have been organised and broadcasted live to the whole world (Public event - The way forward for Scandinavian industry). Additionally, the professional conferences and forums are also organised to exchange the knowledge and experience with industry beyond academia, e.g. European Robotics Forum, and Special Symposium on Human-Robot Collaboration at CIRP CMS conference. IIP has also published several articles in local media such as Dagens Nyheter (Sweden's largest newspaper), Ny Teknik (Tech journal for all engineers) and Dagens Industri.

IIP leads the CE@KTH initiative aiming to boost the research and education in CE at KTH . IIP is also representing KTH in the Ellen MacArthur Foundation's CE100 network and is also a signee of the New Plastics Economy Global Commitment. The IIP CE/CMS team has been active in different activities organised by the EC, EMF as well as conferences such as World Circular Economy Forum,

The DSP unit boasts a vast expertise in the domain of education and besides the didactical activities, it contributes to higher education research in the emerging paradigm of learning factory by promoting a constructively aligned pedagogical approach. These educational development activities have been disseminated through programmes in Vietnam, Thailand and even West Africa.

c. Sustainability and the United Nations' Sustainable Development Goals (SDG)

The new vision for 2040 at IIP is *all about* synchronising sustainability to digitalisation. From waste reduction and sustainable business models, to re-usable automation and collaborative systems, IIP is focusing on sustainability since the launch of the 2016 Roadmap and works at 80% on sustainability.

According to the UN's **Sustainable Development Goals**, the Collaborative Production research contributes in particular to Goals 9 (industry, innovation and infrastructure 100%), 5 (gender equality 80%), 12 (responsible production and consumption 80%), 17 (partnership for goals 50%), 7 (affordable and clean energy 50%), and 13 (climate action 50%). The CE and EPS cases address two of the greatest challenges of the 21st century, i.e. resource scarcity and sustainable development. The impact case is directly aligned to Goal 12 (80%) of the UN's 17 Goals and indirectly addresses several other goals.

d. Structure for increased impact

IIP´s processes, procedures or mechanisms to achieve increased impact and engagement in society are summarised below.

- Strong collaboration with industry
- Formalised IIP Roadmap work now systematic- ITM School Impact Group and industry collaborate(Sandviken, Scania, Volvo, TIETO).
- Growing level of researcher mobility through exchange programmes
- Education at different levels
- Public events, workshops, open-days in collaboration with industry
- Wide media coverage, e.g. website, video, newspaper/magazine articles, etc.

Department of Learning in Engineering Sciences

Self-evaluation
Head of Department: Professor Arnold Pears

Included divisions:

Division of Digital Learning
Division of Language and Communication
Division of Learning in STEM
The House of Science

Department of Learning in Engineering Sciences (LES)

1. Overall Analysis and Conclusion; Strengths and Development Areas

a. Limited SWOT analysis

The Department of Learning in Engineering Sciences (LES) is the result of an integration of earlier divisions of the School of Education and Communication (ECE). The Department was established within the School of Industrial Technology and Management (ITM) as part of a larger restructuring of KTH during 2017. Some of the Divisions had previously been a part of the university administration. The department, with its current structure and funding model, has been in existence since January 2018 and has not engaged in a prior RAE exercise in its current form. Since 2018, the new department has pursued research and teaching excellence in an integrated academic approach. Due to a strong emphasis on providing qualified support across KTH, most notably development of e-learning technologies and university staff training courses in higher education theory and practice, the number of research-active staff in tenure-track positions is relatively low. The reorganisation has focused on strengthening the research mission and establishing a critical mass of research active staff in areas where we identified potential for excellence. Departmental initiatives in research focus on fostering an open, collegial and ambitious research environment in which research excellence is a common goal.

	Strengths	Weaknesses
Research	1. Attractive research profile for public sector agencies and employers, generating access to external funding, in particular industry funded doctoral students. 2. Leading profile in the international research communities in all research clusters, combined with comprehensive international and national collaborative networks. 3. Strong block grant funding provides considerable resilience in the conduct of research and supports strategic staff recruitment. 4. Increasing commitment to developing the teacher education programs at KTH, combined with the recruitment of an associate professor in *Mathematics Education Research*, allows the department to expand its academic horizons and expand its teacher education programs.	1. Activities in the Department are not fully aligned, or strongly linked to clear goals and strategies for development, dissemination and impact of research. 2. Limited volume of external funding linked to relatively few research staff. 3. High teaching and systems development workloads limit the scope for research activity.

Organisation	1. Cross-divisional research clusters ensure the department is well positioned to take a leading role in emerging interdisciplinary areas, e.g. global competence, education for a sustainable future, and citizen science. 2. Strategic recruitments with specific funding from the Vice Chancellor pave the way for new research clusters in Engineering Education for Sustainability and Engineering Education for Equality and Societal Change.	1. Relatively low percentage of early career research staff in comparison to senior academics, research engineers and teaching staff (lecturers/*universitetsadjunkter*). 2. Limited number of staff qualified to act as the principal supervisor of doctoral students (docent competence). 3. Organisational structure is relatively new, and new divisions are not yet fully integrated in terms of mission and operation.

b. Summary statement on contributions of department on impact, infrastructure and sustainable development

LES plays a considerable role in establishing KTH as a leading actor in higher education research and development with impact in organisation and culture in higher education, teacher education, and education that produces engineers with a strong understanding of sustainability issues and a sustainability agenda in their engineering practice.

Impact

- World-class STEM education research with focus on improving all aspects of the tertiary learning experience and equipping staff with research informed educational practices.
- Education of holistic engineering graduates with a focus on inclusive work practices, global competence and sustainable engineering practice.
- Development of curricula and teaching resources for technology and STEM teaching in the compulsory and upper secondary Swedish school system, as well as delivering research and teacher education programmes in the technology and STEM disciplines.

Infrastructure

- Nationally recognised centre of excellence in STEM outreach through the House of Science in collaboration with the Stockholm School District and Stockholm University.
- Division for development of E-learning technology and best practices in technology supported learning for KTH as well as European and International partners.
- Division for learning in STEM, including higher education and compulsory school system research and development, supporting the transformation of STEM education at all levels through applied pedagogical research and innovation activities.

Sustainable Development

- Engagement in citizen science, climate change and sustainability awareness through the House of Science in collaboration with the Stockholm School District and Stockholm University.

- Development of online and campus-based teaching and learning approaches to support integration of the UN sustainability agenda, and goals, into teaching practice across all technical and engineering disciplines.

- Impact in higher education development has a particular focus on working through education to directly achieve goals 4 (quality education), 5 (gender equality), 9 (industry, innovation and infrastructure) and indirectly to 10 (reduced inequalities) 16 (peace, justice and strong institutions) and 17 (partnership).

2. Research Profile

a. General information about the department

Between 2011 and 2017, the department was part of the now-defunct School of Engineering Communication and Education (ECE). Reorganised and enlarged, and with a more focused academic mission, it is now in its third year as part of the School of Industrial Engineering and Management (ITM). After reorganisation, the department consists of three divisions and one centre:

- Learning in STEM, LiSTEM
- Digital Learning
- Language and Communication
- The House of Science (centre)

Research is organised into five clusters to emphasise and enable cross-unit multi-disciplinary and trans-disciplinary research:

- HEOS—Higher Education Organization Studies
- Technology and Science Education
- Digital Learning
- LEEaP – Leading Engineering Education and Progress
- Global Competence

This is the first research assessment exercise for this new department. Research-related performance statistics prior to 2018 in this report are built on attempts to aggregate the performances of the staff and external research projects associated with the divisions from which the department was formed.

b. Central research questions and themes, knowledge gaps addressed, main research activities

Research at LES concerns development of engineering education, including aspects of academic life such as research and supervision training, organisation and academic leadership, outreach and internationalisation. Our mission provides a unique opportunity to engage in applied research and integrate our research findings into teaching practice nationally and internationally. Knowledge creation in the department embraces both specific and general results in relation to academic systems, learning and learning technologies. Research focuses on key issues in higher education, with a focus on sustainability and educational innovation.

Higher Education Organization Studies (HEOS), is an interdisciplinary group studying the preconditions for education and learning as well as other academic activities. The topics include but are not limited to: higher education and research policy development and implementation; institutional

governance; organizational change, identity and culture; academic leadership, management and work; higher education institutions' relations to state, internationalisation, society and external stakeholders and curriculum development. The group started its work in 2012 and has since developed and concluded a large number of research projects, including both empirical and theoretical studies. The group has strong national and international networks and several ongoing projects together with colleagues from other higher education institutions. We also have ongoing collaborations with scholars from other parts of KTH. Our goal is to be internationally recognized and locally embedded. The HEOS cluster is led by Professor Lars Geschwind, joined by Associate Professor Kristina Edström, nine PhD students, one lecturer, one postdoc, and two affiliated researchers.

The **Technology and Science Education** group explores the relationship between technology education and sustainable development, the use of systems thinking within technology education, the need for broadened recruitment to higher technical education, and the understanding of teaching within specific STEM disciplines. One important research goal is to lay the scientific foundation for the teacher education programs at KTH and Stockholm University. The cluster explores how science epistemology, content, and practice is reproduced and transformed when biologists, chemists and physicists take part in teacher education. The group is led by Associate Professor Susanne Engström, and consists of four associate professors, three lecturers, six PhD students, and two research assistants.

Digital Learning examines how technology can be used to support education and learning. The cluster's key strength is its combination of pedagogical and technical competence. Its research is often design-based, exploring, developing and evaluating emerging technologies to support learning. Digital learning is actively involved in national graduate schools on digital technologies in K-12 education and teacher education. The group also actively contributes to research and development of digital learning at KTH together with pedagogical developers, learning designers and IT staff. Although the team primarily examines how technology can be used to support K-12 education, teacher education and higher education, its research also explores how digital technology can be used to support learning in other contexts, such as informal learning outside school settings. The digital learning research team of five PhD students, one research engineer, one lecturer, and one senior researcher is led by Professor Stefan Hrastinski. An associate professor is currently being recruited.

LEEaP gathers staff and doctoral students who focus on understanding engagement with engineering in the context of outreach and attractiveness. Research addresses longstanding challenges facing Engineering and STEM education in Western education systems. Areas of research interest include, student identity, motivation and study trajectories in secondary and tertiary education, challenge-driven education, understandings of sustainable development, teaching practices in technology and engineering education, as well as disciplinary research on topics such as "computational thinking" and international curricula for computing and engineering disciplines. The group comprises two associate professors, three lecturers, one post-doctoral fellow, one affiliated lecturer and seven PhD students. The group is coordinated by Associate Professor Lena Gumaelius and Professor Arnold Pears.

Global Competence is defined as the knowledge, skills and attitudes needed to communicate and work constructively, creatively and ethically in environments characterised by cultural and social diversity. This cluster's research explores how technical universities perceive, support, integrate and assess global competence for students, teachers and staff. Its research also aims to help enhance present and future engineering education. Examples of current research questions include how to assess the benefits of international student exchanges, how to help students transform their experiences from international exchanges into skills that benefit their future employers, and how to use e-communication tools, for example for online meetings, more beneficially and effectively. The cluster is led by Associate Professor Björn Kjellgren, and includes one associate professor and one PhD student. Many of the fifteen lecturers in the Language and Communication division contribute actively to research activities within the cluster.

c. Contributions to the advancement of the state of the art within the research fields of the department

Since its inception in 2012, **HEOS** has developed into one of the leading higher education studies environments in Sweden, with a particular focus on engineering education. The combination of expertise in universities as organisations, policy development and change processes, and empirical as well as sectoral knowledge has attracted funding, produced publications and links to education in the form of PhD theses, master theses and new courses. For many years change (and inertia) has been a prevalent theme in the group, mainly with focus on the meso (university) level. Recently, focus has shifted slightly towards the micro level, and in particular professionalization and the emergence of new response strategies to change. With the recruitment of new PhDs, internationalisation, curriculum design, student-teacher interaction and policy analysis have become more prominent themes.

Research on **Digital Learning** contributes to interdisciplinary progression by including both technical and pedagogical competencies. An example of a truly interdisciplinary project with practical, technical and theoretical contributions is the Math Coach Online project. As part of this project, initiated in 2009, more than 60,000 K-12 students have been tutored by student teachers in mathematics, a technical platform specifically designed for online mathematics tutoring was developed, and theoretical models for online mathematics tutoring have been developed. Another example of a theoretical development is research on asynchronous and synchronous e-learning. One of our earlier papers (Hrastinski, 2008) has been cited more than 1,100 times, and has become one of the most important foundational papers on asynchronous and synchronous e-learning, widely used by both researchers and practitioners around the world.

LEEaP research has been influential internationally in the development of both the philosophy of engineering education and innovation in engineering and STEM education curriculum and practice both in compulsory schooling and tertiary education. The cluster publishes extensively in engineering and technology education journals as well as more general education journals. Cluster representatives are major contributors at national and international conferences in the area such as IEEE/ASEE Frontiers in Education. Members of the cluster also hold leading positions in international associations serving as Vice President for Publications of the IEEE Education Society, leading initiatives such as the Nordic Engineering Hub, directing the NORDTEK group for Engineering education and serving in review panels for the Norwegian, the South African, and the Dutch Research Councils.

d. Quality and quantity of contributions to the body of scientific knowledge

LES has steadily increased its publications during the period covered in this RAE. Figure LES-1 presents the fractionalised publication frequency for the department in 2012-2019. From a single peer-reviewed article in 2013, the publication rate has grown to roughly 10 articles per year in recent years. Scopus coverage for these articles is 77%, though results need to be interpreted with caution due to the low total number of publications. The low total number of publications in the early years of activity reflects the relatively low proportion of active researchers in the department at the time. LES has expanded substantially in terms of the number of research active staff over the period 2017 to 2021.

However, in interpreting the bibliometric data presented in this report it is important to be aware that the series of organisational changes that the department's divisions have experienced have also fragmented the publications in the annual KTH bibliometric exercise which we suspect resulted in missing publications and other inaccuracies. Consequently, the data presented may not be fully representative of the performance of the research staff. Additional analysis shows that our publication volume for the period 2018-2020 is underestimated by approximately 46 publications. We are now taking steps to correct the data.

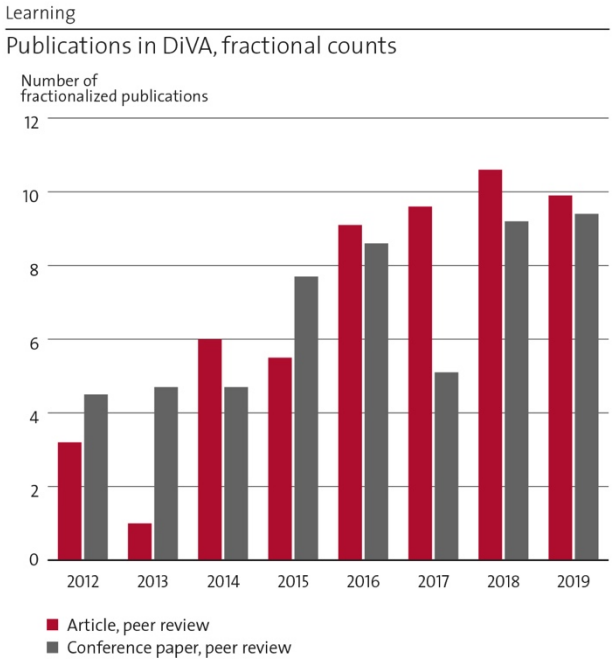


Figure LES-1. Journal and conference publications.

The average fractionalized rate of citation for departmental publications in the publication year and the two subsequent years is 1.0 for WoS and 5.7 in Scopus. The share of publications in the top 20% journals is 25% in WoS and 56% in Scopus. See Figure LES-2.

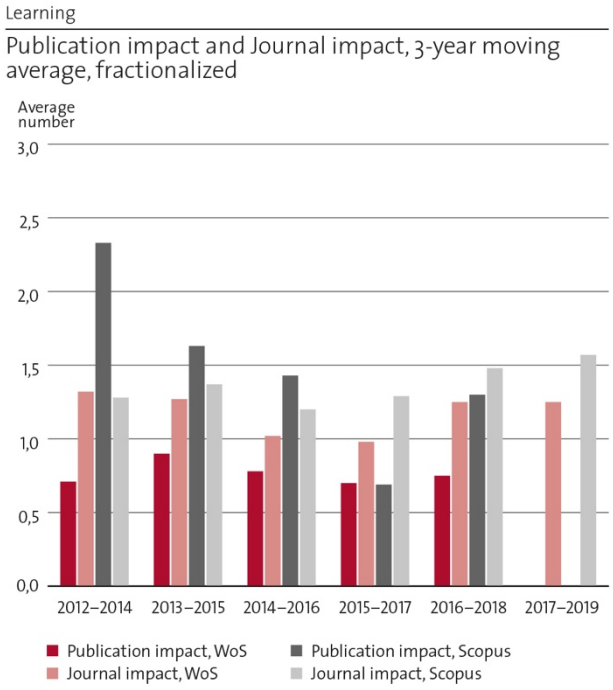


Figure LES-2. Publication impact.

The following publications represents high impact work which is today united under the LES departmental structure. One publication was published outside the time period of the current RAE exercise, but was included due to significant current impact.

Publication	Impact
Crawley, E. F., Malmqvist, J., Östlund, S., Brodeur, D. R., & **Edström,** K. (2014). *Rethinking Engineering Education: The CDIO Approach*. Springer, Cham	The book is a key resource in the CDIO Initiative, founded by MIT, KTH, Chalmers and Linköping university. It is now a global community for engineering education reform, gathering more than 160 institutions worldwide (see www.cdio.org). Scopus counts 478 citations (1899 in Google Scholar) and chapters have been downloaded 37.500 times on SpringerLink.
Edström, K. & Kolmos, A. (2014). PBL and CDIO: complementary models for engineering education development, *European Journal of Engineering Education*, 39(5), 539-555. DOI: 10.1080/03043797.2014.895703	This paper is included in the PhD thesis in Technology and Learning defended by Edström in 2017, one of the first theses in Sweden in this area. It has been cited 117 times in Scopus (225 in Google Scholar).
Geschwind, L., & Broström, A. (2015). Managing the teaching–research nexus: Ideals and practice in research-oriented universities. *Higher Education Research & Development*, 34(1), 60-73. DOI: 10.1080/07294360.2014.934332	This paper discusses the links between teaching and research in Sweden, based on a mixed methods design. It has been influential for both policy and research. It has been cited by scholars globally, as well as in the Swedish higher education policy debate. It has also been used as course literature in educational development courses. Over 1500 downloads and 45 citations according to Taylor and Francis metrics.
Hartell, E**., Gumaelius,** L. & Svärdh, J. (2015). Investigating technology teachers' self-efficacy on assessment. *Int. J. Tech. Des. Educ.* 25, 321–337. DOI: 10.1007/s10798-014-9285-9	This article confirms prior research on the importance of teacher training in strengthening teachers' self-efficacy in assessment, a direct predictor of improved student outcomes. Downloads in excess of 800 and 34 citations (Google Scholar).
Hrastinski, S. (2009). A theory of online learning as online participation. *Computers & Education*, 52(1), 78–82. DOI: 10.1016/j.compedu.2008.06.009	In this paper, a theory of online learning as online participation is suggested, arguing that participation and learning are inseparable and jointly constituting. Though this article is older, we include it as an example of prominent research at LES as ResearchGate is listing it as the currently most read publication from KTH.
Hrastinski, S. (2019). What do we mean by blended learning? *TechTrends*, 63(5), 564–569. https://doi.org/10.1007/s11528-019-00375-5	In this paper, definitions, models and conceptualizations of blended learning and their implications are discussed. The paper has been accessed more than 34,000 times (according to Springer) and cited more than 100 times.
Frezza, S., **Pears, A.**, Daniels, M., Kann, V., Kapoor, A., McDermott, R., Peters, A.-K.,	This publication in the area of competence-based curriculum design has generated significant impact

Wallace, C., Sabin, M., & Cajander, A. (2018). Modeling global competencies for computing education. *Proceedings of the 23rd Annual ACM Conference on Innovation and Technology in Computer Science Education,* 348–349.	since published as a global report 2018. It has been downloaded more than 1500 times and has 35 citations (Google Scholar).
Pinheiro, R., **Geschwind,** L., & Aarrevaara, T. (2014). Nested tensions and interwoven dilemmas in higher education: The view from the Nordic countries. *Cambridge Journal of Regions, Economy and Society,* 7(2), 233-250. DOI: 10.1093/cjres/rsu002	This paper is an example of a journal publication slightly outside the area higher education. It shows how reforms and change processes have affected the Nordic higher education systems. It was the starting point for a comparative project across the Nordic countries funded by the Norwegian Research Council. It was also the basis for workshops with university leaderships in the Nordics. Downloaded over 1000 times, and more than 50 citations.
Pinheiro, R., **Geschwind,** L., & Aarrevaara, T. (2016). Mergers in higher education. *European Journal of Higher Education*, 6(1), 2-6. DOI: 10.1080/21568235.2015.1099455	This is a well-cited introduction to a special issue on mergers in higher education, the result of extensive work in this area together with a network of scholars primarily, but not exclusively, from the Nordic countries. In the same special issue, a model for understanding mergers in higher education was presented. Downloads over 1200 and 52 citations in ResearchGate.
Stenbom, S. (2018). A systematic review of the Community of Inquiry survey. *The Internet and Higher Education*, 39, 22–32. DOI: 10.1016/j.iheduc.2018.06.001	This paper describes a systematic review of the Community of Inquiry survey. The Community of Inquiry theoretical framework is one of the most well-researched theoretical frameworks in the field of online and blended learning. Curently 49 citations according to Google Scholar.

e. Engagement in national and international research collaboration within academia and its outcomes

A strong international collaborative network had been developed prior to reorganisation into the current departmental structure. This work has continued within the framework of the research clusters. Several research clusters have extensive collaboration activities both internationally and nationally. This is increasingly reflected in co-authorship with international and national researchers. See Figure LES-3.

Staff in the Department hold highly recognised international roles, including editorial and reviewing roles in many major international journals, grant application reviewers for Research Councils in a number of countries, and serve as expert advisory board members for EU and Nordic research projects. Below, each research cluster describes its most notable external ties.

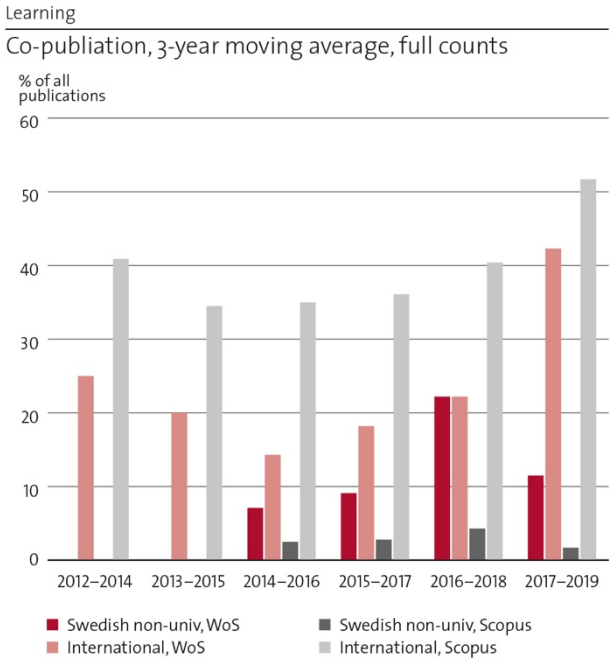


Figure LES-3. Co-publication with national and international scholars, full counts.

HEOS has strong national and international networks and several ongoing projects with other higher education institutions. This is particularly the case in Europe and the Nordic countries, but also increasingly in Africa through participation in a SIDA-funded research school, and globally in the 30+ country strong project APIKS (the Academic Profession in the Knowledge Society). HEOS plays a significant role in the Consortium of Higher Education Researchers, the European Higher Education Society (EAIR), the CDIO Initiative, the Nordic Network for Engineering Education Research (NNEER) and SEFI. One member is the Editor-in-Chief of the European Journal of Engineering Education. We serve on international advisory boards for the FTS project at NTNU in Norway, the 4TU Centre for Engineering Education in the Netherlands, and DTU Engineering Technology in Denmark. Nationally, we have ongoing collaboration with groups at Uppsala University, Lund University and Stockholm University. Furthermore, we have ongoing collaborations with scholars from other parts of KTH, in particular the ABE School and INDEK at ITM. We also work closely with the leadership and support services at KTH, and run joint projects in e.g. with Business Liaison, Internationalisation, and HR. We have excellent networks in the Swedish higher education and research policy sector, with higher education institutions, agencies, foundations, research councils and ministries. We organise critical and constructive research seminars, workshops and other scientific meetings on a regular basis. We typically organise one conference/workshop per year with external guests, both from other universities and external stakeholders. We also participate in the Stockholm Higher Education Research Network seminars (SHERN).

Research collaborations between **Technology and Science Education** include work with researchers at the University of Delaware, New York University, Aarhus University, University of Luxembourg, and the Swedish universities Uppsala, Stockholm, Gävle, Örebro, Gothenburg, Linköping and Linné. Outcomes include publications in journals in science and technology education and presentations at different international conferences such as ESERA, PATT, IOSTE, ECER, and NARST, as well as international collaborations on EU applications. Other outcomes of the research include participating in the National School Board's work with module texts and curriculum revisions, as well as other work at the national level regarding K-12 education.

Digital Learning participates in the GRADE and UPGRADE national research schools on digital technologies in K-12 education and teacher education together with Halmstad University, Jönköping University, University of Gothenburg, Linnaeus University, Mid Sweden University, Umeå University, University of Gävle and University West. These are research schools with more than 30 PhD students. The cluster is also a part of the Scandinavian higher education and e-learning (HEEL) network together with Mid Sweden University, Aalborg University and Umeå University. This Scandinavian seminar and symposium series has been organised for six years. Researchers in the cluster work on the Community of Inquiry (CoI) model, one of the most influential models in digital learning research, also collaborating with professors at several universities in Canada on its further theoretical development.

LEEaP cluster members are involved in a plethora of national and international collaborations, including the Nordic Network for Engineering Education Research (NNEER), CDIO, SEFI, IEEE Education Society and Swednet, with active participation in conferences and meetings. The group is currently a partner in a number of EU and Nordic level projects (ComNPlay Science, TeaEdu4CT, NordenHub, InnoEnergy) and plays a major role in the collaboration with the African region through the Global Development Hub (GDH). Group members occupy a number of high-level roles, including leadership of the Nordic Center for Engineering Education Research, external advisory panel for the EXCITED project at NTNU in Norway, and membership in the Steering Committee of the Uppsala Node of the ULF project for collaborative research between the Swedish school system and universities. One full-time and four part-time PhD positions are funded through the Swedish National Graduate School FontD. Group members conduct funded research together with colleagues from roughly 20 institutions in 15 countries. The group also contribute to broader societal impact through projects like TILLIT TILL IT (programming in schools) and K-ULF (compensatory teaching for learning and research), which develops a co-design based approach to establishing and sustaining research on classroom education in compulsory schools in the intersection between school and the academy.

Global Competence is a founding member, together with the Cambridge School of Engineering, of the Global Engineers Language Skills network, which now includes teachers from over thirty technical universities and engineering departments. The cluster also collaborates with Copenhagen University and the University of Oslo with funding from Nordplus, who have previously helped the cluster to build a network with Aalto University and the University of Iceland. The cluster is currently part of two Erasmus+ projects, 'Becoming a Digital Global Engineer', and 'Tools for Enhancing and Assessing the Value of International Experience for Engineers' together with 18 European institutions in 13 countries.

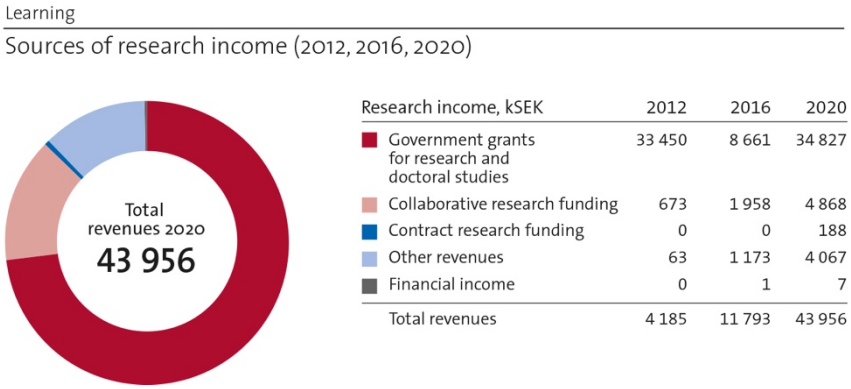
f. Follow up from previous evaluations

There have been no previous evaluations of the department's research.

3. Viability

a. Funding; internal and external

Figure LES-4 shows a steady increase in total research funding for the department in the 6-year period, from less than 10 million SEK per year in 2013 to over 40 million in 2020. There was a dramatic increase in external funding in 2019. In 2018, KTH funds (*TBK*) that had previously been designated as internal development funds were re-designated as research funds, accounting for the large increase in internal base funding. Development and innovation work funded from the research budget include the House of Science, the KTH digital learning program, and funding for courses for KTH faculty on Teaching and Learning in Higher Education (required for the academic career pathway in Swedish universities).



Research income, kSEK	2012	2016	2020
Government grants for research and doctoral studies	33 450	8 661	34 827
Collaborative research funding	673	1 958	4 868
Contract research funding	0	0	188
Other revenues	63	1 173	4 067
Financial income	0	1	7
Total revenues	4 185	11 793	43 956

Figure LES-4. Research income development.

b. Academic culture

LES integrates a spectrum of research and development activities into a vibrant and dynamic research community with a focus on openness and mutual respect. Unlike more homogeneous academic enterprises, one of the strengths of this young department lies in the multidisciplinary profile and the spectrum of activities it embraces. The breadth of the expertise available creates many opportunities for interdisciplinary research, and connects higher education research to both staff development activities and teaching practice. To facilitate this, research is organised into cross-cutting clusters integrating competence from several Divisions into multi-disciplinary groups.

An ambitious and distinct research culture is supported within the current department, focusing on relevant multi-disciplinary metrics in terms of impact, publication strategies and a flexible internal research organisation where research-active staff contribute to several research clusters.

Interchange of ideas, and development of strong research performance is facilitated by a combination of Department-wide seminars (Higher Education Seminar Series) in which the Divisions and Research Clusters meet and discuss each other's work. These broader seminars are complemented by more focused regular meetings within each Cluster where relevant recent publications in the field are discussed and strategic planning of research grant applications takes place. The Research Cluster model also provides collegial support for writing and revising academic articles and identifying new initiatives.

LES introduced a role of Head of Research to the Department Board in 2021. This role coordinates research efforts, helps to identify and prioritise grant application opportunities and coordinate publication strategy. The Head of Research draws on a research board comprising the Research Cluster leaders to help support strategic research objectives, following up outcomes, and compiling an annual research performance summary.

The RAE exercise has been useful input to this process and helped the Department to identify priority areas will help to emphasise strategic and systematic growth based on common goals in the future. This self-evaluation report has been the subject of a department-wide Higher Seminar. The PhD students continued the discussions for an extra hour, writing comments that helped improve the text significantly.

c. Current faculty situation

LES currently has 85 academic positions, now held by 55 women and 30 men. The distribution of employees by category of employment is shown in Figure LES-5. Very few employees are expected to

retire in the next five years. The department currently has 18% research staff, which reflects the historical composition of the divisions included in the current department.

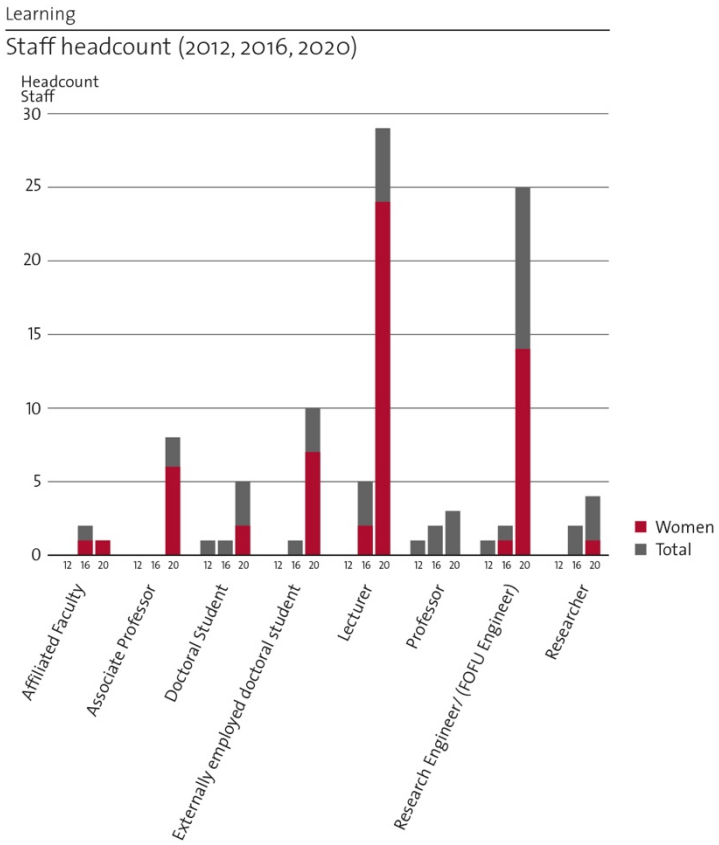


Figure LES-5. LES staff headcount by Jan 1 2012, Jan 1 2016 and Jan 1 2020.

d. Recruitment strategies

The current strategy is international recruitment of high-calibre scholars. Historically, the department had many lecturers, that is, non-tenure-track teaching faculty on permanent positions. While some lecturers have a PhD and are active in research, it is a high priority to increase the number of tenure track academics. Openings due to retirements and resignations are replaced by new tenure track positions to increase the research/teaching excellence of the department.

In addition to the general strategy of increasing the number of active research staff, LES is also pursuing strategic recruitment in priority areas in order to build up critical mass of research-active staff. This will also provide additional redundancy in teaching areas where loss of a single staff member might affect the ability of the department to deliver courses and research outcomes.

The areas of focus in the current five-year plan are: global competence, with special focus on language and communication; digital learning technologies, and higher education research. This is implemented through affiliation of prominent international scholars, especially within HEOS, and through a number of post-doctoral positions and opportunities for international collaborators to spend sabbatical periods here.

It is of high priority to enhance the number of tenure-track staff as a part of the strategy to increase the critical mass in our key research clusters. To this end, LES is recruiting associate professors in Gender and Learning, Sustainability and Engineering Education, and Mathematics Education. Furthermore,

recruitment of three assistant professors in Digital Learning, Higher Education Research and Development, and Engineering Communication has been initiated. Two postdoc positions are planned in the area of sustainability and life-long learning, in collaboration with other ITM departments.

e. Infrastructure and facilities

Research at LES requires no formal physical facilities such as laboratories. However, the department has several digital research facilities. Current IT infrastructure includes, for example, the KTH learning management system, Canvas, along with systems for online learning activities and student assessment. These systems are used to operate courses at KTH, enabling research regarding course design, innovative learning activities and assessment as well as learning analytics. Following this, the digital systems serve a similar role to that of a research lab for testing and evaluating theoretical concepts and hypotheses in practice. The department also has one physical facility, a television studio, which is used for studies on digital learning materials.

The department has a mission to provide research and to support change management towards the future of education that matches the need for flexible, just-in-time and lifelong learning. Examples of current research projects that address this question are TalkMath, Maths Coach Online, and internet-delivered cognitive behavioural therapy. In these projects, the department has built and administers digital infrastructure to study flexible, just-in-time digital education. We anticipate that the future of high-quality education will to a large extent be supported by digital infrastructure, and that innovative technologies such as artificial intelligence and virtual reality will enable new forms of education.

The current digital infrastructure that also operates in regular courses is managed in collaboration with the KTH IT department, while the ones that are used purely for research are managed within the department. The shared infrastructure is currently maintained regularly and is in an acceptable condition, while the systems that are purely for research are maintained based on needs. As digital education grows, the need for digital infrastructure will increase. It is therefore of the essence that we regularly invest in our digital infrastructure in order to become internationally competitive.

4. Strategies and Organisation

a. Goals for development 5–10 years ahead

LES is leveraging its basic funding with the 5–10-year objective to expand the number of research academic staff to match the number of teaching staff. The expansion must rely largely on external research grants, and therefore it is imperative to increase the external funding base. To achieve this objective, strategic appointment of high-profile early and mid-career Associate Professors provides the foundation for attracting additional funding so we can recruit five to ten new academic staff per year over the next five years.

While this expansion is largely dependent on a successful external funding track record, we also see an alternative path forward based on a slower initial growth based on the Departmental age demographic. A number of lecturers will retire in the next few years, and replacing these positions through recruitment of early and mid-career Associate Professors provides an alternative pathway to the goal.

b. Congruence with university-level goals for “A leading KTH” as set out in KTH´s “Development Plan 2018-23” (page 5)

LES plays a key role in fulfilling many of the goals of the KTH development plan. The department is responsible for training “skilled educators” (p.5) and for creating “major social benefits through outstanding collaborations in education and research” (p.5). KTH is to “with the help of digitalisation, develop its education” (p.11) and “increase its world-class research into digitalisation in various areas” (p.11). The department’s cluster in Global Competence contributes with research underpinning meeting the goals to provide “complementary skills, such as intercultural competence, [that] are necessities for

today's – and tomorrow's – labour market" (p.6); to create "initiatives…to strengthen the standing of Swedish in [research] environments, thus contributing to improved integration within KTH's organisation and society at large" (p.14); and, finally, to study the outcomes of international exchanges in order to revitalise European collaboration at the student level (p.14). Higher Education Research and Development Staff Training courses raise awareness of gender mainstreaming and preparing staff for more inclusive educational practices (p. 15) as well as integrating sustainability (p.12) into their courses.

c. Leadership structure and collegial structure

LES is managed by a Head of Department, supported by a departmental board consisting of the heads of the four divisions, the director of studies and the departmental controller. The controller provides economic and administrative support for the board in terms of HR and budget follow-up. The departmental board meets bi-weekly to discuss and plan staff workload, and to follow up budget, HR, and general workplace health and safety issues. Each division holds regular staff meetings where decisions from the board are presented and organisation of the division are discussed. These meetings are open and should be attended by all employees in the division. Division heads hold two-three meetings a year with each member of staff to discuss personal development, workplace performance, and review salary based on the performance of the individual staff member. The department also holds two general retreats (typically of two days in duration) to discuss the strategic development of research and teaching annually and to establish collective vision and a sense of ownership of the joint mission.

d. Strategies for high quality

The main driver of research quality is based on a systematic model for enhanced research impact which underlies all research activities. See Figure LES-6. Within the context of this model, each Research Cluster identifies relevant annual performance indicators and goals.

Review of the research goals and outcomes forms the basis of a yearly research performance report from each Cluster to the Department Board. This report provides a focus for systematic reflection and analysis of overall expectations, annual performance and opportunities for further improvement at the Cluster and Department level. Prior to the pandemic these reports were discussed as part of the annual staff retreat as a part of the process of setting strategic goals for the coming year. In 2020 this retreat was replaced by a research excellence and academic citizenship colloquium using the Zoom platform. These reporting structures and activities are designed to provide opportunity for internal reflection, but, at the same time, provide input to the overall KTH research quality framework.

The systematic implementation of this cycle of goal-setting and follow-up undergirds the initiative to instate a Head of Research to enhance the ability of the department to respond systematically towards enhanced excellence and more extensive research and societal impact.

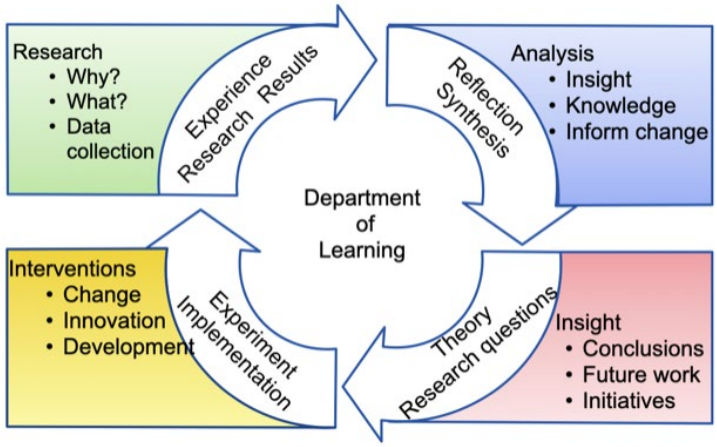


Figure LES-6. Impact of research excellence model

5. Interaction between Research and Teaching at all three levels (BSc, MSc, PhD) of education

In the last decades, several national strategies have been developed to ensure that teacher education at all levels is based on a scientific foundation. Historically, teacher training programs were not conducted by research-active staff, and neither was faculty training at tertiary level of education. LES is a modern department for teacher training, linking teaching and research through all activity areas. LES has five Associate Professors in technology, science and mathematics education, and the research conducted in this area has a significant impact on school practice through the condensation of research results into educational training resource modules for in-service teachers.

Interaction between teaching and learning is a key quality issue in higher education and therefore also for LES. This interaction is multifaceted, and includes a number of aspects, addressed below. Beginning with staff and allocation of resources, time for research from direct state funding (fakultetsanslaget) is allocated to teachers with a PhD (i.e. professors, associate professors and some lecturers). In addition, all academic staff are encouraged to apply for external funding, and can, if successful, reduce other duties accordingly. In terms of research-based teaching at various levels, teachers are to a high degree responsible for courses close to their expertise. Lecturers without a PhD are also encouraged, if time and funding allow, to take part in research activities such as projects, seminars etc. An example is the so called “practitioner research” project which engaged a large number of less research-active staff in knowledge production.

At the bachelor’s and master’s level, LES teaches students who will become or are teachers at different levels of education, as well as engineering students studying language, communication and intercultural competence. Our research into the communicative practices of engineers underpins the design of all language courses. One of our master’s programs, NORDIG, was started based on the research interests of HEOS. Our growing group of PhD students also contribute to teaching and supervision of theses. Master theses at KTH are typically written in collaboration with an external partner (in industry, public sector or other organisations) but also based on research. This is a potential area of development. While there are a number of successful examples of research-driven theses, with ideas from research clusters and even links to ongoing research projects, theses and master students could be more systematically integrated in research activities.

The department’s research in teaching and learning in digital environments and in faculty development also informs the instruction of non-degree-seeking students who enrol in online courses (MOOCs) targeting a global public. These MOOCs were co-created together with teachers and researchers from various fields at KTH. Our inter-disciplinary design team includes researchers and doctoral students in

technology and learning, as well as practitioners in media production. This approach has proven successful for the interplay between research and practice, and has resulted in several publications.

The majority of the MOOC material has been transferred and integrated into regular courses at all three levels (BSc, MSc, PhD), and additional support for blending whole campus courses has been made based on the creation of these MOOCs—for example, the course in Philosophy of Science included in most undergraduate programs at KTH. Another example is the collaboration with MOOC teachers to develop a challenge-driven course in ergonomics provided to KTH students and, at the same time, to students at Botho University (Botswana) via digital media. We are studying these students' collaborations and challenge-driven pedagogy across cultures using digital tools.

The interaction between teaching and research at LES is also evident at a "fourth" academic level: the competence development for KTH faculty. The courses for faculty are increasingly based on research conducted at LES and taught by researchers in relevant fields. For example, the department holds expertise in assessment of learning, organisation of learning environments, and integration of sustainable development in engineering programmes. Several researchers are also knowledgeable in implementing and sustaining change in education at a university, which strengthens the department's role in supporting educational development across KTH.

The link between teaching and research is a long-term and central research interest at the department (in particular within the HEOS group). So far, a number of articles and a PhD thesis (Magnell 2019) have addressed this eternally challenging but important topic. As an example of impact, a report commissioned by the then Dean of Faculty at KTH (*Kopplingen mellan forskning och utbildning vid KTH*) has been utilised and referenced internally and also recently in a self-evaluation report to UKÄ (The Swedish Higher Education Authority).

6. Impact and Engagement in Society

a. Relevance of research to society at large

The research conducted at LES is relevant for the national education sector at all levels. One indication of this is that our faculty are frequently seconded to work in national bodies, thereby putting their research into practice. Our faculty have worked for example at the National Center for Technology in Schools, the National Agency for Education, the Ministry of Education, the Swedish Schools Inspectorate, the Swedish Research Council, *Riksbankens jubileumsfond*, the Swedish Higher Education Authority, the Swedish National Audit office, FORTE, the State Commission on Academic Careers, VINNOVA, the Swedish Union of University Teachers (SULF), the Swedish Association of Higher Education (SUHF), Sweden's government agency for development cooperation (SIDA) and the Swedish Institute for Educational Research. They have also been involved in numerous evaluations and reference groups within and outside the university sector.

Research projects have also contributed to the development of education within Sweden and abroad. For example, the project "*In the borderland between academic disciplines and school science - Science faculty as teacher educators*," financed by The Swedish Research council, explored how science epistemology, content, and practice is reproduced and transformed when biologists, chemists and physicists take part in teacher education. The main conclusion of that study and other ongoing studies is that even those university teachers who are interested in teaching are not able to engage in education, as research and research production are the most highly valued merits.

The role of gender in science teaching is investigated in the project "*Challenging science teacher education: Gender awareness in constructing knowledge of science and science teaching*." The research results are applied in teacher education programs by addressing gender aspects in the technology didactics courses. The purpose is to educate preschool and primary teachers who can build

creative learning situations to support and challenge children, regardless of gender, in order to stimulate the children's interest and knowledge in technology. These are but two examples of many of how our work is used in the world outside the university.

b. Research dissemination beyond academia

There are two areas where the department plays a vital role for the dissemination of KTH research beyond academia. The first is our project leadership of the annual Researchers' Night, and the second is our central role in the development of MOOCs from KTH.

The House of Science centre is the main organiser of the Stockholm region's participation in the European-wide Researchers' Night (*ForskarFredag*) that takes place in September each year. The purpose of the event is to show children and young people that researchers are ordinary people with unusually exciting work. In a typical year, this research festival is fully booked and attended by 6,000 people, mostly school classes with their teachers, filling the Alba Nova Science Center, SciLifeLab, and the House of Science for research presentations, demonstrations, dialogues and workshops aimed firmly beyond academia. The event includes the Research Grand Prix, where researchers compete in presenting their research to a broad audience. Evaluations show that nearly all visitors have talked with a researcher and that half of them leave with a more positive impression of what researchers do than before the event. A substantial majority of the researchers who volunteer to participate find that it helps them become better at explaining their research to a wide audience. The event is also a forum for cooperation among LES divisions, with participation by experts in rhetoric from the division of Language and Communication and with experts in science pedagogy from the LiSTEM division.

In 2015, KTH started an initiative aimed for global outreach of knowledge in areas where KTH is world leading. The planning, delivery and evaluation of these massive open online courses (MOOCs) is based on the ongoing research about teaching and learning in digital environments led by the department.

Between 2016 and 2020, KTH developed 17 unique MOOCs and offered 35 course rounds as partner in the non-profit consortium edX, with a global outreach resulting in about 122,000 enrolments from participants in over 150 different countries. As the only university in Sweden, KTH offered two professional certificate programs targeting people in industry in need of lifelong learning: "Digital Transformation" (including four courses) and "Risk Management of Work-Related Injuries using RAMP" (including three courses). To develop these programs, collaborations were established between KTH and the industry/organisations in Sweden, Estonia, Canada and Botswana. In addition, corporate endorsements from Scania, ABB, and Avonova stated the relevance and importance of these courses. In our efforts to disseminate knowledge via MOOCs, we have also established collaborations with EU-projects and received funding from EIT Health.

The research related to our MOOC initiative regards how universities can increase life-long learning offerings using flexible scalable solutions (digital) for up-skilling and re-skilling of advanced knowledge needed in industry. The studies focus largely on inclusive teaching in terms of gender and diversity.

The MOOC initiative has resulted in collaborations and outreach projects where the research regarding technology and learning/at LES is vital: the development and offering of an open-source app for integrating and learning digital math (conceptual programming) in pre- and elementary schools (Vinnova), and the development and dissemination of the 'RAMP Package,' which aims to reduce work-related injuries via systematic risk management.

c. Sustainability and the United Nations' Sustainable Development Goals (SDG)

The Department's research primarily supports the achievement of Goal 4 (100%), specifically target 4.7: *Education for sustainable development and global citizenship)* LES also makes significant contributions to Goal 5 (gender equality, 60%) through courses and networks on examination and

gender mainstreaming , Goal 9 (industry, innovation and infrastructure, 50%), through digital learning technology development and developing educational models for engineering education to produce relevant engineers with relevant skills and ethical compass to drive innovation and infrastructure. and indirectly to Goal 10 (reduced inequalities 20%) by designing better education resulting in more well designed and inclusive products and policies, Goal 16 (peace, justice and strong institutions, 40%) in particular the work of HEOS and LEEaP in terms of equipping citizens for the future, and producing strong relevant modern universities. Finally, Goal 17 (partnership 10%) drawing on strong networks for international collaboration and contributions to the Unite! University project.

Our research approach can be characterised as applied and action-based in the sense that it aims to enhance and improve the quality of the education, and is often performed in close dialogue and collaboration between researchers and teachers in their context.

The following high level research themes focus LES activity in sustainable development and related research areas:

- What should students learn? LES engages with this theme as a partner in the revision of the CDIO Standards and Syllabus with respect to integration of sustainable development, in close collaboration with the Nordic Five Tech consortium members. Erasmus+ projects also aim to enhance European capacity in engineering education through better integration of global competence training into curricula.

- How should students learn? Research and development effort in this area centres on developing, supporting and evaluating the implementation of challenge-driven education in engineering education courses and programs at KTH. Challenge-driven education is a solution-oriented and impact focussed project-based teaching and learning approach supporting students' development of key competencies for sustainability. Applying and deepening disciplinary knowledge and skills is intimately linked to projects that address pressing societal challenges, often in developing countries.

- How should student learning be assessed? Integration of sustainable development in engineering education has previously been limited to providing students with basic knowledge and concepts. More ambitious curricula now emphasise developing skills and key competencies. LES has identified both substantial deficiencies, but, also opportunities for research and development in assessing such skills and competencies.

- How can integration of sustainable development in engineering education curricula be characterised, assessed, and enhanced? LES provides expert guidance as KTH works towards attaining the goal of integrating sustainable development into all parts of the curriculum. This provides a valuable benchmark and provides unique material and data for research.

In addition to publication in scientific journals and conferences and collaborations with various partner universities, the sustainable development agenda is also effectively disseminated to teachers at KTH and partner universities through integration in higher education faculty development courses such as LH215V Learning for Sustainable Development, LH217V Leading Educational Development, LH233V Teaching and Learning for Challenge-Driven Education, LH3000 Basic Communication and Teaching, and in the Enhancing Higher Education program and various workshops.

While the contribution is primarily focused on SDG 4 (Quality Education), a number of other SDGs, listed earlier are also central to the LES mission. The contribution we make to improving engineering education programs lies within a multitude of disciplines, not only at KTH but also at other universities across the world including the global south. The bibliometric analysis (7-year) for LES reveals 31

publications referring to SDG 4, five referring to SDG 5 (Gender Equality), three for SDG 9 (Industry and Innovation) and one each for goals 8, 10 and 12, in total 42 publications (non-fractionalized.)

LES has a broad scope of research in this area, has established good collaborations, and has achieved relatively large dissemination and impact. However, the volume of publications can be seen as sub-critical since this research is being performed by a handful of researchers who can only spend a fraction of their time on these activities. Opportunities for improvement include formulating a clearer strategy and strengthening leadership in the area. To this end we have appointed an associate professor in Engineering Education for Sustainable Development (EESD) who, in the near future, we hope to connect to a cluster of 1-2 additional senior researchers, 1-2 post-docs, and several PhD students as we expand our external funding portfolio.

d. Structure for increased impact

LES works to increase impact by increasing the visibility and accessibility of its research through the use of social media, blogs, and a policy that all research staff should prioritise publication in high-impact open-access journals and conferences. In addition, the department has implemented strategic approaches to disseminating research through social media channels, in particular establishing Google Scholar profiles and Research Gate presence, to enhance the accessibility of research ideas and results. To further increase visibility and impact, we identify outstanding members of the department and support them in taking leading roles as editors of journals, chairs of conferences and evaluators of grant proposals both nationally and internationally.

Impact on teaching is twofold. Research in STEM learning informs our educational offering, both in higher education development to KTH staff and in teacher education for the Swedish schools in STEM subjects. We are also active in helping to contextualise the latest learning and teaching research, making it easier to use in daily teaching practice. Further, we collaborate with disciplinary colleagues from many parts of KTH, helping to define dimensions of joint action and collaboration in crosscutting and transdisciplinary research, in particular working to transform disciplinary practices, and develop future engineers for sustainability and equal opportunity.

Engagement with society is a strategic priority for LES, and we are working to strengthen this area through engagement in the Government National Initiative ULF (https://www.ulfavtal.se) through a new three-year project with a budget of 5 million SEK, as well as through development of new initiatives through the House of Science to engage with young people in the context of STEM education and activities.

Department of Machine Design

Self-evaluation
RAE Coordinator: Professor Mats Magnusson
Head of Department: Associate Professor Martin Edin Grimheden

Included divisions:

Integrated Product Development and Design
Internal Combustion Engines
Mechatronics and Embedded Systems
System and Component Design

Department of Machine Design (MMK)

1. Overall analysis and conclusion; strengths and development areas

a. Limited SWOT-analysis

The Department of Machine Design is part of the School of Industrial Engineering and Management. The overall mission of the Department is to serve industry and society on a long-term basis by developing and delivering excellent knowledge and highly skilled people for a wide range of important aspects of industrial product development and design.

In this section, strengths and weaknesses at Department of Machine Design (MMK) are presented, in order of magnitude. Given the differences between the research performed in the department's four divisions, the observed strengths and weaknesses vary considerably. Therefore, these are presented at divisional as well as departmental level. The main focus of the analysis has been on research and organisation, respectively.

	Strengths	Weaknesses
Research	1. Publishing in highly ranked journals. 2. Nationally and internationally recognised as key actor in several core research areas. 3. Comprehensive range of research areas, covering all aspects of industrial product development, in particular related to digitalisation and sustainability. 4. Close collaboration with industry and public administration, with strong international networks, reflected in affiliated faculty, industrial PhD students, collaboration networks and centres, international collaboration and industry-funded research. 5. Multi-disciplinary focus, ability to coordinate research activities and address new research areas.	1. Extremely dependent on external research funding, which often also does not fully cover overhead costs. 2. Funding for new equipment as well as maintenance and upgrading of physical infrastructure is missing, limiting capacity for conducting experiments. 3. Funding and time for individual research missing for some faculty members due to heavy teaching load.
Organisation	1. Strong and ambitious leaders: researchers have many strategic responsibilities across KTH and elsewhere, enabling cross-disciplinary initiatives and enabling collaboration with industry and other universities. 2. Strong connection between research and education, including recent research results in curricula and including students in research activities.	1. Fragmented – some units are small and lack critical mass making them sensitive to changes in external funding. Difficult to formulate coherent research strategy beyond divisional level, but this is nevertheless increasingly taking place. 2. Lack of administrative support, more administrative tasks are performed by researchers and

	3. Key drivers of excellence centre and KTH-internal cross-disciplinary centre. 4. Physical infrastructure in terms of laboratories, allowing for different types of physical experiments.	support systems are not always functioning very well. 3. High overhead costs at KTH is challenging and gives us a disadvantage compared to many international universities with sponsored facilities.

We also note a number of opportunities and threats for the department as a whole.

Opportunities:

- There are very concrete industrial challenges in the research areas, which are also in focus by many funding programs (a diversity of funding sources available).
- Established international networks provide for further opportunities here. The EU initiative on Digital Innovation Hubs offers opportunities to expand and coordinate innovation related activities, and to strengthen education and research.
- Increased collaboration across divisions. Clear opportunities for more boundary-spanning projects that can leverage the broad set of competences, e.g. in relation to cyber-physical systems, electrical drive trains, digitalisation/AI and circular economy.

Threats:

- Dependence on key individuals who bring in large amounts of external funding and/or generate many high-level publications.
- Sensitive to changes in external funding. Highly dependent on a limited number of sources of funding.

Identified development areas:

Based on the SWOT analysis, a number of areas for future development have been identified.

- Increased research collaboration across divisions targeting complex challenges of great value for industry and society at large, e.g. sustainability, digitalisation, and electrification of transports. The ongoing IRIS initiative constitutes a fruitful vehicle for this development, but other opportunities concerning AI, cyber-physical systems, electrical drive train and particle emissions should be investigated.
- Develop existing collaboration structures with industrial partners. Reinforce collaborations with key industrial companies. Leverage networks and research centers for additional research projects and industrial PhD students.
- Improve publication quality and output. A department-wide initiative to establish clear and focused publication strategies at departmental and divisional levels was initiated in 2019 and is continuously updated.
- Secure stability of funding by exploring new funding opportunities and working for appropriate levels of KTH-internal funding.
- Upgrading of lab facilities. As this requires substantial investments, different ways of funding important infrastructure need to be investigated. More efficient use of existing infrastructure through sharing of facilities with other departments and external stakeholders may reduce necessary investments.
- Improved administrative support. More administrative work is performed by researchers, taking important time away from research. Despite high overhead costs the service level is gradually decreasing.

b. Summary statement on contributions of department on impact, infrastructure and sustainable development

Based on the self-evaluation, a number of contributions to impact, infrastructure and sustainable development have been identified at Machine Design.

Contributions to impact

First, we note that the department performs leading research in several scientific fields, as reflected in well-cited publications in high quality journals. The department generates useful and usable research output of great importance for reduced environmental impact, e.g. in the areas of biofuels, particle emissions, renewable energy, and circular economy, and supports competitiveness and innovativeness of companies and public organisations by contributing to new and improved technical capabilities, in particular related to cyber-physical systems, digitalisation and AI, as well as organisational capabilities, related to for instance innovation eco-systems and innovation management systems.

Contributions to infrastructure

Machine Design develops and operates physical lab facilities for research on internal combustion engines, mechatronics, tribology, and embedded control systems. These labs are of fundamental value in order to undertake relevant applied empirical research and are key to fruitful collaboration with industry. Furthermore, these facilities are of great value for education at all levels, as they allow engineering students to develop more comprehensive skills.

Contributions to sustainable development

Almost all research performed at Machine Design has direct implications for sustainability. Several research groups display strong research performance in different areas related to sustainable development. More specifically, we observe important contributions in the following research areas:

- Reduced particle emission from vehicles;
- Improved use of renewable fuels;
- Intelligent automation leading to flexible, secure and resource-efficient manufacturing and transportation systems;
- Business model innovation and servitisation, enabling sharing approaches and circular economy.

2. Research profile

a. General information of the department

The department focuses on industrial product development and design, aiming to develop and deliver knowledge and skilled people in a wide range of technical domains. Product development covers many different activities and includes technical aspects as well as those of a financial and social nature. The combination of these different areas is essential for successful product development. In Machine Design, knowledge and engineering ability are of central importance as regards devising complex mechanical and mechatronic components and systems. To generate financial gains, product development normally takes place in an organisational setting. Thus, the strategy, organisation and methodologies of the associated activities are important. The human role in technical systems (e.g. as commissioner, developer or user) is fundamental in product development. Consequently, it is also an integral part of the subject. Based on this holistic vision for research and education, research in Machine Design has over the years developed a comprehensive range of knowledge and competences, primarily covering the following areas:

- High-performance mechanical and mechatronic components and systems, including internal combustion engines.

- Physical phenomena that can limit or facilitate new designs.
- Design methodology and development methods for composite physical and cyber-physical products.
- Product development and innovation processes taking into account technical, financial, environmental and organisational considerations.
- Method development in innovative design, user-driven design and service design.
- Tools and computer support in development and design.

b. Central research questions and themes, knowledge gaps addressed, main research activities

To allow effective handling of the area's overall diversity and complexity, research is organised on the basis of a number of distinct specialisations. More specifically, these are: System and Component Design; Internal Combustion Engines; Mechatronics and Embedded Systems; and Integrated Product Development and Design. Each of these four divisions is of quite different size and comprises a number of more or less clearly delineated research groups.

System and Component Design

In the System and Component Design division, three inter-related research groups exist, focusing on machine elements, tribology, and machine design, respectively. In machine elements, research focuses on more sustainable, environment-friendly and energy-efficient components and systems, i.e. roller bearings, slide bearings, gears, couplings, bolted joints, gaskets and various types of lubricants oils, greases, aqueous lubes and ionic materials. The mechanical and electronic components now included in ever more machines are increasingly being developed in ways that reduce the electronic-mechanical distinction. Thus, important parts of the research are the development of: machine elements that are more controllable and adaptive; active strategies for machine maintenance; sensor technology for multi-parameter measurement; and, tribotronic systems.

Research in tribology is directed towards the modelling and simulation of friction and wear with a holistic perspective of system effects such as emissions, energy efficiency, material hygiene and design. Hence, the research scales from surface topography to system behaviour. The overall aim is "modelling and simulation of friction and wear, with an overall perspective on the system effects of emissions, energy efficiency, material hygiene and design". One part of the research is focused on airborne particle emissions from wear processes in brakes, between tyre and road surface, and between wheel and rail.

Research in machine design covers both development and analysis of products. It primarily focuses on problems related to mechanical systems. However, it also takes in connections to/with adjacent systems and environments. In respect of technical systems and components, important elements of the subject are methods and technologies for: behaviour simulation; performance forecasts; dimensioning; and, optimisation. One important research aspect (which takes in various disciplines) is the development of methodologies for more efficient development and analysis of mechanical systems via optimisation of product properties. Statistical, quasi-statistical, kinematic and dynamic models are examples of models that are interesting for behaviour simulation and product-performance forecasting. The applications vary from small to large products and systems, e.g. from small table-based haptic units to winch systems for wave-energy generation. Another important part of the research is building prototypes for: verifying and validating simulation models; and, testing new product concepts.

The division has three professors, leading research in the different research groups. The staff consist of two adjunct professors, four associate professor and three assistant professors. Together they supervise 15 PhD students. Moreover, the division has four affiliated professors, illustrating the strong collaborations that exist with both international colleagues and industrial companies.

Internal Combustion Engines

Internal combustion engine research is largely about combining knowledge in basic subjects with a demanding application that is of great practical importance – the internal combustion engine. In the research, fundamental physics is interfaced with engine technology. The latest research discoveries are covered with the emphasis on global and local environmental issues. Energy supply issues (e.g. biofuel's possibilities and future scenarios) are important starting points for our operations. These latter are pervaded by the conducting of research aimed at making drive systems more efficient. Thermodynamic and combustion technology studies are carried out using experiments and leading simulation programs for both 1D and 3D calculations. The regulation and development of control systems is an area that is brought to the fore. Given the experimental nature of the research performed, it is of particular importance that the unit has a modern engine laboratory at its disposal.

On short and medium term, electrification is not viable for heavy-duty long-distance transports. Hence, renewable fuels are needed to decarbonate transportations and fulfill global climate goals. An overarching research aim for the division is to reduce CO_2 emissions and local emissions, specifically particulate and NOx. The current research target segment lies on ICEs for heavy commercial vehicles (HCV) and for marine applications. More specifically, the research on internal combustion engines is currently related to:

- Sustainable mobility for land and sea transportation, more specifically targeting
- Decarbonisation
- Zero emissions
- Efficiency
- Future power trains

A key research area is the gas exchange system, including turbo charging and exhaust recirculation systems. This research is done within the competence centre CCGEx, where more fundamental research in flow mechanics and acoustics is combined with applied engine research. Another research area is diesel combustion investigated by optical analysis of combustion in engines with optical access and by analysis of the fuel injection spray in a spray lab. This research is a joint effort with the Swedish heavy-duty truck manufacturer Scania.

A professor leads the unit with a staff of one adjunct professor, one associate professor and one senior researcher supervising ten doctoral students. There are also two technicians responsible of operating and sustaining infrastructure consisting of four engine labs and a spray lab. The unit runs currently about ten externally financed research projects with an outcome, last year, of 17 articles and two graduated PhDs. The ratio between external funding and internal research faculty funding is approximately four to one (~13 Msek/3 Msek). The faculty funding covers parts of the costs for senior staff and infrastructure.

Mechatronics and Embedded Systems

Our main contributions related to autonomous systems are mainly within the context of trustworthy systems but also to the general areas of application of research results into industrial practice. In the areas of Integrated CPS design our main contributions are within areas of optimal design of complex integrated products, design of additive manufacturing methods for non-metallic materials as well as 3D/4D-printing.

The research at the Mechatronics division is carried out in five research groups, which focus on broad and multi-disciplinary research areas: Cyber-Physical Systems (CPS), focusing on e.g. autonomous road vehicles and safety; Mechatronics, focusing on model-based design, co-optimisation and control theory; Model-based Engineering, focusing on viewpoint and tool integration and software contracts; Education, focusing on the research-teaching nexus and life-long learning; and Innovation Ecosystems, focusing on public-private cooperation and governance. The research by the five groups overlap across

these research areas, with the most visible research centred on three themes: (a) Trustworthy CPS, (b) Integrated CPS Design and (c) Educating the CPS Engineer.

Trustworthy CPS focuses on both the enabling and the manufacture of CPS that need to be safe, secure and dependable. The former includes suggesting novel architectures to ensure critical system properties, elaborating risk analysis and management approaches, and verification and validation methodologies for highly automated CPS. Risk management techniques include, for example, optimising collision avoidance for active safety or automated driving during different road conditions and environments, and minimising the severity of unavoidable collisions. The latter involves empirical investigations at several levels of the sociotechnical system surrounding CPS manufacture: for instance, on how the practice of safety engineers and technology trends leads to conflicts between different engineering communities, and how innovation ecosystems in which trustworthy CPS are put together might be biased by public-private cooperation.

Integrated CPS Design focus on design, control and manufacture of CPS built with novel manufacturing methods enabled by recent achievements mainly within additive manufacturing. This involves all stages of this process: from the use of advanced artificial intelligence algorithms to elicit the impact of these products.

Educating the CPS Engineers focuses on the teaching practices for engineering students that will work with the complex CPS products of the future. This also involves empirical investigations at several levels of the associated sociotechnical system, i.e. those surrounding higher education institutions and continued education. Associated investigations have thus studied the relationship between research and engineering proficiency at the master's level for CPS engineers, and the interaction between academia and firms when students write their master theses.

Mechatronics and Embedded Systems is the largest division at the department, consisting of one professor, two adjunct professors, five associate professors, two assistant professors, six researchers, five research engineers, 20 PhD students and technical and administrative staff.

Integrated Product Development and Design

Research at Integrated Product Development and Design focuses on methods, organising and control for effective development of sustainable, innovative products, services, and businesses. The research aims to generate in-depth knowledge and concrete results that can be used in practice. The research is based on both qualitative and quantitative research methods, and often includes action- or change components.

The research at Integrated Product Development and Design focuses on three overall areas: innovation, sustainable product development, and sustainable product and service design. Even if three research groups can be identified, the boundaries between these are not very clear and multiple researchers contribute to several of these areas in joint research projects.

The innovation research is characterised by a comprehensive approach including products, processes and organising. Innovation management has a specific focus on innovation processes, creativity and ideas, and innovation ecosystems. Another stream of research addresses disruptive business model innovation, including servitisation, as well as development of new revenue models and pricing approaches. A particular interest exists in understanding how digital technologies, and in particular AI, influence innovation and firm value creation. This research is performed both in close collaboration with partner companies, including the use of experiments and quasi-experiments. Another stream of research focuses on development of sustainable product service systems, thereby supporting the transition towards a more circular economy. Different research disciplines are used to investigate these aspects and create change, and in that way support the transition to more sustainable practices.

Particular emphasis is for instance given to the adoption of electrical vehicles and the use of new business models for personal transportation. Yet another research area deals with human-centred design, aiming to understand people's everyday life and develop systems and services based on this understanding. The research often addresses social sustainability and can include e.g. norm-critical design, work environment or socio-technical challenges.

Integrated Product Development and Design has three professors, leading the research in different areas. Other members of the division are two adjunct professors, three associate professors, one senior lecturers, five researchers, and two post-docs. A total of eleven PhD students are supervised at the division.

c. Contributions to the advancement of the state of the art within the research fields of the department

The research at Machine Design generates substantial contributions to the state of the art throughout all the different areas in which research is performed. Notable advancements can for instance be seen related to wave energy, renewable fuels, tribology and tribotronics, cyber-physical systems, circular economy, design, and innovation management.

The energy losses associated with using energy and creating it are a significant fraction of all generated energy and result to a large extent from the frictional losses in moving parts in both machines and generation systems. Research results from the System and Component Design division have the potential to significantly reduce these losses (SKF Evolution). Other major research outputs from the System and Component Design division include wear processes as a contributor to airborne particles in the nucleation mode (nano-sized particles down to 1 nm); work on vehicles with disc brakes that reduced the PM10 levels with two thirds; novel test rigs for generation of airborne particles; new methods for emission factor determination; new models for particle emission modelling. The Department of Machine Design has been cooperating closely with several companies developing wave energy converters. The cooperation has been composed partly of a number of student projects as well as senior expert help where the department's researchers have contributed to the development of the wave power plant components and systems. The department has also been involved in the development of several wave power test rigs.

Research results on the applicability of renewable fuels for internal combustion engines have been adopted by research partners in industry, ending up in new and improved designs of engine systems and components. The results that have been used by industry have for instance dealt with material compatibility with renewable fuels, combustion processes, emissions (gaseous emissions and particulates), engine efficiency, and gas exchange. In the gas exchange and combustion areas a number of important and innovative developments have been initiated - some with patents granted and others with planned patents.

The work on integrated CPS design offers concrete contributions to industry. Some examples of these are how the comfort of 3D-printed prostheses can be monitored to avoid discomfort and injury; to the closed-loop control of soft materials to enable 4D-printing, for instance to create soft robots able to grip fragile items and work in close quarters with humans; and including the infrastructure for 3D-printing novel materials, for instance by modifying the way and speed of delivery of novel materials to ensure robust manufacture. The research also includes methods and techniques for integrating viewpoints, such as the CPS design contracts developed by the division in collaboration with UC Berkeley. As part of the research on trustworthy cyber-physical systems, the AD-EYE simulation and execution platform (www.adeye.se) has been developed to support integration and dependability related evaluation of architectures and algorithms for highly automated vehicles. AD-EYE as a prominent feature, provides a configurable safety supervisor architecture.

Research in Integrated product development and design emphasises drivers and obstacles for a transition to a more sustainable society, and how design can create opportunities for new daily practices. In trans-disciplinary projects, this often includes design interventions and large-scale Living labs engaging end users. Some examples of this research are norm-critical designs, new ways of visualising energy consumption, and design and adoption of radically new mobility services. Other important contributions consist of research and change projects aiming at increasing innovation capabilities of public organisations, e.g. the Swedish Police, and company boards. Over a long period of time, the research group has also contributed actively to the development of the Swedish Association for Innovation Management Professionals ("Innovationsledarna") as well as the development of the new ISO standard for innovation management systems launched last year. One of the researchers in the division received the Bruno Mattsson design award in 2019, arguably the most prestigious design prize in Sweden.

d. Quality and quantity of contributions to the body of scientific knowledge

There is a notable positive trend in the number of journal publications from the department. See Figure MMK-1. With the exception of a dip in 2017-2018, the number of publications reveals a clear linear improvement. The number of journal articles in peer-reviewed articles shows an increase of approximately 50% from 2012 to 2019. As the number of individuals engaged in research has also increased by around 50% we can see that the number of publications per researcher appears to be relatively stable.

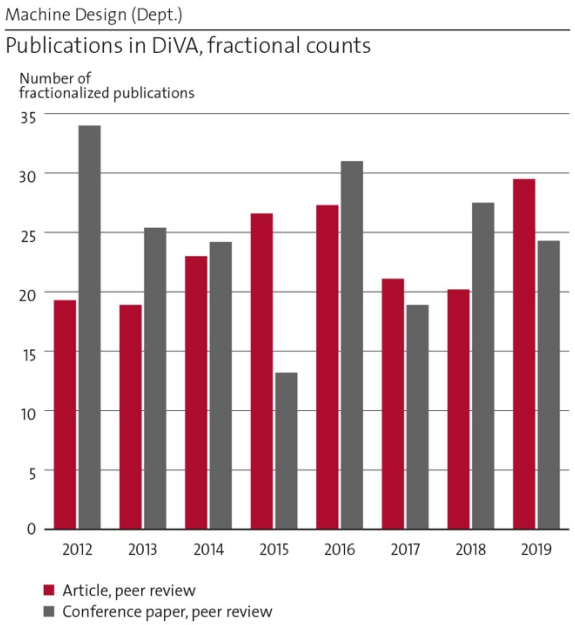


Figure MMK-1. Journal and conference publications.

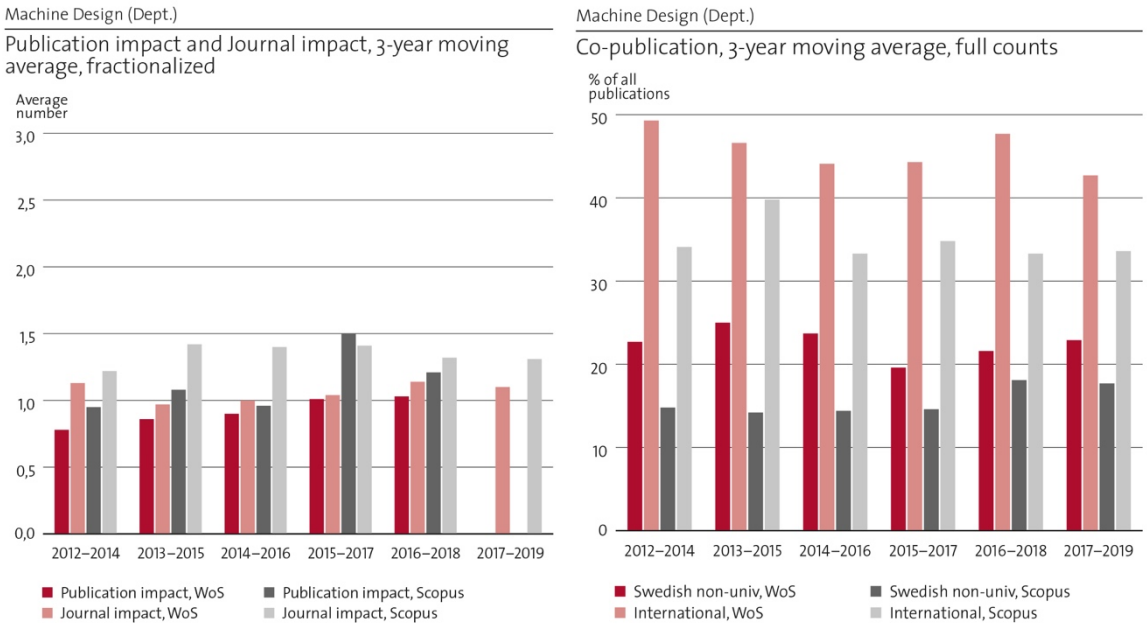


Figure MMK-2 (a) Publication impact in WoS and Scopus, and (b) Co-publication with scholars outside KTH.

A similar overall trend cannot be seen for conference papers. The numbers for these fluctuate substantially, and if there is any trend it is a slightly negative one. Considering the mentioned increase in terms employee numbers, it can be concluded that the productivity in terms of conference papers has dropped. These patterns underline the deliberate efforts at the department to prioritise journal publications and focus less on conference papers. The number of PhD theses is quite stable, but some fluctuation exists due to uneven admission patterns. The number of licentiate theses has dropped to a very low level, which can be explained by an emphasis on reducing overall time to the PhD degree and few students being admitted only to the licentiate degree.

A positive development can be observed in terms of citations, as well as publication and journal impact, see Figure MMK-2 a. The share of publications that are uncited seems to be fairly stable over time, which indicates a gradual improvement as later publications have had less time available to get cited. The number of publications in WoS is quite stable over time, which is somewhat surprising as there has been an intensified focus on publishing in leading journals. However, the share of publications that are among the top 10% has increased around ten times. Also the percentage of publications in the top 20% journals has increased substantially, with approximately 100%. Despite these improvements it should be noted that the applied nature of large parts of the department's research to some extent limits the possibilities to publish in leading journals, but may nevertheless offer great value in terms of practically useful and usable findings.

Among the department's publications, we would like to highlight the following few works in particular.

Article	Importance
Pilkington, G. A., K. Harris, E. Bergendal, A. B. Reddy, G. K. Palsson, A. Vorobiev, O. N. Antzutkin, S. Glavatskih and M. W. Rutland (2018). "Electro-responsivity of ionic liquid boundary layers in a polar solvent revealed by neutron reflectance." *J Chem Phys 148*(19): 193806.	Example of leading multi-disciplinary research in a highly novel area of research.

Nosko, O., Vanhanen, J., Olofsson, U. (2017), "Emission of 1.3–10 nm airborne particles from brake materials," Aerosol Science and Technology, 51(1), pp. 91-96.	Another example of fruitful multi-disciplinary collaborative research with high relevance for sustainability.
Binder, C., F. A. Nada, F., Cronhjort, A. and Norling, D (2017). "Heat Loss Analysis of a Steel Piston and a YSZ Coated Piston in a Heavy-Duty Diesel Engine Using Phosphor Thermometry Measurements." *SAE International Journal of Engines*, ISSN 1946-3936, E-ISSN 1946-3944, Vol. 10, nr 4, s. 1954-1968.	Example of useful and usable collaborative research with other Swedish universities.
Lihui Wang, M. Törngren and M. Onori (2015), "Current Status and Advancement of Cyber-Physical Systems," *J. of Manufacturing Systems*, Vol.37, Part 2, p.517-527. http://www.sciencedirect.com/science/journal/aip/02786125	The results of a close collaboration with KTH Department of Production Engineering. Since its publication in 2015, it has received close to 450 citations in Scopus, underlining its importance in the field. This article received the 2020 Best Paper Award from the Journal of Manufacturing Systems as the most cited article during five years.
Bogers, M., Zobel, A-K., and Afuah, A., Almirall, E. Brunswicker, S., Dahlander, L., Frederiksen, L., Gawer, A., Gruber, M., Haefliger, S., Hagedoorn, J., Hilgers, D., Laursen, K., Magnusson, M., and Majchrzak, A., McCarthy, I. P., Moeslein, K. M. and Nambisan, S., Piller, F. T., Radziwon, A., Rossi Lamastra, C., Sims, J. and Ter Wal, A. L. J., (2017). "The Open Innovation Research Landscape: Established Perspectives and Emerging Themes across Different Levels of Analysis," *Industry and Innovation* Vol. 24, No. 1, pp. 8-40.	This article on Open Innovation is the result of an "open" writing process, in which leading researchers in the field were invited to a PDW at the Academy of Management conference in 2015. This article has received a very high number of citations (close to 300 Scopus citations since 2017).
Ehrnberger, K., Räsänen, M., & Ilstedt, S. (2012). "Visualising Gender Norms in Design: Meet the Mega Hurricane Mixer and the Drill Dolphia." *International Journal of Design*, 6:3. http://index.ijdesign.org/index.php/IJDesign/article/view/1070	The paper in question is a good example of the norm-critical design research performed. The article has received much attention among both researchers and in society at large.

e. Engagement in national and international research collaboration within academia and its outcomes

Researchers at Machine Design have numerous strong collaborations with international colleagues and co-writing with practitioners and international colleagues is consistently at a good level. The percentage of all Machine Design publications with international co-authors is stable over time, reaching almost 50%. Also, the share of publications with practitioners is stable over time, amounting to slightly more than 20%.

A number of professors at Machine Design have central roles in international research networks and are visiting professors at universities abroad. Prof. Glavatskih is a visiting Professor at Ghent University, Ghent, Belgium, and visiting Professorial fellow at the University of New South Wales, Sydney, Australia. Professor Mats Magnusson is Permanent Visiting Professor at LUISS Business School, Rome, Italy, and is the President of the Continuous Innovation Network. Professor Martin

Törngren has recently performed longer research stays at UC Berkeley and Stevens Institute in New York. He is also a key player in several EU projects on cyber-physical systems.

Much of the research at Machine Design is performed in collaboration with companies, and with colleagues at other Swedish and international universities. Some of the most important ones for each division are briefly outlined below.

System and Component Design: In the research large synchrotron facilities: ILL (Grenoble, France)**, ISIS (UK), ANSTO (Sydney, Australia), MAX IV(Lund, Sweden) are used. These are all cutting edge international collaborations. Together with RIVM (Netherlands), FOI (Sweden) and University of Birmingham (UK), University of Trento and Brembo (Italy), novel research is ongoing into the health effects of particle emissions, and the development of emission factors for different traffic fleets.

Internal Combustion Engines: Collaborations with Chalmers, Lund, CCGEX, Scania, VOLVO Cars, VOLVO Trucks, Wärtsilä, Borg Warner, Kemi KTH, and Energi KTH.

Mechatronics and Embedded Systems: Through ICES (Innovative Centre for Embedded Systems) a number of research and innovation actions are performed, with clear industrial impact. Strong collaboration with INCOSE. Another activity is WESE, Workshop on Embedded Systems Education. The workshop series is run by the unit which thereby coordinate a rather large global network of researchers in the area. Outcomes are joint publications, editor of special issues. WASP is an arena for PhD students in the field of AI and Artemis/Excel is an important platform for joint EU research grant applications. The division has ongoing joint research projects with UC Berkeley, Stanford, JKU Linz, and Fortiss.

Integrated Product Development: Researchers have leading roles in CINet, the Swedish Product Development Academy, the Swedish Network for Advanced Business Studies, the Design Academy, the network organisation IMIT (Institute for Management of Innovation and Technology) and in the journal Creativity and Innovation Management. The number of ongoing international collaborations is high, including e.g. LUISS Business School, Wageningen University, Marburg University, Anhui University of Technology, University of Catania, Hosei University, University of Southern Denmark, Aarhus University, Aalborg University, Politecnico di Milano, and JKU Linz. Moreover, research is performed with a number of leading companies, e.g. Husqvarna, Sandvik Coromant, Scania, BMW, as well as with the Swedish Police and the Swedish Defence University.

f. Follow up from previous evaluations

The following six quotes represent the main outcome of RAE 2012:

1. "The strategic opportunity for KTH to use its current competence and enthusiasm for sustainability is being lost through allowing a dis-integrated drift of separate actions and plans."
2. "Create processes to identify collaborative projects across UoAs that could be viewed as ‘strategic’."
3. "Providing incentives and environments for enhancing internal collaboration within the KTH."
4. "Create a Grand Challenge as a focus to bring together the researchers. The platforms are not likely to deliver the integration potential and are not playing any significant role."
5. "The university has the chance to establish a research environment for their interdisciplinary platforms for research in advanced materials and processes and information technologies with a cyber-physical infrastructure. Strengthen the developments of the evolvable production system by additional (universities funding) for an original contribution by KTH."
6. "Incentives to increase and enable more interdisciplinary work within KTH ought to be considered, e.g. specific funding of joint projects.”

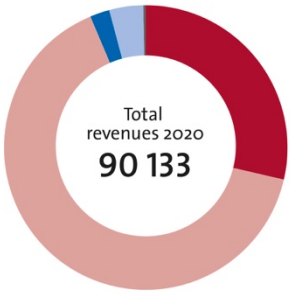
The school level IRIS ambition is a direct response to basically all of the recommendations above. The department has taken a broad focus in IRIS, are engaged in all four areas and have joint research ambitions with all other departments within the school. All IRIS projects relate to sustainability and are of strategic character. Beside IRIS, the department hosts several research centres (CCGEx, ITRL, TECOSA, ICES), which all brings researchers together across entire KTH. These ambitions directly respond to previous RAE suggesting for example the department to take a role as system architect within KTH. The centres in particular also create opportunities for doctoral students to get access to international networks and research. Since RAE 2012, international collaboration has increased shown by doctoral students participating in international summer schools, by the department hosting several summer schools and by an increase in faculty sabbaticals – both incoming and outgoing.

3. Viability

a. Funding; internal and external

Machine Design

Sources of research income (2012, 2016, 2020)



Research income, kSEK	2012	2016	2020
Government grants for research and doctoral studies	28 831	25 974	25 806
Research grants	28 714	47 609	58 636
Contract research funding	653	1 807	2 054
Other revenues	5 543	3 914	3 628
Financial income	93	4	9
Total revenues	63 834	79 307	90 133

Figure MMK-3. Research income development.

Overall, Machine Design is funded approximately with 31% educational funds, 19% basic university funding and 50% external funds. In absolute numbers, Machine Design has grown with about 40% since 2012, with increases in educational funds and external funds. The basic university funding has seen a slight decrease in the period. In comparison with the other departments within the ITM school, Machine Design has a higher ratio between external funds and basic university funds than any other department, with 2.5 times external funding per base funding. In 2012, this ratio was about 1.3.

During the period 2012 until today, the main external sources are national Swedish funding agencies, such as Vinnova (Sweden's innovation agency) and the Swedish Energy Agency who together represents half of the external funds. Funds from EU projects represents about 20% and private funding mainly from industrial collaborators represents about 15%.

External research funds, by agency (kSEK):

	2012	2013	2014	2015	2016	2017	2018	2019	2020
Vinnova	10,277	8,907	7,015	7,524	13,425	20,084	22,113	15,518	18,544
STEM	3,833	11,540	8,548	3,014	7,132	16,663	12,030	15,020	9,979
EU		3,212	3,945	11,217	14,037	14,186	4,670	6,503	5,160
Ericsson					4,233			6,102	
SSF		1,899						3,062	3,931
Wallenberg foundations					2,453	6,178	5,985		
Scania	1,639	2,263	3,301	3,948		3,234	4,347		4,429
VR	2,836	2,549	2,327	3,045					

Since educational funds are considered stable, the situation is somewhat stable, but if considering the relation between external research funds and basic university research funds, the situation is potentially highly volatile. Another complication is that many research agencies, in particular the EU projects, requires co-funding from basic university funds, which quickly drains resources and leaves no flexibility or possibilities for strategic investments.

c. Current faculty situation

The faculty currently consists of the following:

- 8 professors (2 women)
- 8 affiliated or adjunct professors (1 woman)
- 14 assistant and associate professors (4 women)
- 22 researchers and postdocs, on permanent or temporary contract (7 women)

Half of the faculty has tenure track positions and the other half does not. In the majority of the researcher positions, the work performed by the researcher, and the responsibilities, would motivate that the position should rather be a tenure track position. The main reason against this has been a combination of short-sighted decisions and challenges with recruitment in the tenure track system. The faculty have a sound age balance. The career stage balance is as well sound, with all assistant professors on track for promotion to associate professor and many associate professors on track for promotion to professor. The gender balance varies greatly between the different divisions, but at the departmental level it cannot be found to be satisfactory. In three of the divisions, women are in a clear minority. In Integrated product development and design the gender distribution is completely even and with two out of the three professors being women. In this division there is also a strong focus on norm-critical design and since much of the research addresses organizational issues it is clear that gender issues are an important and integrated aspect. Nevertheless, at the overall level the gender balance is not satisfactory and improving it is of the highest priority in all recruitment activities. The current strategy is, among many other measures, to focus on developing research and future positions in areas where we see it to be more likely to recruit female candidates.

d. Recruitment strategies

The long-term ambition is to have a stable funding situation with the same ratio of permanent positions vs. temporary positions as with the permanent funding vs. the external funds. Further, the ambition is that all permanent staff should have tenure track positions. Recruitment strategies follow Swedish law and regulations, as well as KTH guidelines, which facilitates the safeguarding of fair and equal opportunities.

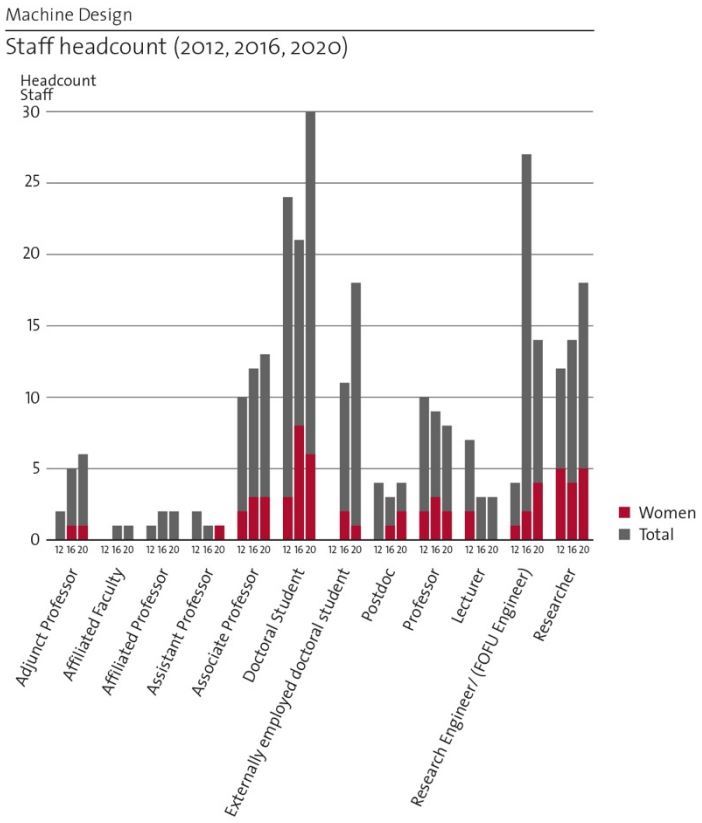


Figure MMK-4. Staff, by category.

e. Infrastructure and facilities

Many research activities at Machine Design (as well as educational programmes and courses) require infrastructure such as laboratories and workshops. As described above, the department has grown about 40% during a period of 8 years while maintaining the same infrastructure.

Infrastructure for research consists of laboratories, workshops and equipment with support staff. A fully equipped mechanical workshop supports both research and education. The department also hosts a prototyping center, which supports both research and education, as well as the rest of KTH and other partners. The prototyping center complements the mechanical workshop by providing modern tools such as laser scanners, laser cutters, sheet forming machines, 3D-printers and milling machines.

For research on internal combustion engines, the department runs a major test facility with four test cells for full-sized truck engines, with cooling systems, fuel systems and monitoring with a separate laboratory for fuel-related experiments. For research on tribology and machine elements, the department runs eight test cells, most with climate control and advanced measuring systems. Also, a clean-room with advanced equipment for experiments and measurements on nano-level is used.

In Mechatronics-related research, a motion-control lab is equipped with several systems for motion detection. An electronics laboratory provides all necessary resources to produce embedded systems, from PCBs to actuators. The emerging research on AI, autonomous systems etc. includes major computing resources which are hosted locally.

The current trends point toward less use of the larger, major settings such as full-scale engine research, and instead towards smaller setups, less focus on validation tests and more focus on studies on specific phenomena. We therefore see the need of shifting toward more flexible laboratory facilities that are less

dependent on heavy infrastructure. We also aim to increase synergies with our educational programmes and courses and use these for both research and teaching. In terms of workshops, the longer term strategy is to integrate with workshops at other departments. In terms of space and facilities, which carry the largest cost, our strategy is to have as much flexible space as possible where many activities can share the same space.

4. Strategies and organisation

a. Goals for development 5–10 years ahead

Machine Design has a unique possibility to be at the forefront of several current technological shifts thanks to our current setup. Many of these are in the interfaces between existing areas and show huge potentials for further development and directly relate to many sustainability goals. For this to happen, we need to enable new areas and ambitions at the borderlines between existing research themes, we need to be in the forefront of digitalisation, and we need to be able to adapt to changes. There are opportunities within the transformation from internal combustion engines to hybrid drive trains, as well as in ongoing transformations to embedded control systems, edge computing, artificial intelligence and machine learning. These areas relate to existing fields at Machine Design or elsewhere, so for us to develop further in these areas means building bridges and collaborating between divisions, as well as with other partners at KTH and elsewhere.

One possible step of the indicated transformation is a discontinuation of the Internal Combustion Engine division in its present format. Due to decreasing external funding, lack of funding mechanisms for infrastructure and difficulties to attract students it does not appear feasible to continue existing activities to a full extent and different ways forward, carefully considering experimental equipment, facilities, and collaboration partners, are at present investigated.

On the positive side, we see opportunities to further strengthen the position of Machine Design and enhance our contribution to a sustainable and resilient society by extending our research towards complex dynamic (sociotechnical) systems. We aim to draw on the existing system knowledge at Machine Design and the methodologies developed at Integrated Transport Research Lab (ITRL) to establish a new unit at the department. By focusing on complex systems, this new unit can provide a necessary component in design of sustainable products. It also provides a complementary tool for cross-unit collaboration, multidisciplinary research and contributes to the department's role as a system architect at KTH.

One often lacking mechanism to reach these goals is to foster future leaders, research leaders and researchers skilled at managing collaboration and cross-disciplinary projects. Consequently, this should be a prioritised action for future development.

b. Congruence with university-level goals for "A leading KTH" as set out in KTH´s "Development Plan 2018-23" (page 5)

A leading KTH

In parallel to the huge sustainability challenges, we are faced with mega-trends such as digitalisation, urbanisation and demographic changes which in turn pose challenges and opportunities that cannot be addressed by a single individual or organisation. Effective collaboration will be the key to success. The technological shift embodied by digitalisation provides unprecedented opportunities for innovation. With this shift we refer to smartness, automation and connectivity, combined with other technological developments and a transition towards a global data and service economy. Digitalisation also poses several new challenges and threats referring to the need for new business models and the unprecedented complexity of future connected smart industrial systems, which have to be engineered

to be sufficiently safe, secure, available and cost-efficient. Emerging digital technologies are present in the different fields at ITM. However, specific research into how digitalisation transforms business and systems engineering methodologies that provide resilient systems for a circular economy is still in its infancy. The potential of connections between current research areas at KTH creates exciting opportunities to lead this development. We will make efforts to establish research areas within digital transformation and industrial disruption. An initial step is to provide a cross-disciplinary platform where workshops, seminars and other traditional academic activities can fertilise the development.

World-class research, cross-disciplinary research

As more and more machine elements are integrated with electronic components the distinction between mechanical and electronic parts is gradually disappearing. This trend also points out a direction in which machine components should be developed. The demand is for more controllable and adaptive machine components. The research group develops tribotronic systems as well as active machinery maintenance strategies based on AI and multiple parameter sensor technologies.

At KTH there is a possibility to further enhance a unique competence in aerosol research formed by the collaboration between the Tribology and Internal Combustion Engine research groups at the department of Machine Design and KTH Building Technology. This collaboration has the potential to develop a system approach that covers the research field from the sources of airborne particles (engine exhaust emissions and wear processes) to filtering of indoor environments and ventilation systems.

Another scale of the research is transmissions and especially failure modes and energy efficiency of gear transmissions, but the research activities also involve other components as the tyre to road contact and mechanical brakes. This is an area with an ongoing large-scale industrial transformation that for the vehicle industry for instance involves changes of the platforms to hybrid and electrical vehicles. At the department of Machine Design there is large potential in cooperation here since the joint competences within the Mechatronics, Internal Combustion and the System and Component divisions here enhance all aspects of the current trends in electric drives.

Based on the above, a number of key actions can be derived:

- Create awareness of climate change and sustainability challenges, and develop the culture of collaboration, innovation and entrepreneurship needed to address the challenges.
- Attract top talents and qualified staff who are ready to take on the tasks.
- Contribute to the transformation of industry in key related fields (such as manufacturing, energy and transportation) by focusing research in the relevant areas, connecting research and education, establishing best practice exchange with and within industry, and by developing new interactive forms for collaboration.
- Create strategic collaborations and networks with relevant stakeholders within the school research profile while sharing the same vision; engaging regional, national and international organisations, covering relevant eco-systems of stakeholders.
- Create incentives, resources and infrastructure; exploit synergies and existing resources that support actions driving towards the vision. This includes developing suitable funding strategies and proactive measures for establishing funding.
- Continuously develop leadership capabilities and collegial structure enabling cross- and multi-disciplinary work.

Curiosity-driven research, social benefits and digitalization

During the past years it has become more and more obvious that systems thinking is a crucial component for sustainable development in general, and sustainable product development in particular. When new products are implemented in the society, they affect and are affected by users, business, other products and services, policies etc. To reach the climate goals, adapt to climate change, and

develop a resilient society it is necessary to have frameworks and methods do integrate these different perspectives and understand the complex dynamic systems. This is important now and will be even more important in the future.

We aim to build on the systems thinking and systems engineering knowledge developed at all units at Machine Design and explicitly underpinning the research approach at Integrated Transport Research Lab (ITRL) to establish a new or enlarged unit focusing on complex dynamic systems. The interest within this field is already proven by the great interest from funding organisations and industry in ITRL. With the mentioned unit we aim to: Emphasize research on system thinking and systems engineering and explore the opportunities to create a new cross-unit, cross-disciplinary master program. Furthermore, experiences from ITRL tell us that this is a research field that attracts both female and male students.

c. Leadership structure and collegial structure

A suitable leadership structure and truly collegial work constitute two fundamental pillars for successfully managing and developing the department in the desired direction. The perception is that the present organization at Machine Design is well-functioning. The department is formally organized in four units each led by a unit manager. Two units are organized with subunits with delegated responsibility, either focused on teaching activities or a research field. In several units, smaller research teams are led by senior researchers. All educational activities are coordinated, and led, by a director of undergraduate studies and the doctoral program is led by a program director. The master programs, and their sub-tracks, are each led by a program director. All managers, and the overall program directors, together with a business controller constitutes the department management group, led by the head of department. Many cross-department activities are led by academic staff, ranging from shorter development- and social activities to responsibilities for coordination of laboratory resources. These leadership roles are acknowledged and promoted.

All academic senior staff, plus key non-academic staff, constitute the Department Faculty. This group consists of in total 50 professors (including adjunct-, associate-, assistant-) and researchers. The Department Faculty meets monthly in its entirety, as well as at a yearly two-day conference. The Department Faculty is the main forum for strategic discussions regarding research and education, and all major changes and activities should be intensively debated in this group. Each unit meets in the same setup, either bi-weekly or monthly, and at an annual strategic conference. At these unit meetings, all members of the units are involved.

d. Strategies for high quality

The majority of research performed is funded through external sources and achieved in competition with others. In all cases research grants are awarded based on quality of previous work and strategic ambitions. The department fully respects this system and sees this as a mechanism for assuring high quality in research. In all other aspects, open access publication and public dissemination of all activities are essential.

5. Interaction between research and teaching at all three levels (BSc, MSc, PhD) of education

The department hosts two master programs that attracts large numbers of students every year. Research leaders at the four divisions are directly involved and the master programmes are directly in line with the research fields of the department. On PhD level, courses are offered by all divisions, by most of the senior research staff.

Both master programs include extensive problem-based, project-organized courses in the final year, “capstone-courses”, up to 30 ECTS. In these courses, students handle projects relating to current research projects and collaborating companies. The projects are typically led by the researchers and directly relate to their research ambitions. Projects can include design of infrastructure for research

experiments, development of test rigs. These projects directly enable students to interact with the current research projects. The BSc level includes a thesis project of 15 ECTS in the third year, which often also relates to current research projects and is often supervised by PhD students. The MSc level includes a 30 ECTS thesis project, which at times is supervised by PhD students and often relate to the current research projects.

6. Impact and engagement in society

a. Relevance of research to society at large

As described above, most of the research done by the Department of Machine Design is performed in collaboration with industry or public administration. Several researchers have joint positions in industry and we have a large number of adjunct and affiliate professors.

b. Research dissemination beyond academia

The applied nature of the research performed at Machine Design is in many cases completely dependent on strong collaborations with industrial firms and other key stakeholders in society. Many of the research projects funded by Vinnova also include implementation activities, making also these a fundamental activity for the researchers.

c. Sustainability and the United Nations' Sustainable Development Goals (SDG)

100% of the research performed at Machine Design directly relates to the United Nations' Sustainable Development Goals. The research at Machine Design explicitly addresses 11 of the 16 SDG:s, with a strong emphasis on SDG:s 7 (Affordable and Clean Energy), 9 (Industry, Innovation and Infrastructure) and 11 (Sustainable Cities and Communities). Examples of research directly relating to SDG 7 are our ongoing projects on wave- and wind energy. Projects in innovation management, circular economy and industrial internet of things relate to SDG 9 and our research on autonomous vehicles and transport systems relate to SDG 11.

d. Structure for increased impact

As a consequence of the character of our research, the department has built long-lasting relationships with key collaboration partners and has well-functioning structures in place for knowledge transfer and involvement in change initiatives and innovation. In particular, we would like to stress the importance of industrial PhD students and adjunct faculty. The latter often also play a role in receiving industry funding for applied research projects. Another important component are the different centres, e.g. ICES and the recently started TECoSA. Several researchers have also been active in diffusing their research to a wider audience, through public lectures, debate articles and other types of media participation. Popular versions of parts of the research is also published in the Swedish magazine Management of Innovation and Technology, which reaches approximately 25.000 decision-makers in Swedish industry and is edited by a Machine Design colleague.

As mentioned above a large part of the research at Machine Design is of an applied nature and is often performed in close collaboration with industry. Whereas this may in some cases limit the possibilities to publish in high-level journal, it often has a positive effect on the impact that is generated. The impact cases presented in the Appendix illustrate the variety of impact made by the department.

Appendix 1: Impact cases

Impact case 1. Methodology for environmental performance improvement

Department of Sustainable Production Development (HPU)

a. Summary of the impact

Dating back to 2009, an industrial need was identified in reducing waste/cost caused by environmental aspects, also adding value to the production system by green strategies and actions within automotive industry. A project Green Production Systems (2009) funded by VINNOVA was initiated by M. Bellgran (Haldex and Adj prof at MDH) and run together with Haldex, Volvo CE and MDH. Inspired by an industrial model, a tool called Green Performance Map (GPM) was developed and tested for the purpose of identifying, visualizing and prioritizing environmental improvements in production. A number of related research questions on lean and green, sustainable production, change management etc. where approached. Due to the industrial anchoring of the method, it has since then been trained at universities like MDH, Chalmers, LU and KTH, and implemented in companies like Volvo CE in Braås. New at HPU/KTH in 2017, Bellgran initiated a pilot together with AstraZeneca (AZ) to test the GPM-method in the pharma sector. The pilot was a success and resulted in more pilots at the AZ site in Södertälje, spreading also to pilots at Scania. The method is now a global lean standard at AZ and prepared as global standard at Scania. There are also ongoing discussions on a national roll-out of the green kaizen method together with the new national node for Sustainable Production (SuPr) and as part of the national SME-Lean program called Produktionslyftet. The essence of the approach and methodology is to encourage environmental engagement from all employees, reducing the negative environmental impact as well as saving costs and improving productivity at the same time.

b. Underpinning research

Besides the early industrial tests and implementation, research results were published in research papers, a licentiate thesis by Höckerdahl (2011), and a handbook for industrial use by Bellgran, Kurdve, and Wiktorsson et al. (2012). The GPM methodology was further refined and validated through a series of research projects. Examples of key publications are Kurdve & Wiktorsson (2013), Kurdve et al (2014), a PhD thesis by Shahbazi et al. (2018), Bellgran et al. (2019) and more.

The GPM method has created industrial impact at e.g. AstraZeneca in the P2030-funded Green Kaizen project (2018) with successful results in terms of energy and material efficiency improvements. The method is a global lean standard with AZ, adapted to suit their specific context, and has been used by a large number of teams at AZ (especially the global Quality Labs have a high implementation speed). The roll-out of the method at AZ has been followed by an industrial AZ PhD student within HPU focusing on corporate lean deployment, and the results have been published. The method is set as a global standard at Scania as well under the name of Green Accelerator (status: decided with ongoing planning). In the two related innovation projects Leda Grönt (2019-) and Green Kaizen in SME's AZ, Scania, InMotion and Alfa Laval are partners in continuing disseminating and building knowledge of the method and environmental improvements in general. New knowledge and research results in relation to GPM is constantly developed on aspects such as environmental improvements and green change management. A circular economy approach is built-in the GPM-method through the use of the commonly used waste hierarchy model, and explored further in subsequent research as a way to operationalize circularity in production.

As part of the dissemination and method implementation, the green kaizen method has been further integrated in the professional education program of KTH-Södertälje LeanCentre (www.kth.se/leancentrum), such as the course Green and Lean offered to SMEs and others, and in the pilot course Sustainable transport systems for Scania (2021), combined with knowledge on circular business models and life cycle analysis for production (taught by PhD students at the department). The

method is trained and applied as part of a toolbox for industrial sustainability work in the master course Sustainable in Practice at HPU. The method has been in focus in some 5-6 bachelor and master thesis work at KTH.

- M. Kurdve and M. Bellgran, 2021, "Green lean operationalisation of the circular economy concept on production shop floor level," Journal of Cleaner Production, vol. 278.
- Bellgran, M., Kurdve, M., Hanna, R., 2019. Cost driven Green Kaizen in pharmaceutical production – Creating positive engagement for environmental improvements. Procedia CIRP 81, 1219-1224.
- Linderson, Sara; Eshetu Birkie Seyoum; Bellgran, Monica: Bottom-Up Lean Practice Deployment in a Global Setting: A Case Study from the Pharmaceutical Industry, Proceedings of the Swedish Production Symposium, Jönköping 2020 (digital).
- Lindahl, Emma; Bellgran, Monica; Kurdve, Martin (2020), Re-engineering the waste hierarchy to manage the integration of Circular Economy in production operations, Euroma conference 201020.

c. Sources to corroborate the impact

In addition, results from Green Kaizen research have been presented in a large number of events over the years for different target groups, e.g. a full-days conference on “Green Production Systems” 2012-09-06, at industry seminars, for the Delegation for Circular Economy, for politicians, research seminars and conferences like Lean Forum 2019 etc. More sources, see below:

Recorded seminars, such as from the Södertälje Science Week in 2019, 2020 and 2021, see webpages:

- Öka tempot i miljöförbättringsarbetet! – Science Week 2019, https://sscp.se/scienceweek/program2019/oka-tempot-i-miljoforbattringsarbetet/
- Lean Produktion för klimat och konkurrenskraft eftermiddagspass – Science Week 2020, https://sscp.se/scienceweek/program2020/lean-produktion-for-klimat-och-konkurrenskraft-eftermiddagspass/
- Gröna förbättringar i produktionen, så här gör vi! – Science Week 2021. https://sscp.se/scienceweek/program2021/grona-forbattringar-i-produktionen-sa-har-gor-vi/

The method and corresponding research information could be found on e.g. the national webpage Kostnadsdriven grön kaizen—Kunskapsförmedlingen.
https://kunskapsformedlingen.se/projekt/kostnadsdriven-gron-kaizen/

Lean Forum » Lean & Green – det är på riktigt nu | Monica Bellgran, KTH, med exempel från Scania och AstraZeneca. https://leanforum.se/konferenser/dag-1-lean-forum-2019/programpunkt/lean-green-det-ar-pa-riktigt-nu-monica-bellgran-kth-med-exempel-fran-scania-astrazeneca-volvo-ce-och-haldex/

Impact case 2. Open infrastructure for digital and virtual production and logistics

Department of Sustainable Production Development (HPU)

a. Summary of the impact

In 2017 a novel testbed project was initiated in dialogue with Scania and AstraZeneca, among others, funded within Produktion2030. The formed *DigiLog* project was based on connecting the vision of connecting relevant testing facilities for production logistics means at KTH, Scania and AstraZeneca, and disseminate broadly.

The combination of digital and physical models that connects the testbeds creates new opportunities for system innovation – which can benefit the learning for different target groups, from undergraduate students and researchers to industry practitioners. The testbeds allow to test and experiment with different configuration of components, interconnecting these, and allowing interactions. The mix of physical and virtual testbeds makes it possible to export and import collected data from actuators and sensors in multiple environments and thereby identify possible improvements at process (information and material flow), organisational (layouts and operational issues) levels as well as on how digitalisation technologies can support the human in executing the daily task. They support a step-wise transition towards digitised logistics, in which companies and users can find the right level of automation and to select the right technology for their logistics related problems leading to a more sustainable production. The digital twin opens for experimenting with new ways of processing, analysing and using the collected data (both simulation model & physical lab) for improved planning, optimisation of running processes and for maintenance purposes.

b. Underpinning research

The established testbed and infrastructure have been the basis for a number of recent research projects, defined in collaboration with industry and partner universities and institutes. Projects such as SCARCE II, C-PALS, EXPLAIN, HUPMOBILE, IAM, LOVIS, SmartPM and UniLog (see https://www.kth.se/hpu/research/current-projects) all are based on the open infrastructure of HPU, formed in the wider context of Södertälje Science Park, KTH Leancenter and SuPr. C-PALS has been appointed an Eureka SMART success story (2019), while LOVIS and C-PALS both were appointed as within the 50 most important research projects in Sweden 2021, by the Royal Swedish Academy of Engineering Sciences (IVA). Examples on early academic references include:

- Y. Jeong, E. Flores-García och M. Wiktorsson, "A Design of Digital Twins for Supporting Decision-making in Production Logistics," Proceedings of the 2020 Winter Simulation Conference, 2020.
- Baalsrud Hauge, J., Zafarzadeh, M., Jeong, Y., Li, Y., Khilji, W. A., & Wiktorsson, M. (2020). Employing digital twins within production logistics. In IEEE International Conference on Engineering, Technology and Innovation, ICE/ITMC 2020.
- M. Zafarzadeh, M. Wiktorsson, J. Baalsrud Hauge, Y. Jeong. "Data-Driven Production Logistics - An Industrial Case Study on Potential and Challenges," Smart and Sustainable Manufacturing Systems, vol. 3, no. 1, s. 53-78, 2019.
- M. Wiktorsson, S.D. Noh, M. Bellgran, L. Hanson. “Smart Factories: South Korean and Swedish examples on manufacturing settings”. Procedia Manufacturing, Elsevier, Vol. 25, p. 471-478, 2018

c. Sources to corroborate the impact

In addition to the partners mentioned above, the testbed project has helped HPU to establish research activities with Fraunhofer Chalmers Center, as well as to increase the involvement of SMEs through the involvement of Virtual Manufacturing and Södertälje Science Park, which has opened up the possibility

to target SMEs both for knowledge transfer as well as for increasing our knowledge on SMEs challenges in the digitalisation transformation process. The plan is to take these activities further to develop the different digital twins for planning and educational usage. See www.kth.se/hpu/research/labs-for-sustainable-production-development

The testbed for production logistics is one key element in the infrastructure for sustainable production, as part of the larger setting of Södertälje Science Park like the KTH LeanCentre, used for professional education, and *Open Prototyping Södertälje* (OPS), used as an open makerspace one evening a week, open for the public. OPS is run by SSCP, using KTH infrastructure with a prototyping lab with seven 3D printers and a large selection of materials. The CAD program used in OPS is Fusion 360, which is free for private persons, students or small businesses.

Another example on SME engagement and impact within digitalising production is the collaboration project ASPIRE (VINNOVA/P2030) starting in 2018, and partnering with RISE, Chalmers and five manufacturing companies where four are SMEs: Brogren Industries AB, Federal-Mogul Göteborg, Volvo Penta AB, Tyri Sweden AB and Marcus Komponenter AB. Researchers from HPU work especially close with Marcus Komponenter, an SME of 17 employees. The project focuses disturbance handling in production and aims at giving SMEs a better foundation prior to automation and digitalization investments. The project develops a practical methodology that can guide the companies towards being more proactive in managing disturbances and taking steps in their digitalization.

Impact case 3. Industrialisation and scale-up

Department of Sustainable Production Development (HPU)

a. Summary of the impact

A crucial part in the overall product realization process is the industrialization phase where new products are prepared for production. It means adapting the existing, or designing a completely new production system comprising the facilities, machines and product equipment, the material supply and product flow, information system, as well as the people in the production system. Both lack of focus in the manufacturing industry and identification of a clear research gap was the background to research within the area, initiated in a collaboration between the Haldex group (M. Bellgran) and Mälardalen University (M. Bellgran, J. Bruch, C. Rösiö, and Industrial PhD students) from 2008 and forward.

In 2017, the issue of industrialization (or new product introduction) was approached at HPU/KTH together with Södertälje Science Park, the Royal Swedish Academy of Engineering Sciences (IVA), and the startup Pharem Biotech in a pilot study called “Production Angels”, this time targeting startups with physical products and their struggle in industrializing and scaleing-up their new product innovations, from prototype to volume production. The concept of Production Angels has been developing since then, and after a series of pilots and tests, the concept comprises a number of modules like coaching, production angel panel, training, knowledge development, and digital matchmaking. Probably one of the most important results are the creation of awareness (through seminars, panels, discussions with funding agencies and politicians) of the hour glass-shaped innovation system in Sweden, where extremely small resources are invested in the production scale-up phase (the valley of death). The concept is now ready for implementation in a larger scale, and ongoing discussions with VINNOVA (May 2021) are held to prepare for roll-out on a national basis together with partners.

By May 2021, 50 hardware startups have participated in the program, together with 15 SME producers, and 15 production experts from different organisations (as coaches or production angels in the panels). Collaboration partners are mainly Ignite Sweden, Teknikföretagen, PRV, Manufacturing Guide, Toolspace & KTH Innovation, SVID, Swedish Scaleups, and SISP. As example of RoI, the startup Mimbly (www.mimbly.se) calculated savings on 2,8 MSEK as result of their participation in the Production Angel program, and their Swedish supplier Prodma (www.prodma.se) estimates a production of 96 MSEK in coming 3 years. According to Jan Kristoffersson, CEO at Prodma AB: “Production Angel’s Digital Matchmaking is an extremely efficient way of making contacts leading to real businesses. We are close to an industrialization & production agreement with one startup, contract manufacturing with another, and loose discussions with yet a third one”, see www.produktionsanglar.se.

In parallel with the startup-scaleup focus, initiatives for research and innovation on industrialization of new products within larger companies was initiated in collaboration with AstraZeneca 2018, where HPU-researchers within production management collaborated with the AstraZeneca team in their ongoing capital investment program for improving Operational Readiness in production. The project aimed at building new knowledge, and proposing a framework that manufacturers could utilize for decision-making and analysis, trusting that sustainability and lean requirements were considered (measured by relevant KPIs), and achieved in the design and operations of new production systems. Scientific results from the empirical studies 2019-2020, were e.g. presented at SPS and EurOMA conferences 2020 and published in the proceedings. Industrial contribution was in the form of a revised and improved capital investment model that integrated operations (ramp-up phase) at early investment stages, including tangible green targets. The industrialization research continues in a new VINNOVA project, Alistair (2020) utilizing AI to create a sustainable green-field pharma production factory in Umeå (with researchers from Production management at HPU, Mechatronics at KTH, Diamyd, and AI-Mainly).

b. Underpinning research

There are a number of scientific publications on production system design, industrialization, production introduction, ramp-up etc. as a platform for the industrialization research (by Bellgran together with Säfsten, Rösiö, Bruch, Javadi et al.), see e.g. Bellgran, M & Säfsten, K. (2009): Production development – design and operation of production systems, Springer Science & Business Media (google scholar: English version cited by 381, Swedish version from 2005 cited by 195).

To support hardware start-ups in their production launch and scale-up in Sweden, the new concept Production Angels (Produktionsänglar, see www.produktionsanglar.se) were developed during pilot projects funded by Vinnova, Tillväxtverket and the Swedish Energy Agency. The concept was initiated by Prof Monica Bellgran at HPU based on earlier scientific and industrial experience in the industrialization area, and is performed together with Södertälje Science Park. Since 2017, the concept is developed including a modular program with production and sustainability workshops, coaching of production experts, matchmaking between startups and producers, training modules etc. In parallel, knowledge is developed through three thesis work, ongoing data collection by interviewing all startups in the program (today summarized in a scientific report of 14 startups, see reference), and a study of the innovation system from a production scale-up perspective. The scale-up research is in an early stage, but initial findings are reported in:

- Sefton, M., Rönkkö, I., Bellgran, M. (2020): Hardware Start-ups in the Scale-up Process of Production – A Mapping of Challenges, SPS 2020, in *Proceedings of the Swedish Production Symposium*, October 7-8, 2020 (pp 378-391).
- Bellgran, M. (2021), *14 svenska startups på väg mot produktion – Hur ser vägen ut och vad behövs för att fler hårdvaru-startups ska ta sig över dödens dal.* En rapport från Produktionsänglar. TRITA-ITM-RP 2021:1, HPU/ITM/KTH rapport 2021.

Related theses work to mention: 1) Lucas Molin: Overcoming the Valley of Death. (Master thesis KTH 2020). 2) Rönkkö, I., Sefton, M., Hårdvarustart-ups i uppskalningsprocessen (Bachelor thesis KTH 2019), 3) Bachelor thesis 2019, 4) ongoing bachelor thesis project 2021.

c. Sources to corroborate the impact

Produktionsänglar – från prototyp till produktion – Science Week 2020

Varför har vi 1000-tals affärsänglar men bara två produktionsänglar? – Science Week 2021

Produktionsänglar hjälper startups över ”Dödens dal” – DN.se 210104

Produktionsänglarna från Södertälje – DN.se 200127

From innovation to production – KTH

Pharem participates in project: “Produktionsänglar – ett innovativt koncept för industrialisering och uppskalning” – Pharem

www.manufacturingguide.com/en: Ditt stöd för produktutveckling och tillverkning | Hitta leverantör, metod & material

Produktionsänglar: Information and training films on ”Digital Matchmaking”, ”Trailer to introfilmer”, ”Kravspecifikation”, ”Avtal och allmänna bestämmelser 1”, ”Avtal och allmänna bestämmelser 2”, ”Immaterialrätt” [www.youtube.com/playlist?list=PLi3iKiq6hupfnJ8Fb8R0I11v-VD4MbT29]

Industrialization in focus at Annual conference of Sweden’s Innovation Agency, VINNOVA: Del 8: VINNOVA Årskonferens, 27/11 2013. www.youtube.com/watch?v=zdorwzgTz4g

Impact case 4. Building a cashless society in Sweden

Department of Industrial Economics and Management (INDEK)

The payment system is the aorta of the economic system and constitutes the most critical infrastructure for a modern society and its economic system. If this system does not function, all other infrastructural systems like energy, water, transportation, food, heating, education and health care would not be able to deliver their services. Payment infrastructure has been relatively stable for a long time but is now facing a radical transformation process where the critical roles of the state, of banks, of technology providers, of retailers and of other service providers are changing. This also brings significant challenges for consumers. Sweden is in the forefront in this transformation by moving towards a cashless society where innovative payment services, regulation, customer behavior, values, trust and other critical factors are making the country stand out in this transition. Niklas Arvidsson's research has led to insights shared by governmental agencies as Sveriges Riksbank, Riksgälden, Tillväxtanalys and PTS as well as companies like banks, Fintechs, retailers, card scheme operators (VISA and Mastercard), cash-in-transit service companies, telecom operators in addition to industry associations like Svensk Handels and Bankföreningen. Niklas has been interviewed by a large number of Swedish and international newspapers and TV-stations, and presented to central banks, banks, retailers, and many more.

The research at KTH has led to articles, books and other publications. It has focused on how the Swedish payment system is changing, what explains this, innovations and implications. Our insights related to politics, governmental agencies, banks, retailers and consumers have been well received and demanded. Additional projects have pursued problems and opportunities including studies of innovations like Swish, the transformation of the payment system in itself, consumer attitudes towards mobile payment services, the role of digital platforms in the payment industry as well as the implications for competitive pressure as payments become digital.

The most evident impact is seen in the book called Building a Cashless Society – The Swedish Route to the future of Cash Payments, written by Niklas Arvidsson and published by Springer Verlag in 2019. This book has received a lot of attention from all over the globe and has been downloaded more than 78000 times (see http://link.springer.com/book/10.1007/978-3-030-10689-8).

Another recent indication of impact is the participation of Niklas Arvidsson in the TV program called Ekonomibyrån on February 8, 2021 (Ekonomibyrån - Kontantdöden | SVT Play) in a discussion of cash payments and the implications from the transformation of retail payments in Sweden. This has also been viewed over 4700 times on LinkedIn.

Niklas Arvidsson has been invited to participate in a number of parliamentary investigations, worked for Riksgälden during a year in a project on the future of how the state of Sweden will structure payments to and from the state, acted as an expert in an innovation procurement project by PTS and in hearings and projects at the Riksbank and for other organizations.

The research and network that the research is built on have also led to a number of positive effects for students at KTH. In courses both at the bachelor and master level, there have been guest lecturers from Riksbanken, Nordea, Swish, PA Consulting, Safello, CGI, PRV, Ericsson Financial Services, and the Swedish Findec Association. It has also led to several master thesis projects on the transformation of the payment system, IT-security compliance in payments, the future of banking, the implications from new payment service regulation, digital payments, mobile remittances, and mobile money.

Impact case 5. Using immersive technologies like Virtual Reality to peak performance of organizations and their people

Department of Industrial Economics and Management (INDEK)

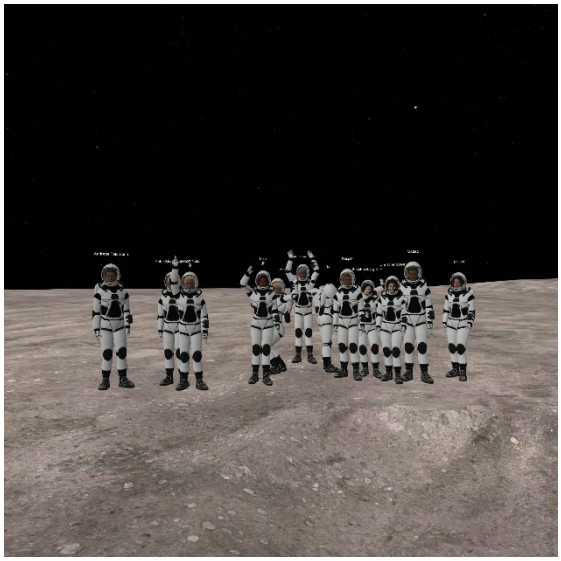
Soft skills are intangible and hard to measure for the purpose of human due diligence in large-sized organizations/multinationals. What if organizations could be more efficient in education and assessment of social skills in the workplace with a special focus on equality? This impact case tackles this problem with an approach to improve the soft skills more tangible by using data-driven and research-based training and assessment methods conveyed through scalable immersive Virtual Reality experiences.

Anna Blendow, HR manager at KTH/ITM, working on a critical management challenge.

The aim of this concept is to create social sustainability in the workplace, to become more fair and social. Soft skills training is expected to grow rapidly for a long period of time according to Transparency Market Research (2020) and PWC (2019, 2020). The concept positively influences society by decreasing the possible conflicts at the workplace and miscommunications based on power imbalances. Furthermore, educating people on these issues potentially will improve the gender, age, and other types of inequality and diversity in companies. Thus, this concept correlates with UN Sustainable Development Goals, such as lowering inequality, climate change, and environmental degradation.

This impact case focuses on the top priority challenges management of large organizations are having with people management in. It's a solution that can be described as a "research-engine"; organizations get access to the latest science in management and organization through dramatized scenarios in Virtual Reality, 3-dimensional immersive experiences that reflects typical challenges in the workplace for the purpose of deep learning and assessing skills: human due diligence analytics. Anonymous user data are collected which is an innovation as such: creating quantitative data from a qualitative study. The design idea is based on "nudging" which was awarded Nobel Prize 2017.

VR is also the future of collaboration in organizations and its benefits is obvious in the on-going pandemic. This impact case includes the creation of real-life cases to meet and collaborate, as avatar is 3-dimentional virtual worlds. An example is that we co-organized a social event at the Nordic academia conference ScAIEM in November 2020.



The solution has achieved interest and attention in all sectors of society: private, academia and public sector. According to pilot test, the solution has potential to become a valuable asset in most parts of the “employee journey” in organization. Also the field of psychology. Researcher across Sweden, Nordics, and Europe has connected to this knowledge hub of innovation driven science on VR in organizations, and BBC spent as much as 5 minutes in their broadcasting to the Arabic world.

VR is in a growing extent studied in psychology such as: stress (Baños et al., 2011), execise cognitive function (Zhuang et al., 2013), CBT and exposure theraphy (Flobak et al., 2019), communications (Dias et al., 2012) and PTSD (Rothbaum et al., 2014). Authorities and companies can benefit from applying “nudging” can serve as a political instrument to drive sustainability by encouraging appropriate behaviors (Carlsson, 2019). The researcher behind this impact is in the forefront of studies in the field of organization, an on-going studying of how VR is received by staff and the perception of being represented by avatar in a virtual world in a highly professional organization as well as the experiences from participation in a conference in Virtual Reality.

References (selection)

Carlsson, Frederik, et al. (2019) Nudging as an environmental policy instrument. Department of Economics, Göteborg University.

Soold, H. (2018). KTH Tech talks. Poddtoppen. Retrieved December 3, 2020, from https://poddtoppen.se/podcast/1085679583/kth-techtalks

Transparency Market Research. (2020). Soft Skills Training Market To Reach US$ 53.4 Bn By 2030. Transparency Market Research. Retrieved December 6, 2020, from www.transparencymarketresearch.com/soft-skills-training-market.html

Impact case 6. Ripple effects in gender equality work

Department of Industrial Economics and Management (INDEK)

Research in gender and organization at Indek has developed knowledge on and methods for gender equality work which has had an impact on gender equality work carried out in Swedish industry since the RAE 2012. A research and development project funded by VINNOVA "Eivor & Mai – A research and development project for gender equality work with a power perspective" (2013-2015) with PI Prof. Anna Wahl, has had ripple effects. The project involved women and men producers and directors from the Swedish film industry and women and men researchers within the Swedish metals industry. After the project was finalized, one of the participants from Höganäs AB, Ann-Cathrine Hellsén became responsible for driving the gender equality agenda at Höganäs AB. In 2019, Höganäs AB was awarded Näringslivets Jämställdhetspris www.industriradet.se/jamstalldhetspris/2019/, a prize awarded by the Council of Swedish Industry. Another participant, Jenny Kylefors at Scania Group, has since the project commissioned a number of masters' thesis at KTH analyzing Scania from a gender equality and diversity perspective that have been supervised by Docent Charlotte Holgersson. The collaboration with the film industry in Eivor & Mai led to a broader collaboration with performing arts in the wake of the #metoo movement. In 2017, the Swedish Performing Arts Association and the trade union for Performing Arts and Film appointed a commission against sexual harassment within performing arts in 2018 chaired by Prof. Anna Wahl. The commission carried out an inquiry and produced a report with suggestions for future work for change (www.svenskscenkonst.se/media/1592/rapport_ett_tillfalle_att_ta_vara_pa_webb.pdf). The initiative received special nomination within the category "Diversity & Equal Opportunities" at the The Pearle* 2018 Awards that celebrate the achievements of Employers' Associations in the European live performance sector (www.svenskscenkonst.se/aktuellt/nyhetsarkiv/kommissionen-mot-sexuella-trakasserier-prisas-i-eu-finansierat-projekt/).

Based on research on gender equality work, Wahl and co-authors have developed a theoretical framework over dimensions that affect the transformative potential of the methods commonly used in gender equality work (Wahl 1994; Holgersson & Höök 1997; Wahl 2014; Wahl, Holgersson, Höök & Linghag 2001/2011/2018). This theoretical framework can be used both as a tool in the design of change initiatives and for evaluating methods. For example, Benschop, Holgersson, van den brink & Wahl (2015), analyzing research on three popular methods (mentoring, training and networks) argue that a power perspective is key to the transformative potential of these methods.

References (selection)

Benschop, Yvonne, Holgersson, Charlotte, Van den Brink, Marieke och Wahl, Anna (2015) Future challenges for practices of diversity management in organizations. Bendl, Regine, Bleijenbergh, Inge, Henttonen, Elina och Mills, Albert J (red) *Handbook for diversity in organizations*. Oxford: Oxford University Press.

Holgersson, Charlotte och Höök, Pia (1997) Chefsrekrytering och ledarutveckling som arenor för konstruktion av ledarskap och kön. *SOU 1997:135 Ledarskap, kön och makt*. Stockholm: Fritzes.

Wahl, Anna (1994) Att arbeta för förändring. *SOU 1994:3 Mäns föreställningar om kvinnor och chefskap*. Stockholm: Fritzes.

Wahl, Anna, Holgersson, Charlotte, Höök, Pia och Linghag, Sophie (2018) *Det ordnar sig. Teorier om organisation och kön*. Tredje upplagan. Lund: Studentlitteratur.

Impact case 7. Evolvable Production Systems

Department of Production Engineering (IIP)

a. Summary of the impact

The Evolvable Production Systems (EPS) research began in the late 1990's and led to the formulation of an entirely new paradigm for system design in 2002. The work presented in 2002 led to the formation of a large research group at European level, including University of Nottingham, Universidade Nova de Lisboa, FESTO AG, Electrolux, Bosch and others. This research group obtained 6 large European Commission projects during the period 2004-2010: Assembly Net (FP4), A3 (Marie Curie), microSapient (FP5), EUPASS (FP6), IDEAS (FP7), PRIME (FP7). The work has resulted in commercial applications (see below) and was the first group to demonstrate Plug-&-Produce production system components in industry at the FESTO site in November 2011. The research group, led by Prof. Onori, obtained several awards, including the Japan Robot Association (JARA) award, Emerald Literati, Outstanding Journal Paper and 2 EU Success Story awards (IDEAS, openMOS).

The EPS paradigm showed that production system modules could be linked to product features. It also enables the creation of "families" of modules that configure and organise without human intervention, thus cutting installation costs dramatically. EPS also introduced a novel multi-agent based software control approach that will eliminate the need of old Programmable Logic Controllers (PLC). The work has led the IEEE to register the EPS paradigm and the European Commission has set their work as a Success Story as well as using the Evolvability criterion as fundamental for future industry. Companies now produce EPS production modules, including FESTO AG and MASMEC SpA. Last year the company ELREST GmbH launched a series of industrial controllers for EPS applications as standard products.

EPS is widely recognized as one of the pillars behind Industry 4.0, with strong applications in Germany (FESTO, OPEL, etc). Impact on the sustainability includesThe re-usability of system components, and the associated business models, introduce a completely novel approach to sustainable production: implementation costs are radically eliminated and new businesses will emerge (depots of modules, module adapters, etc.). This will require an entirely new grasp on educational needs, which are being addressed at IIP through specialisation courses. NOTE: EPS has also led to the Sharing Economy impact case at IIP (L.Wang, X.Wang).

Furthermore, the EPS research is now moving to standardising this approach at communication protocol level and industrial interfacing level. Work is ongoing with COLLADA, ELREST, FORD, and other partners within the newly started Horizon2020 project openMOS.

The EPS paradigm and IDEAS project resulted in a set of new, commercially available products. These were marketed by FESTO GmbH, ELREST GmbH, MASMEC SpA. In the following years other companies have endorsed this approach and, thanks to OpenMOS results, now offer similar solutions: AFAG, FORTISS and ASYS Group.

b. Underpinning research

The research in EPS has had massive circulation and won the Best Journal Article 2013 with Emerald Press. The work has also resulted in the IDEAS project being named Success Story at H2020 level in 2014, and has had widespread publication through authors such as Niels Lohse, José Barata, Mauro Onori, Svetan Ratchev, Pedro Ferreira and Luis Ribeiro.

c. Sources to corroborate the impact

Onori, M. et al; “The IDEAS project: Plug & produce at shop-floor level”*;* Assembly Automation 04/2012; 32(2):124-134., DOI:10.1108/01445151211212280; *Best Article of 2013 Award; Emerald Press*

Ribeiro, L. and Rosa, R. and Cavalcante, A. and Barata, J. (2012) IADE – *Ideas Agent Development Environment: Lessons Learned and Research Directions* ; Proceedings of the 4th CIRP Conference On Assembly Technologies And Systems (CATS), Michigan: CIRP.

https://cordis.europa.eu/article/id/91246-eus-revolutionary-assembly-platform

Impact case 8. Circular Manufacturing Systems

Department of Production Engineering (IIP)

a. Summary of the impact

In 2011, the Circular Manufacturing Systems (CMS) team in Manufacturing and Metrology Systems (MMS) unit of IIP proposed a visionary framework for the manufacturing industry to intentionally design closed-loop systems. Since then the team has played the role of core knowledge provider to industry, academicians, students and policy makers as well as positioned itself as a major player in CMS both in national and international context.

Impact on the sustainability

Environmental impact: CMS address the issue of resource scarcity by keeping the loop of resources closed as long as possible. This not only reduces dependency on resources but also minimises the environmental impact that would otherwise cause use of virgin materials and wastes from manufacturing activities and product end-of-life. Besides, research in CMS is directly aligned to Goal 9 and Goal 12 of the UN's 17 Sustainable Development Goals and indirectly addresses several other goals.

Social impact: Through research projects such as ResCoM, ReCiPSS, SerBIT and CIS Sotenäs the MMS unit has supported 5 European OEMs in exploring and implementing CMS. 9 SMEs (both Swedish and European) and a municipality in Sweden involved in these projects received support to develop methods and tools that are crucial for implementing CMS or become circular. Furthermore, 3 spin-off companies have taken shape by participating in the above mentioned projects and are trying to establish themselves commercially as well. The team is also representing KTH in the EMF's CE100 network and signee of the *New Plastics Economy Global Commitment*. The team has always been an active participant in different networking/ dissemination activities organised by the EC, EMF as well as major conferences such as World Circular Economy Forum, Circular Materials Conference and European Circular Economy Stakeholder Platform, etc.

MMS division is also leading CE@KTH initiative aiming to boost the research and education in CE at KTH and in Sweden. Besides research and education, the initiative has created an industrial network of more than 20 companies across Sweden.

Educational impact: Through the contributions of CMS team at KTH more than 300 undergraduate and 50 graduate students have undergone education in CMS in past 5 years. Furthermore, CMS has been a main theme for B.Sc. thesis since several years and the team is successfully running a PhD course on CE for last two years. CMS is also new research area developed at IIP, which is now an active topic for PhD research under production engineering program. A new M.Sc course in CMS is under development and will be launched in autumn 2021.

b. Underpinning research

The research in CMS has generated more than 10 highly relevant publications cited more than 1500 times including collaborations such as 'Från värdekedja till värdecykel- så får Sverige en mer cirkulär ekonomi' published by the Swedish Government.

Selected publications:

Lieder M., Rashid A. "Towards Circular Economy implementation: A comprehensive review in context of manufacturing industry", *Journal of Cleaner Production*, Vol.115, (2016): 36–51.

Rashid, A., Farazee M. A., Krajnik, P. & Nicolescu, C. M. (2013). Resource Conservative Manufacturing: An essential change in business & technology paradigm for sustainable manufacturing." *Journal of Cleaner Production*, 57.

Impact case 9. Maths Coach Online

Department of Learning in Engineering Sciences (LES)

a. Summary of the impact

What if learning could be supported anytime, anywhere, based on the needs of learners? In mathematics, students often study in afternoons and evenings. A challenge is that the teacher is not available to support them when they are stuck, and many do not have parents with mathematical expertise. This hinders students from advancing and undertaking more advanced mathematical problems. The *Maths Coach Online* (MCO) project attempts to meet student needs when they are studying, which is when they have the greatest need to get support.

Since 2009, the MCO project has conducted more than 60,000 free evening tutoring sessions to K-12 students who need help with their math homework. The tutors are student teachers in mathematics, who gain experience in using digital technologies in their teaching, as well as practice in tutoring. They use software that we have specifically developed for MCO, including text-based chat, formulas and a digital whiteboard. The tutors can work with up to five K-12 students simultaneously in different windows, which is very cost effective. The program aids student learning because students can take the time to work independently on a problem and continue the chat conversation later.

Beyond helping K-12 students to succeed in maths, MCO provides a platform for research on digital mathematics and tutoring. Our research is interdisciplinary, with practical, technical and theoretical contributions. We gather permission from all students who use the service to store the conversations for research purposes. The resulting database is a unique resource for studying online mathematics tutoring and learning. The technical platform, specifically designed for online mathematics tutoring, is continuously updated based on our most recent research. The platform is also used to collect data and conduct surveys. Our theoretical contributions to online tutoring research include the study of how productive relationships between tutors and K12 students can be encouraged, the role of emotional aspects in tutoring, and the effects of different question-asking strategies on student learning and satisfaction. In the spin-off project *TalkMath Online* (www.talkmath.org), we have made an adapted version of the software available for any education institution, teacher or student to use (Jansson, Hrastinski, Stenbom, & Enoksson, in press).

The project is currently funded by Swedish municipalities and Aston University, and has had many partners over the years. Tutoring is provided by Aston University and Linköping University, while KTH provides the technical infrastructure and pedagogical training. Via Aston University, the tutoring can be used by any K-12 student in the UK, although the project is mainly marketed in the Birmingham area. Via Linköping University, tutoring is offered to K-12 student in six Swedish municipalities, although students from other municipalities are welcome subject to available tutors. The project has received corporate sponsorship from Midroc Automation.

For the future, we have two goals. The first goal is to turn MCO into a national tutoring service. MCO was recently selected by the KTH management as one of the main “fundraising cases” at the university with a goal to attract 25 MSEK in order to turn MCO into a national project with resources to be able to tutor on a national basis at no cost for the K12 students. The second goal is to identify international partners who would like to join the project.

b. Underpinning research

There have been many publications based on the project. In some studies, researchers and students have analysed conversations from our database. In other studies, the purpose of the research has been to contribute towards improving pedagogical tutoring methods or to improve the technical infrastructure. Seven journal papers, one book chapter, ten conference presentations/papers, one PhD thesis, one licentiate thesis, and ten bachelor/master theses have been published based on the project.

Jansson, M., Hrastinski, S., Stenbom, S., & Enoksson, F. (in press). Online question and answer sessions: how students support their own and other students' processes of inquiry in a text-based learning environment. Internet and Higher Education.

Hrastinski, S., Stenbom, S. Benjaminsson, S., & Jansson, M. (2019). Identifying and exploring the effects of different types of tutor questions in individual online synchronous tutoring in mathematics. Interactive Learning Environments. https://doi.org/10.1080/10494820.2019.1583674. Citation: 11

Hrastinski, S., Cleveland-Innes, M., & Stenbom, S. (2018). Tutoring online tutors: Using digital badges to encourage the development of online tutoring skills. British Journal of Educational Technology 49 (1), 127–136. https://doi.org/10.1111/bjet.12525. Citation: 21

Stenbom, S., Jansson, M., & Hulkko, A. (2016). Revising the Community of Inquiry framework for the analysis of one-to-one online learning relationships. The International Review of Research in Open and Distributed Learning, 17 (3), 36–53. https://doi.org/10.19173/irrodl.v17i3.2068. Citation: 52

Stenbom, S., Cleveland-Innes, M., & Hrastinski, S. (2016). Emotional presence in a relationship of inquiry: The case of one-to-one online math coaching. Online learning, 1 (20). https://doi.org/10.24059/olj.v20i1.563. Citation: 31

Hrastinski, S., & Stenbom, S. (2013) Student–student online coaching: Conceptualizing an emerging learning activity. Internet and Higher Education, 16, 66–69. https://doi.org/10.1016/j.iheduc.2012.02.003. Citation: 36

Stenbom, S., Hrastinski, S., & Cleveland-Innes, M. (2012). Student–Student Online Coaching as a Relationship of Inquiry: An Exploratory Study from the Coach Perspective. Journal of Asynchronous Learning Networks, 16 (5), 37–48. Citation: 41

c. Sources to corroborate the impact

The MCO project has received extensive media coverage in, for example, Swedish television, Swedish radio, Computer Sweden, *Ny Teknik* (New Technology, https://www.nyteknik.se/karriar/de-vill-hoja-mattenivan-6418225) and *Skolporten* (The School Portal).

In 2019, the project was selected among 1,507 applicants and shortlisted for the *Reimagine K12 education award* (www.reimagine-education.com).

The main page for the project is found at https://liu.se/en/article/mattecoach-pa-natet; a recent article in English praising its impact: Ten years of Maths Coach Online.

Impact case 10. The CDIO initiative for engineering education development

Department of Learning in Engineering Sciences (LES)

a. Summary of the impact

The CDIO Initiative for engineering education reform started as a project in 2000 by the Massachusetts Institute of Technology (MIT) in the United States, and three Swedish universities: Chalmers, KTH Royal Institute of Technology and Linköping University. The starting point was the recognition that engineering education had become increasingly distanced from engineering practice, creating a need to "educate students who understand how to Conceive-Design-Implement-Operate (CDIO) complex, value-added engineering systems, within a modern team-based engineering environment". The initial project had funding from the Knut and Alice Wallenberg Foundation for the first four years.

The four partners set out to jointly develop the reform concept methodology, and simultaneously applying it in their respective curricula. Quite soon, other universities showed an interest and were welcomed as collaborators and to date the CDIO Initiative is a worldwide community with over 160 institutions. It is still attracting new collaborators (recently TalTech in Tallin, Estonia). The CDIO community holds two international meetings per year, one of which is the annual conference attracting 200-300 participants. Since 2016 it contains a dedicated research track, led by Kristina Edström.

The CDIO curriculum model can essentially be characterised as programme-centric development method. It is codified in the CDIO Standards (Crawley et al., 2014; Malmqvist et al., 2020a; Malmqvist et al., 2020b). Many hundreds programme leaders and curriculum developers worldwide are using CDIO as a frame of reference and inspiration for their work. By extension, the educational programmes are reaching a very large number of students.

For the past three years, the CDIO concept has been subject to a thorough renewal in a democratic process. The aim is to address changing conditions and needs, most notably sustainable development, digitalization, and the accelerated pace of development. The process also takes into account the experiences reported within the CDIO community through a systematic review of previous conference contributions. Just as in the founding years, KTH is taking a leading role in this work (Rosén et al., 2019; Malmqvist et al., 2020a; Malmqvist et al., 2020b; Rosén et al, 2021). For instance, the new CDIO Standard for Sustainable Development was formulated and then put to test in an institution-wide program evaluation at KTH, leading to refined definitions and distinctions (Rosén et al., 2021).

b. Underpinning research

The work in CDIO has been documented, subjected to peer review, and shared in scholarly ways. Publications range from single-author work to those reflecting longstanding international collaborations involving many contributors. Key resources are the book by Crawley et al. (2014) and conference papers where any updates are proposed and negotiated (some recent prominent examples are Rosén et al., 2019; Malmqvist et al., 2020a; Malmqvist et al., 2020b; Rosén et al, 2021). Journal articles include a special issue in the European Journal of Engineering Education (Edström et al., 2020) and other papers (among them Edström & Kolmos, 2014; Edström, 2018).

Key figures in CDIO recently published a Springer book on how universities can improve their impact of on economic development by furthering knowledge exchange in all areas – education, research and activities to catalyse innovation (Crawley et al., 2020).

Selected references (LES authors in bold, citation statistics from Google Scholar):

Crawley, E.F., Malmqvist, J., Östlund, S., Brodeur, D.R., & **Edström, K**. (2014). *Rethinking Engineering Education: The CDIO Approach, 2nd ed*. Springer, Cham. (1902 citations)

Edström, K. & Kolmos, A. (2014). PBL and CDIO: complementary models for engineering education development. *European Journal of Engineering Education*, *39*(5), 539-555. (227 citations)

Edström, K. (2018). Academic and professional values in engineering education: Engaging with history to explore a persistent tension. *Engineering Studies, 10*(1), 38-65. (15 citations)

Edström, K., Malmqvist, J., & Roslöf, J. (Eds.) (2020) Special issue: Scholarly Development of Engineering Education - the CDIO approach. *European Journal of Engineering Education*, 45(1). (The papers have in total 108 citations)

Crawley, E.F., Hegarty, J., **Edström, K**., & Garcia Sanchez, C. (2020). *Universities as Engines of Economic Development: Making Knowledge Exchange Work*. Springer, Cham.
(The first citation recorded was made by Henry Etzkowitz)

Rosén, A., **Edström, K**., Grøm, A., **Gumaelius, L**., Munkebo Hussmann, P., **Högfeldt, A-K**., Karvinen, M., Keskinen, M., Knutson Wedel, M., Lundqvist, U., Lyng, R., Malmqvist, J., Nygaard, M., Vigild, M., Fruergaard Astrup, T. (2019). Mapping the CDIO Syllabus to the UNESCO key competencies for sustainability. *Proceedings of the 15th International CDIO Conference*, Aarhus University, Aarhus, Denmark. (5 citations)

Malmqvist, J., **Edström, K**., & **Rosén, A**. (2020a). CDIO Standards 3.0 - Updates to the Core CDIO Standards. *Proceedings of the 16th International CDIO Conference*, hosted on-line by Chalmers University of Technology, Gothenburg, Sweden. (3 citations)

Malmqvist, J., **Edström, K**., **Rosén, A**., & Campbell, D. (2020b). Optional CDIO Standards: Sustainable Development, Simulation-Based Mathematics, Engineering Entrepreneurship, Internationalisation and Mobility. *Proceedings of the 16th International CDIO Conference*, hosted on-line by Chalmers University of Technology, Gothenburg, Sweden, June 8–11, 2020. (3 citations)

Rosén, A., Hermansson, H., Finnveden, G. & **Edström, K**. (2021). Experiences from applying the CDIO standard for sustainable development in institution-wide program evaluations. *Proceedings of the 17th International CDIO Conference*, hosted on-line by Chulalongkorn University & RMUTT, Bangkok, Thailand. (To be presented in June 2021)

c. Sources to corroborate the impact

In the recently decided long-term strategy for sustainable development at KTH (University-wide sustainability objectives 2021-2025 and climate objectives 2021-2045), the goal for education is expressed in terms of the new CDIO Standard for Sustainable Development (Malmqvist et al., 2020b; Rosén et al, 2021).

NTNU, the Norwegian University of Science and Technology, NTNU, recently launched a high-profile project Fremtidens teknologiutdanning, FTS (Technology Education of the Future). In a comprehensive process of consultation, the CDIO approach was chosen as a major underpinning concept. The report Vision and recommended principles (in Norwegian) refers to CDIO and addresses key elements such as integrated curriculum, program-driven curriculum development approach and faculty development (triple competence). It also declares a new ambition for NTNU faculty to be more active in international engineering education communities, especially in the CDIO initiative, SEFI and Nordic5Tech. Scholars from LES play leading roles in all these three networks.

While CDIO was developed for higher engineering education, it has also impacted the secondary school on the Swedish national level. When developing the 4th year for the secondary school program Technology, the Swedish National Agency for Education (Skolverket) consulted with KTH experts (Kristina Edström and Jakob Kuttenkeuler) and came to use CDIO as inspiration: Teknikprogrammet. The concept was launched in 2014 in a series of conferences featuring a keynote by Edström & Kuttenkeuler, “Ingenjörsutbildning med CDIO”, held in Skellefteå, Sundsvall, Västerås, Norrköping, Nässjö, Skövde and Malmö.

Impact case 11. KTH Mobility Pool – Sustainable transport

Department of Machine Design (MMK)

a. Summary of impact

KTH Mobility Pool was a four-year research project at KTH Integrated Transport Research Lab funded by the Swedish Energy Agency. The project explored possibilities to replace car-based work travel with a product-service system where light electric vehicles (LEVs) were used in a shared system at two workplaces. The project was based on a transdisciplinary research approach, promoting not only interdisciplinary research between different academic disciplines, but also engaging research partners from all sectors (public, private and third sectors) in order to learn how to tackle complex sustainability issues. Several stakeholders were involved from start to end and included a municipality (Botkyrka municipality), a large corporation (IKEA), a car manufacturer (Renault), a service provider (Sunfleet), an influential NGO (Gröna Bilister), an environmental consultancy (EcoTraffik), and an interdisciplinary academic research team (KTH). Moreover, employees at the municipality and corporation where the product-service system was deployed and tested were also involved as users and thereby co-researchers.

In the KTH Mobility Pool project, a pool of LEVs was tested at two workplaces, Botkyrka municipality (with 5 vehicles) and IKEA in Älmhult (with 7 vehicles) for 6-12 months each, with the purpose of replacing the use of the fuel-powered private cars. The vehicles accommodate two people and have a range of 50-80 km depending on driving conditions. The pool had two different types of users*: 1) daytime users* who used the vehicles during workhours for meetings, errands and lunches, and these could use the vehicles for work-related activities as well as for private matters, and *2) caretakers* who drove the vehicles to and from work every weekday, and who charged the vehicles at their homes and could use the vehicles in evenings and weekends. Few of the people who registered either as caretakers or daytime users had tried electric vehicles before and none of them had tried a LEV. The project got approximately 200 people to test a LEV and thus opened their eyes to alternatives to fuel-powered cars. This trial also initiated many discussions with family members, friends, colleagues and neighbours. Since the vehicle in itself draws attention, the participants in both Botkyrka and Älmhult testified that they often had to inform approaching people about the details of the vehicle, electric vehicles in general and also about the project.

After project completion, three car-pools have been set up in municipalities on the West Coast of Sweden. The project contributed directly to new business models and additional commercial services were developed based on the caretaker model.

The project attracted a great deal of media attention, e.g. six citations in Dagens Industri, and articles in Smålandsposten, Älmhultsbladet, TV4 local news, and a Mobility conference was filmed by Utbildningsradion (Karlstad, 2019). A number of workshops were also conducted in public schools of Sweden, e.g. Bäckahagens Skola, as well as with numerous NGOs, to engage citizens in future sustainable mobility solutions. The project was also presented during a visit of the Brazilian president Dilma Rousseff at KTH in 2015.

The results from KTH Mobility Pool project, including identified barriers and opportunities for the development of sustainable mobility solutions, have spread to further debate and evolved into new research projects. The project played a major role in the debate about the energy efficiency and the weight of vehicles, where references to the project are still relevant, see for example Ny Teknik (January 2020) and Gröna bilister continuous communication, and three presentations at the conference Traffic and Environment were carried out. The project and its results have also been presented at numerous international research conferences. Furthermore, the project has influenced several other research projects at KTH following similar methodology such as Mistra SAMS living labs, Scania Go living lab, Sverige Allmännyttan living labs and Urban mobility.

b. Underpinning research

A user-centered and service design approach was used in KTH Mobility Pool to involve and engage users from the early stages of the work and throughout the whole process. This was done through setting up two living lab experiments in the two geographically different contexts and workplaces, where users lived with the prototyped design for a period of 12 months in each site. Throughout this period, all stakeholders were actively involved in the experimentation. In particular the users were actively involved by both trying the alternative service system as well as participating in different workshops where they shared their experiences before, during and after the trial while also providing feedback on the solution from their everyday life perspective.

Both the service system and the users became central to the analysis as well as the related aspects around mobility infrastructure such as charging, parking spaces, rules and regulations, and other stakeholders involved in the mobility system. The users of the vehicles were followed using interviews, questionnaires, workshops, diaries as well as measurements of driving data. The feedback of the users and the observations of the project participants were continuously monitored. In addition, numerous workshops were conducted with project stakeholders around core issues emerging from the experiment's output.

The project consisted of three main phases:
1) Preparation for field trials with concept demonstration and feasibility study with data collection.
2) Implementation of concept demonstration in two half-year stages at two test sites: IKEA Älmhult and Botkyrka municipality, with parallel data collection.
3) Analysis and synthesis of collected data as well as supplementary data collection and concept development together with the project participants.

Final report download (PDF)

Sopjani, L., Stier, J. J., Hesselgren, M., & Ritzén, S. (2020). Shared mobility services versus private car: Implications of changes in everyday life. *Journal of Cleaner Production*, *259*, 120845. Diva link 12 citations

L. Sopjani *et al.*, "Involving users and user roles in the transition to sustainable mobility systems: The case of light electric vehicle sharing in Sweden," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 71, pp. 207-221, 2019. Diva link 32 citations

D. Gürdür and L. Sopjani, "Visual Analytics to Support the Service Design for Sustainable Mobility," in *2018 IEEE Conference on Technologies for Sustainability, SusTech 2018*, 2018, pp. 84-89. Diva link 4 citations

L. Sopjani *et al.*, "Co-creation with diverse actors for sustainability innovation," in *Proceedings of the 21st International Conference on Engineering Design (ICED17), Vol. 8: Human Behaviour in Design, Vancouver, Canada, 21.-25.08.2017*, 2017. Diva link 5 citations

M. Hesselgren, H. Hasselqvist and L. Sopjani, "Design strategies for exploring and bridging: Intersections of everyday life and decision making for sustainability," in *Conference proceedings of the Design Management Academy: Research perspectives on creative intersections*, 2017, pp. 189-205. Diva link 3 citations

L. Sopjani *et al.*, "Aligning private and public domains for sustainable disruptive innovation," in *Proceedings of 17th International CINet Conference*, 2016. Diva link

L. Sopjani, J. Janhager Stier and S. Ritzén, "User involvement in disruptive innovation – A study on users of a light electric vehicle sharing system," in *Proceedings of 23rd Innovation and Product Development Management Conference*, 2016. Diva link 4 citations

Impact case 12. Increasing life expectancy in urban areas

Department of Machine Design (MMK)

a. Summary of the impact

Emissions are a drawback of the transport sector. Whilst exhaust gases from road transport are monitored and regulated by European legislation, lower concern has been regarded to emissions originating from the wear processes. For decades, the dominant source of particles in road traffic was from vehicle exhaust. However, the non–exhaust emissions, predominantly from brakes, tires, and roads, are now with the aid of our research, reported to exceed those from the exhaust of vehicle fleet. During the wear process, the contacting bodies generate airborne particles. These particles can penetrate the human body in many ways, including contact with the skin, when breathing, and when eating with potential adverse health effects. Particles smaller than 10 μm in diameter can enter the human body, and the smaller the particle size, the deeper the particle can penetrate. Concentration of particulate matter (PM) continued to exceed the EU limit and target value in large parts of Europe in 2014, for which a total of 16 % of the EU urban population was exposed to PM10 (PM fraction consisting of particles with aerodynamic diameter smaller than 10 μm) levels above the daily limit value.

We can reduce PM10 emissions from road traffic by 20% by reducing emissions from disc brake systems, and thereby increasing life expectancies in the urban regions. Every increase of 10 $\mu g/m^3$ PM10 particles increases the total mortality by 0.6% in European Cities.

Another impact in this field from the Tribology research group is studded tyre-to-road wear emissions. Here, the research group has developed patented studs that provides less particle emissions, less wear of the road and less toxic/unwanted materials. Here the impact can be described in terms of the elimination of a hazardous and a conflict material, Cobalt, in the stud. Fully implemented, a transfer to the new stud material will reduce the road wear by 50 %. As an example, a major road in Stockholm “Essingeleden” today is refurbished with new road material every eighth year due to studded tyre wear.

A third example of impact is the airborne emission factor models for train traffic in underground tunnels developed by the Tribology research group. These models are used in the development process of the Stockholm new underground system. By using better-calibrated emission factors, it has been possible to downsize the capacity of the ventilation system by 30 %.

b. Underpinning research

Through our past and ongoing EU FP7 and H2020 projects (ReBrake, LowBrasys, ECOPADS, nPETS and ECODISCS), and Trafikverkets BVFF and Railroad group projects we have come far in justifying non–exhaust sources as a large contribution to the total PM10 and PM2.5 in the air. Also, the ultrafine fraction below 100 nm from non-exhaust sources has been highlighted by the research group. The underpinning research is focused on airborne particle emissions from engine exhaust emissions as well as from wear processes in brakes, between tyre and road surface, and between wheel and rail. Both the tribology and the internal combustion engine research groups are involved in this research, often with joint PhD supervision and shared experimental infrastructure. At KTH there is a unique competence in aerosol research formed by the collaboration between the Tribology and Internal Combustion Engine research groups at the department of Machine Design and KTH Building Technology. This collaboration has developed a system approach that covers the research field from the sources of airborne particles (engine exhaust emissions and wear processes) to filtering of indoor environments and ventilation systems. Together with Karolinska Institutet (Sweden), Stockholm University (Sweden), Institute Mario Negri (Italy) and CSIC (Spain) novel research is ongoing into the health effects of particle emissions, and the development of emission factors for different transport sectors. Major research outputs from the UoA include wear processes as a contributor to airborne particles in the nucleation mode (nano sized particles down to 1 nm); work on vehicles with disc brakes which

continuously generate airborne particles due to the disc cleaning function in new electric vehicles; novel test rigs for generation of airborne particles both at lab scale and in industrial scale as disc brake dynamometers; new methods for emission factor determination; new models for particle emission modelling.

Olofsson, U., Tu, M., Nosko, O., Lyu, Y., Dizdar, S. A pin-on-disc study of airborne wear particle emissions from studded tyre on concrete road contacts, Wear, 2018, 410-411, pp. 165–172, 7 citations in Scopus

Nosko, O., Vanhanen, J., Olofsson, U Emission of 1.3–10 nm airborne particles from brake materials, Aerosol Science and Technology, 2017, 51(1), pp. 91–96, 31 citations in Scopus

Nosko, O., Olofsson, U., Effective density of airborne wear particles from car brake materials, Journal of Aerosol Science, 2017, 107, pp. 94–106, 21 citations in Scopus

Perricone, G., Alemani, M., Wahlström, J., Olofsson, U., Towards a test stand for standardized measurements of the brake emissions, Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering Volume 230(11), pp. 1521-1528, 27 citations in Scopus

c. Sources to corroborate the impact

The impacts are varied and include models for prediction of airborne particles implemented in commercial software's such as (IDA Tunnel); new low emissions cupper free pad materials for disc brakes, implemented by Brembo SPA; new low particle emissions driving strategies for trains in tunnels and at platforms; measurement strategies for particle emissions from tail pipes; and even lectures for train drivers, unions and health care representatives. An additional impact can be viewed in the service of "translation on demand" for union representatives wishing to have PhD theses translated into Swedish from English. Research results have been presented by staff in interviews for national television news programmes as well as national and international radio broadcastings. To date, around 30 daily newspapers have also presented research results from the UoA.

Some important statements of the impact are cited here:

Rickard Nilsson Research officer Stockholm public transport: *"KTH's particle emission research is a significant contributor to planning of the future traffic in Citybanan and in the planning of new deep-level underground traffic"*

Video from the PAUS project with interview with environmental officer from "Förvaltningen för utbyggd tunnelbana" (in Swedish)

Patent with Sandvik AB on material for studded tyres: Tire Studs, patent no 20203072.2-1012