The Research Council of Norway

Evaluation of Mathematics, ICT and Technology 2023-2024

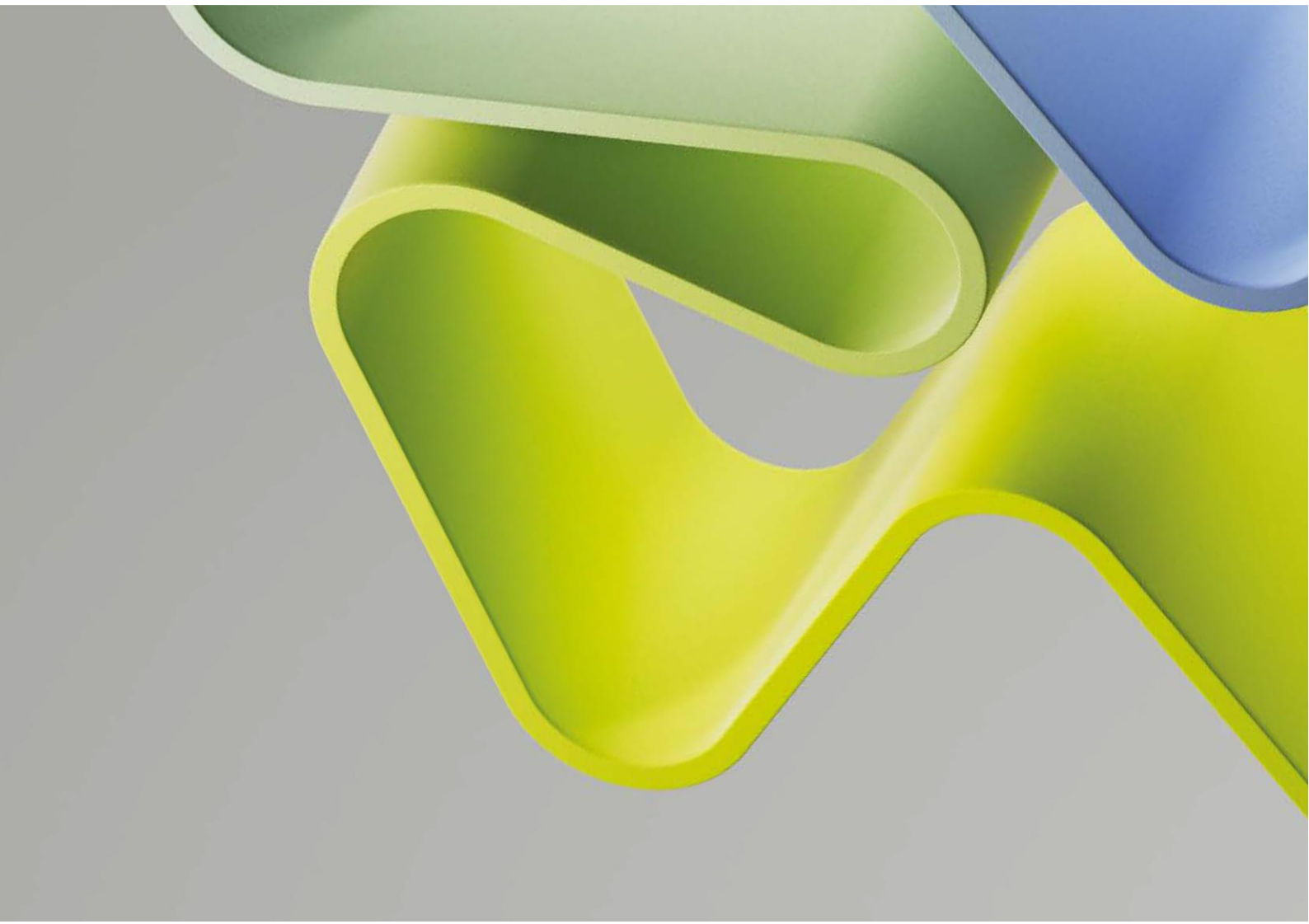
Evaluation Report for Administrative Unit

Administrative Unit: **Department of Mechanical and Industrial Engineering (MTP)**

Institution: **Norwegian University of Science and Technology (NTNU)**

Evaluation Committee Higher Education Institutions 3

December 2024



Contents

Statement from Evaluation Committee Higher Education Institutions 3

The members of this Evaluation Committee have evaluated the following administrative units at the higher education institutions/research institutes within Mathematics, ICT and Technology 2023-2024 and has submitted a report for each administrative units:

- Department of Industrial Technology, UiT The Arctic University of Norway
- Department of Electric Energy (IEL), Norwegian University of Science and Technology (NTNU)
- Department of Marine Technology (IMT), Norwegian University of Science and Technology (NTNU)
- Department of Mechanical and Industrial Engineering (MTP), Norwegian University of Science and Technology (NTNU)
- Faculty of Engineering and Natural Sciences (FIN) / Faculty of Technology, Environmental and Social Sciences (FTMS), from 1.1.2026, Western Norway University of Applied Sciences (HVL)
- Department of Mechanical, Electronic and Chemical Engineering, Oslo Metropolitan University (OsloMet)
- Faculty of Computer Science, Engineering and Economics (IIØ), Østfold University College (ØUC)
- Department of Electrical Engineering (IET), UiT The Arctic University of Norway
- Department of Technology and Safety (ITS), UiT The Arctic University of Norway
- Department of Electrical Engineering (IT) and Cybernetics (EIK), University of South-Eastern Norway (USN)
- USN School of Business, University of South-Eastern Norway (USN)
- Department of Microsystems (IMS), University of South-Eastern Norway (USN)

The conclusions and recommendations in this report are based on information from the administrative units (self-assessment), digital meetings with representatives from the administrative units, bibliometric analysis and personnel statistics from the Nordic Institute for Studies of Innovation, Research, and Education (NIFU) and Statistics Norway (SSB), and selected data from the National survey for academic staff in Norwegian higher education and the National student survey (NOKUT). The digital interviews took place in the autumn 2024. The members of the Evaluation Committee are in collective agreement with the assessments, conclusions and recommendations presented in this report. None of the committee members has declared any conflict of interest.

The Evaluation Committee has consisted of the following members:

Professor Lina Sarro,
Delft University of Technology (Chair)

Professor Stefania Bruschi,
University of Padova

Professor Khaled Ahmed,
University of Strathclyde

Professor Andreas Müller,
Johannes Kepler University Linz

Professor Maria Teresa Correia de Barros,
University of Lisbon

Professor Kostas J. Spyrou,
National Technical University of Athens

Description of the Administrative Unit

Mechanical and Industrial Engineering (MTP)

Norwegian University of Science and Technology (NTNU)

The administrative unit

MTP's research is mainly in mechanical and industrial engineering and in competitive and sustainable manufacturing. This is a large unit with 125 academic staff, of whom 21 (3 women) are full professors, 3 (1) adjunct professors, 23 (5) associate professors and 1 (0) university lecturer. There are 57 (23) PhD students employed in the department and 21 (6) researchers and post-docs. Another 40-60 students are enrolled in the PhD programme but employed elsewhere (either as *industrial PhD* or the funding expired from MTP with PhD thesis pending).

The research groups of the administrative unit

The unit comprises five research groups:

- Design, Analysis, Manufacturing & Materials (DAM)
- Robotics and Automation
- Production Management (PM)
- Project and Quality Management (PQL)
- Reliability, Accessibility, Maintenance and Safety (RAMS)

The unit's work and strategies

MTP's research goals are closely linked to the (research) strategies of the Faculty of engineering (IV) and NTNU. IV's research strategy is divided into five main strategic areas, each supported by a number of enabling technologies.

- Sustainable and reliable energy
- Green shift in the built environment
- Competitive and sustainable manufacturing
- Sustainable exploitation of mineral resources
- World-leading in the oceans and the High North

At the level of MTP, the strategy is revised annually, starting with the research groups whose proposals are then prioritised by MTP management before being committed and deployed in the research groups.

The unit's work in its sector

The unit is a major producer of engineering degrees and highly-cited research with teaching strongly based on research. It has structures in place to support innovation and technology transfer. The unit's research is deliberately applied, and the self-assessment argues that to some degree it performs functions normally performed at research institutes, such as standardisation and technology transfer.

The future of the unit

This is not discussed in the self-assessment report.

Overall Assessment

The Mechanical and Industrial Engineering (MTP) unit is a department of the Faculty of Engineering (IV) at NTNU. It is a strong department with very good research output and societal impact through industry projects, research centres and knowledge transfer. The unit has conducted internationally leading research on sustainable energy, materials and production. It is well recognised and has been a driving force in various larger national projects, for which Project Norway is a good example. It is actively involved in three national infrastructures, Manulab, Smart-H and HydroCen that provide high-quality environments for research on future manufacturing, hydrogen, and hydropower generation. The long-standing collaboration with major Norwegian companies (Sintef, Equinor, Hydro) is testimony to its research quality as well as the impact of research conducted at MTP.

MTP is organised in five research groups – Design, Analysis, Manufacturing & Materials (DAM), Robotics and Automation (RA), Production Management (PM), Project and Quality Management (QM), and Reliability, Accessibility, Maintenance and Safety (RAMS). These all perform well, though due to their different sizes the number of research outputs differs significantly among the groups. The DAM group is the largest and is subdivided into three subgroups. This subdivision does not introduce an additional formal administrative layer but is rather a consequence of the fact that the DAM group evolved as a merger of three entities that now coexist as subgroups. Although each of the five groups is well recognised in its respective research domain, it is not advantageous to have groups with very different sizes. Moreover, the three subgroups of DAM have obvious overlaps with the other four research groups. As a result of having several groups of different sizes, MTP currently runs many small and medium size projects which lead to a diverse research portfolio. The unit may find it difficult to define a long-term strategy in which a large number of such projects can be integrated.

MTP's management group has implemented a bottom-up-top-down approach to define strategic priorities for the annual planning. This allows all groups to contribute and to define PhD topics across different groups.

As an academic unit, MTP has a significant contribution to all levels of education. The unit is a major contributor to the integrated MSc programme (MTEK) at IV, which is very successful. It established novel approaches and facilities to hands-on and project-based teaching. This is a significant achievement shared with other Norwegian universities.

MTP established an integrated PhD programme to attract qualified candidates from the early stage of their study. This has also attracted PhD candidates from other universities and departments.

The gender balance is good for employees but not for students. The unit has implemented several actions to attract female students and employees (female network, direct recruitment, role model programme, restart Scholarship).

The Terms of Reference for the administrative unit is attached to the report.

Recommendations

1. It is recommended to restructure the unit along the two main pillars, Mechanical engineering and Industrial engineering, and to integrate all 7 groups. This shall not only generate synergies but also strengthen MTP's research by combining the overlapping expertise of the five groups (and the three DAM subgroups). The co-location of the groups should be helpful to this end.

2. If the unit decides not to overhaul its structure, it is recommended at least to reconsider the names of the groups. For example, the PM group's focus is mainly on logistics and supply chain management, which is only a small part of production management.
3. The PQL group is has been an initiator of Project Norway, and has taken an active role in its operation and development. This active involvement needs significant effort. The PQL group should reconsider the extent of its involvement in Project Norway in view of the large effort needed to run the project compared with the scientific output and actual impact on society.
4. The strategic planning of the unit should set topical targets for all groups. Research on hydrogen will certainly be one topic, but smaller groups should be motivated and supported to enter into new areas.
5. The department has a very solid financial situation. This should be complemented by projects funded through EU calls.
6. MTP's research groups mostly conduct applied research, helping it pursue industry projects. It should also consider how to strengthen basic research. The ERC grant obtained by the unit is a good example.
7. To sustain success in research, it is important to homogenise the research activities among researchers. It is recommended to set clear goals for individual employees to achieve high-quality research outcome from all researchers, depending on their position.
8. It is recommended to extend the outreach activities of the unit. The TrollLabs could be very helpful to attract schools and to raise interested in MTP's curricula.

1. Strategy, Resources, and Organisation of Research

The department of Mechanical and Industrial Engineering (MTP) is one of eight departments at the Faculty of Engineering (IV). It was established in 2017 by merging the Institute of Production and Quality Engineering (IPK), the Institute of Machine Design and Materials Technology, and the Institute of Physical Metallurgy (IPM). MTP pursues research in Mechanical and Industrial engineering, which are two of IVs five strategic research fields. It made substantial contributions in the field of material and production systems partly through its involvement in the MANULAB and Hydrogeni centres.

The unit is organised into five research groups that are evaluated here: Design, Analysis, Manufacturing & Materials (DAM), Robotics and Automation (RA), Production Management (PM), Project and Quality Management (PQL), and Reliability, Accessibility, Maintenance and Safety (RAMS). The DAM group is organised as three subgroups: Design and Engineering, Materials, and Manufacturing (which exists as separate subgroup since 2 years only). Thus, MTP effectively covers seven research areas spanning from engineering to management science. The five groups are of very different sizes and for historical reasons have different organisational structures. The DAM and PQL group dominate the unit to some extent compared to the RA, PM, and RAMS groups. As one consequence, the productivity and recognition of individual researchers varies significantly. The unit contributes to national infrastructures MANULAB and SMART-H (DAM group), and significantly to the Project Norway research centre (PQL group).

MTP is well-integrated in BSc and MSc programmes, in particular in the Mechanical Engineering study programme. Between 100 and 120 PhD candidates are enrolled and employed by MTP. In the last 3 years, around 75 PhDs have finished, which is at the top of

all NTNU departments. Annually, MTP funds 12-15 PhDs are from its internal budget. The unit has invested significantly in research and teaching facilities.

The funding situation of the unit is good, and MPT has invested in infrastructures such as maker spaces, multiple-use teaching rooms and meeting areas for students and employees. The main national funding sources are RCN and industry, and at an international level, the main source is the European Union. Stable funding is ensured by conducting research on a broad spectrum of areas.

MTP has produced the highest number of publications of all departments of NTNU.

1.1 Research Strategy

MTP conducts multi-disciplinarity and application-oriented in the area of material and production systems. MTP has set to become the leading academic institution for research as well as education within its field(s) in Norway as the principal strategic aim. It contributes to NTNU's strategic areas Health, Oceans, Energy and Sustainability.

MTP pursues a bottom-up process to redefine its overall strategy leading to specific actions and priorities for the coming year(s). The strategy regarding research and innovation, education, and organisation and management is revised annually. This revision process iterates from the research groups, who define recommendations, then elevates to MTPs management, and goes back to the research groups before the final prioritisations are made jointly.

Research projects within the individual groups and across the unit are quite diverse. Currently the MTP strategy is rather general while the groups have their individual plans. Some groups have a clear strategy to sustain a leading position while others seem not be coordinated along an overarching strategy, which makes it difficult to generate synergies and so to ensure long-term sustainable external financial resources for the unit as a whole.

<u>Recommendations</u> to the administrative unit.

- Given the different areas of the groups, it is important to define an overall strategy with complementary research topics allowing for generating synergies between the groups.
- It will be crucial for a healthy development of the unit that all 5+2 groups can contribute equally.
- As PQL gave up the lead position of the Project Norway, the PQL group should make use of the resources freed while capitalising on the outcome of the Project Norway.
- The leader of the unit's biggest group (DAM) is member of the IV Innovation Committee. It is important that the needs of the smaller groups are represented well and also that the expectations of the faculty are conveyed to all groups.
- Extend the investment to teaching facilities including such for digital learning (online and offline) making use of the TrollLab.

1.2 Organisation of Research

MTPs research falls mainly in two areas, Mechanical engineering research and Industrial engineering research, both of which are within IVs strategic area 'Competitive and Sustainable Manufacturing (in Norway)' and some of the cross-disciplinary areas.

The operational management of each of the five research groups is led by a research group manager. The organisation is a flat three-level hierarchy, which implies that the responsibility for the individual employee in the research group resides with the administrative head of the

unit/department. Each area is led by a research group manager who reports to the department head, who has the final authority also on HR related matters. The responsibility of the research group managers within the groups is ensuring transparency between the research group and the management, as well as to run the operational and strategic initiation and deployment activities in the group. A research group manager has authority over the operation and strategic allocation of resources. It his/her responsibility to monitor the group's research and education activity.

To reduce the workload of the department head, MTP has introduced a Deputy of education and a Deputy of research, who represent the MTP department internally and externally. The deputy of education in particular deals with matters related to teaching, internally toward the groups, and externally toward the IV faculty and the faculty's study programme.

MTP has implemented a process for handling project initiatives, in which projects are planned through an annual strategy process. Research group managers approve applications regarding resources and research strategy before they are elevated to the level of the department. The procedure includes a follow-up check against the strategic planning during the project. Each research group manager has a typical annual turnover target of 15 MNOK.

Owing to MTP's history, the research activities of the five groups span a large variety of areas. This diversity allows the unit to balance its activities and funding, in a strategic planning process across the groups in line with the MTP wide strategy. A key issue is that the DAM group comprises close to half of the institute's resources in terms of professors, full professors, and Ph.D. candidates, while the individual groups have rather different organisational structures.

Recommendations to the administrative unit.

- Despite the size of MTP, it is recommended to keep the 3-level hierarchy. The role and duties of the deputy heads of research and education should be assessed and possibly redefined.
- MTP should better define the areas of research, and how the five different groups coordinate define their strategy for research and recruitment but also for implementing consistent curricula. Joint efforts should further increase the chance to obtain EU project funding.
- MTP should think beyond the current organisational structure, which is largely driven by history, and consider restructuring. Manufacturing and automation, for instance, is a topic that is addressed by the RA but also by the Manufacturing subgroup of DAM.
- The three subgroups clustered as DAM introduce a virtual layer. It should be considered to either make them self-contained groups or to merge them organisationally.
- The organisational restructuring should establish ways to involve PhD students in research projects. The cross disciplinary nature of the unit may provide unique opportunities.
- As research on hydrogen will remain important, the unit should consider defining PhD topics in this area involving multiple groups of MTP.
- Raise the number of PhD candidates to 3 per researcher for all groups.
- As manufacturing is one of the research foci, the unit should consider extending the curriculum towards sustainable production.
- Continue to recruit group members graduating from MTPs own programmes at NTNU.

- A long-term initiative could be to cooperate with other universities to establish dual degree programmes as a means to sustain an influx of international students and eventually increase recruitment opportunities.
- The quality of (applied) research conducted at PQL is high, but the level of publications is not outstanding. PQL also has strong collaboration with industry but is only marginally involved in international projects. The unit should use the opportunity provided by Project Norway to reduce the demands on its management to devote more effort to obtaining international recognition and funding.

1.3 Research Funding

Currently, 100 MNOK out of the total annual budget of 180 MNOK is external funding. MTP received an annual average of 51 MNOK base funding from the Ministry of Education and Research during the 2018 – 2022 period. It obtained 78 MNOK from national grants (60 MNOK from RCN), 3 MNOK from contracts with industry and public sector, and 6 MNOK from international grants (4 MNOK EU funding). At present, less than 5-10 % of MTP's research is financed through EU grants. A large part (40-50 MNOK) of the research budget is used to finance PhDs, research and Post Doc positions.

MTP strategically invests to attract externally funded projects. To this end, every year, 15-20 strategy deployment actions are defined along with responsibilities and deliverables and are supervised by a management group. The annual strategy is revised in November every year. This has allowed MTP fully to finance 12-15 internal PhDs from its own funds every year. It also made it possible to invested 150MNOK in infrastructure over the past 4-5 years, providing the necessary foundation for future research. The infrastructure investments include maker spaces, flexible teaching rooms for multiple uses and social areas for students and employees.

The research funding well reflects the number of PhDs (about 25) awarded annually. Many projects are small and medium size so that MTP handles many medium scale projects with 5-10 MNOK budget that add up to a total turnover of 90-100MNOK annually, which is operationally and administratively demanding. The investment led to a publication output of 427 credits/points (in the Norwegian system) in 2022, which is the highest within NTNU.

The department obtained several fixed-term, industry sponsored professor positions (usually 5-6 years). Currently Equinor is funding two professor positions (Field Robotics, Welding and Joining) ending in 2030. These funded positions have been helpful in establishing research in new directions with industrial relevance.

<u>Recommendations</u> to the administrative unit.

- Try to consolidate some of the many small and medium size PhD projects and define larger projects to reduce the administrative overhead per PhD.
- MTP has been very successful in obtaining RCN-funded projects. Given shifting priorities in national (and international) research funding, it will be important to be resilient to reductions in income from RCN, and to align the research with future RCN foci and strategic planning.
- The percentage of EU funding in the overall budget should be increased. This will require strategic partnerships with international collaborators. The unit should exploit its networks to advance in this direction.
- Continue and strengthen industrial partnerships through endowed chairs.

1.4 Research Infrastructures

MTP is currently part of three national infrastructures, Manulab, Smart-H and HydroCen. 1) The Manulab infrastructure addresses digital, physical and human aspects for manufacturing research. It comprises equipment hosted by MTP and Sintef in Trondheim and Oslo, and by NTNU's IVB and IHB departments in Gjøvik and Ålesund, respectively. The infrastructure necessitated a significant in-kind investment of 20MNOK by MTP. 2) Smart-H is an infrastructure established for hydrogen research. Its close connected to MTPs nanomechanical laboratory allows generating synergies between the two. 3) HydroCen is a national infrastructure coordinated by NTNU's EPT department. Its purpose is to conduct research and education in the field of hydropower. MTPs is responsible for hosting and managing two advanced fatigue testing machines. At a local scale, the PM group operates a "Logistics 4.0 lab", which is unique in Norway.

The department uses international infrastructure through PhD and projects that are carried out at international institutions. The department is not currently involved in European ESFRI infrastructures.

Recommendations to administrative unit.

- Participation and involvement in national infrastructures seems rather imbalanced. DAM's involvement in Manulab and Smart-H is clearly justified by its research areas, but it is important to provide substantial infrastructure to all groups, including the smaller ones. This may involve realigning research strategies of the groups so to benefit from existing infrastructures.
- Try to bundle resources allocated to smaller projects that have similar demands for equipment and permanent staff.
- If the department deems this advantageous, it should consider ways to participate in ESFRI infrastructure projects.

1.5 National and international collaboration

MTP has track record of collaboration projects with national and international partners. These are mainly in the areas of mechanical and manufacturing engineering, production engineering and management, hydrogen and energy, maritime and subsea technology, production management and logistics. Several projects are with large Norwegian companies, e.g. Sintef, Equinor, Hydro. These projects facilitate knowledge transfer from research to industry. Several industrially funded professorships were established, which is also a means to pursue joint research.

MTP is also involved in several centres for Environment-friendly Energy Research (FME), (e.g. Hydrogeni) and Centres for Research Based Innovation (CRI), as well as in multiple national PhD research schools (e.g. Complex Systems). These involvements were important for establishing research at the department.

The department is member of several Marie Currie actions and student exchange networks. The department conducts joint PhD projects with renowned international institutions, e.g. CERN, Texas AM, Kyoto University, Politecnico di Milano, Stanford University, Tampere University, University Bologna, Denmark's Technical University, UC Berkeley, KU Leuven. With some of these institutions, joint PhD and postdoctoral degree programmes are in place.

The department had implemented International Chair professorships with University of Padova and Stanford University, which have produced high-impact research.

Recommendations to administrative unit.

- Strengthen partnership with industry through joint research projects and research centres, especially with larger companies that foster cross-discipline research (e.g. Sintef)
- Maintain an active role in FEM and CRI centres. MTP should try to achieve a sectoral lead within these centres.
- Continue with cotutelle agreements and preform regular assessments to make ensure quality of the awarded degrees and the coherence in terms the topical alignments with the department's research strategy.
- To really profit from Marie Currie actions and PhD schools (also for recruitment purposes) requires some level of supervision. The department should make sure that sufficient resources are allocated to this.
- MTP needs to increase its visibility in EU related networks. This is important for obtaining EU funding and sustaining long term funding.

1.6 Research staff

MTP employs 2 researchers (1108), and 10 researchers (1109), of which 50% and 20% are female, respectively. It has 9 (33,3% female) PostDoc researcher, 23 (21,7% female) associate professors, 21 (14,3% female) full professors, and 3 (33,3% female) adjunct professors. There are 57 (40,3% female) PhDs directly employed by MTP through research projects (while in total there are between 100 and 120 PhD candidates enrolled in the PhD programme). MTP has a relatively good gender balance of Post Docs and PhDs. There are only a few adjunct professors (professor II), basically because they are funded by industry.

The percentage of female PhDs is around 40%. The department is active in promoting women, e.g. some of the female associate professors take an active lead as role model. It remains challenging to increase the number of female researchers because the percentage of female students is low (about 20%). Thus, recruiting international female researchers will be crucial.

MTPs research staff is of diverse nationality. The typical challenge for professors from outside Norway is the (justifiable) requirement to teach in Norwegian. All new recruits for permanent positions are required to attend language courses, if necessary.

New recruits are granted a start packages in the range of 3-4MNOK. To recruit new faculty members, and to offer long-term development plans, MTP offers a selected number of MSc students the option to pursue a PhD followed by a PostDoc contract that may eventually lead to a researcher position and possibly an associate professorship. This is also a means to attract international students. Currently 8 people are going through this process. Mentoring is offered to associate professors, and their teaching load is reduced, to support their application for promotion to full professor. The nominal teaching load is 50% and the other 50% for research.

Typically, 1-2 individuals are on sabbatical leave every year. A sabbatical is usually a whole year, which makes it difficult for the individual planning, however. As an alternative, shorter stays at international research institutions are possible through the various agreements. These usually serve to access research facilities.

Recommendations to the administrative unit

- Understand why only a few department members take a sabbatical leave. The option of taking shorter stays is certainly a good idea, but it may not serve the original purpose of a sabbatical.
- Researchers that are preforming exceptionally well could be partially released from teaching for a limited period. This could be made more formal by defining performance indicators for the time of reduced teaching.
- The Female Network and the mentoring programme are very important and should be supported particularly with the different cultures inherited by the merger that founded the department.
- The effectiveness of the integrated PhD programme in attracting qualified candidates should be reviewed. If many of the candidates recruited have an MSc degree from another university or another study programme, the integrated PhD could be restructured as a regular PhD funding scheme but with early involvement/recruitment. This could also attract international candidates.

1.7 Open Science

MTP has a data management plan intended to make data findable, accessible, interoperable and reusable (FAIR). Data can be made available in the national repository DataverseNO under a CC-BY license. It uses self-archiving (green), open access publishing (gold), and hybrid publication methods. Researchers must apply to NTNU's publication fund to cover the article processing charge for open access publications. NTNU aims to provide access to all research results, data, and learning resources to students and the public.

The IPR ownership of ideas and inventions belong to NTNU, with a few exceptions. NTNU Technology Transfer Office (TTO) handles IPR issues.

Recommendation on how to promote open science

- MTP should consider establishing an OA publication fund that allows researchers to publish in gold AO journals without the need to apply to NTNU. A list of accepted journals could be established and updated to this end.

2. Research production, quality and integrity

MTP conducts multi-disciplinary and application-oriented research. It covers a wide range of research topics within the field of mechanical and industrial engineering, and comprises five groups:

- Design, Analysis, Manufacturing & Materials (DAMM) is the largest group subdivided into three subgroups focussing respectively on i) design, analysis, and production of systems and products, ii) fatigue and fracture mechanics of composites and polymers, and tribology and surface technology, iii) manufacturing processes particularly aluminium forming.
- Robotics and Automation (RA) with focus on digital factories and Industry 4.0, and Automation and digitalisation for offshore systems.
- Production Management (PM) with focus on supply chain management, logistics and energy.
- Project and Quality Management (QM) with focus on project management in a broad sense.

- Reliability, Accessibility, Maintenance and Safety (RAMS) focussing on reliability engineering, maintenance, risk management, and social security/safety and sustainability.

MTP should exploit its breadth by establishing research projects across different research groups to generate synergies, for example in hydrogen research. The department has strategically developed laboratory facilities and infrastructure for application-oriented research in collaboration with industry.

MTP produces more papers and PhD graduates than any other department at NTNU. It wins about 2.4 MNOK of external research funding per scientific employee. Two MTP professors have obtained ERC grants, but RCN is the most important funding source. MTP professors have also been awarded highly competitive national projects, but there are few EU funded projects.

The different groups are well-positioned in their respective R&D domain. MTP is a research partner in the FME Hydrogeni centre running from 2022 to 2030. This is an important project as it will enable research in the core research area of hydrogen technology, and to produce relevant research output.

MTP follows the NTNUs Code of Ethics and guidelines for combating scientific malpractice, which are consistent with good international practice. The individual researcher has an independent responsibility to ensure that research takes place in accordance with good research practice, recognised scientific and ethical principles, and agreed internal and external frameworks. NTNU follows international guidelines for good research and ethical practice.

2.1 Research quality and integrity

Research group Design, Analysis, Manufacturing & Materials (DAM) overall assessment

The Design, Analysis, Materials and Manufacturing (DAM) research group was established in 2010 with the idea of pursuing an interdisciplinary approach connecting the three major areas Design and Engineering, Materials, and Manufacturing. The group is accordingly subdivided into 3 areas (sub-groups), each with a leader who reports directly to the head of the DAM group. The research group comprises 67 people in total, including 9 professors, 13 associate professors, 7 researchers, 7 postdocs, and 31 Ph.D. students. The group has access to state-of-the-art equipment both locally and via national infrastructure, which permits it to do strong research of an international level.

The research group has a very broad spectrum of competencies in terms of processes and materials. These are the basis for collaboration with industry and with a commitment to science shown by the number of high-budget projects and high-impact publications in peer-reviewed international journals. The external funding is rather high. Funding from industry and other private sector as well as international funding have particularly increased in 2022, whereas funding from RCN decreased. The level of funding up to 2022 is compliant with the proposed benchmark.

The number and quality of scientific publications are rather high, even there is large variation; some researchers perform very well, while others perform less. Nevertheless, given the NTNU key performance indicator (KPI) on publications and the benchmark proposed by the research group, the overall scientific performance is very good.

The societal contribution of the research group is already significant, and could be increased via more incisive dissemination actions, such as the organisation of thematic workshops and public engagement events.

Overall, the performance of the research group is very good.

Research group Robotics and Automation (RA) overall assessment

The Robotics and Automation (RA) group was established in 2012. Its research includes robotics, manufacturing, machine learning, and control systems, with key contributions in mathematical modelling, simulation, adaptive control, and water treatment schemes. Specific objectives include graduating 20 master's students annually, graduating 4 PhDs per year with high-ranking journal publications, and forming internationally significant research teams in robotic production, machine tools, and subsea control. Credible strategies have been outlined for these goals and good results have been achieved. They share their findings through international conferences and respected journals, maintaining quality comparable to other institutes. Group members participate actively in international committees such as IEEE, IFR, and NFEA, although they rarely organise workshops or serve in conference committees. The RA group has a strong network and are invited as external reviewers at prestigious universities like KU Leuven, University of Agder, Aalborg University, and Lund University. The research efforts at RA are part of national and international projects with industrial and academic partners, though specific leadership roles and contributions are sometimes unclear. The research group is well known internationally, and the quality of the scientific production is excellent. Internationalisation efforts imply participation in projects, the invitation of external researchers and the organisation of conferences, but internal and national collaborations for high-quality research deserve further confirmation by taking on the job of project coordination. The group’s collaboration with industry partners produces social and economic benefits, exemplified by the development of NOV's Anti-Sway Rotator product, improving the efficiency and safety of lifting operations. While no patents were secured, the release of a ROS node and Modelica component designs had some local impact.

Research group Production Management (PM) overall assessment

The Production Management (PM) research group was established in the late 1990s and has developed into the current team of over 15 members. The PM research group is a strong group in terms of organisation and strategy, with a clear structure and division of tasks and responsibilities. The group's strong industrial network ensures that course content remains relevant and engaging, reflecting the latest industry practices and challenges. The group is responsible for about 10-15 MNOK per year of research projects, resulting in about 30 publications per year in journals and conferences, 2-4 PhD defences per year, 25-45 master theses, several special issues in journals, conferences, industrial seminars and public speaking events. The group’s 5-year benchmark focuses on the number of PhDs graduated per year, publication points achieved, doing strategic research occupying at least 10 FTEs each year, running a major scientific conference and hosting annual strategic management workshops. Compared with the other national and international groups in this field, the PM research group is among the top ranked teams and has great potentials further to sustain this position. Overall, the current research and education portfolio is excellent, but in the area of production management, the group could face a major challenge in the future as its primary funding and focus is tending towards supply chain management, logistics and energy. In terms of societal contribution, the PM research group needs a more focused, tangible and measurable strategy. Although it has contributed well and generated societal impacts, there is no visible roadmap to tackle current and future challenges.

Research group Project and Quality Management (PQL) overall assessment

The Project and Quality Management (PQL) research group was established in 2012 following a split into two groups of a former research group at MTP. It has seven permanent staff members, 15 PhD students and one postdoctoral researcher. The quality of the research is high, but the number and level of publications are not outstanding, and neither is the involvement in international projects. Although the group members have different backgrounds, it is not very clear how they interact and participate in research projects and how they involve PhD candidates and postdoctoral researchers in their activities.

The group has developed and run the Project Norway research centre, thus establishing an important basis for industry transfer and interaction with Project Norway itself. It has developed very interesting and relevant projects at the national level, with an important societal contribution. It has also participated in the Concept research programme, through which it has secured important funding. The benchmark of the research group is very clear and includes challenging goals for project funding and adequate load balance between research, education and administrative involvement for its members while simultaneously considering ensuring the effectiveness of PhD training. The group stimulates international collaborations and networking. The group has an important role in education in several courses offered by NTNU, both at the bachelor's level and at the different masters and the PhD programmes. The activity of the group is largely focused on industry and the group prioritises its role as a consulting over its role as research entity.

Research group Reliability, Accessibility, Maintenance and Safety (RAMS) overall assessment

Research of the Reliability, Accessibility, Maintenance and Safety (RAMS) led to results that have been widely used in the offshore oil and gas industries, railway, maritime, and road transportation sectors, wind power industries, for preventing accidents and mitigating the damages of accidents, so as saving lives of employees of the relevant industries, improving well-being of employees and neighbourhood residents, protecting the community from pollution and threat. Compared with the other national and international groups in this filed, the RAMS research group has a good foundation but needs to make substantial improvements in order to achieve a recognised international standing and visibility beyond the Norwegian communities, in which RAMS researchers are mostly active. RAMS needs to improve its organisation and strategy to create a clear structure and division of tasks and responsibilities. As RAMS topics are highly relevant in society, the research and innovation strategy of the RAMS should become measurable, providing out of the box solutions with economic and societal impact in national and international level. This requires major revision of benchmarks and improvement of the research strategy. To sum up, the current research and education portfolio is promising but requires major enhancements. In terms of societal contributions, however, the PM group requires a more focused, tangible and measurable strategy. Although they have contributed well and generated societal impacts, the roadmap to tackle current and future challenges is not visible.

3. Diversity and equality

MTP obeys NTNUs development plan for gender equality and diversity 2023-2025. This implies that faculty members are asked to attend relevant meetings organised centrally by NTNU.

The percentage of female students is low (about 20%) while the percentage of female PhDs (around 40%) is acceptable. The department is active in promoting women, e.g. some of the

female associate professors take an active lead as role model. MTP has a good number of international employees with different ethnical background, which indicates that the unit is supporting to hire international faculty and also to make them stay.

4. Relevance to institutional and sectoral purposes

MTP's research is innovative and highly relevant for the institute's objectives in the sector of materials and production systems. Relevant courses are offered on a BSc, MSc, and PhD level. MTP graduates app. 200 MSc students and 70 BSc students annually. Every year 2.250 students attend MSc courses, and 320 students attend BSc courses. MTP is the major contributor to the 5-year integrated MSc programme (MTEK) at the institute.

The department offers courses for continuing education, including flexible MSc programmes intended for the industrial and public sectors. Its courses in project management have a particularly large impact due to the large number of students attending these courses.

The education is research-based, which is a unique strength of MTP. This is achieved by the requirement that all (associate) professors do teach as well as pursue research projects. The graduation of ca. 25 PhDs annually and the annual external project funding of nearly 100 MNOK is testimony. All study directions and study programmes have knowledge, competence and capability/skill goals.

MTP provides infrastructure and fosters teamwork and innovation in education and research. It hosts NAPIC, the centre for aluminium product innovation. Several innovations and companies (e.g. Seram Coatings) have emerged from research at MTP.

Students get involved via capstone projects and student competitions. MTP is responsible for a course on innovation, TMM4220 Innovation by Design Thinking, which is offered to students across different study programmes and faculties. Maker Spaces offered by MTP allow continuous engagement of students. The department supports commercialisation, startup and patenting in conjunction with NTNU's TTO.

MSc students are admitted to the research group of the main supervisor. While working on the thesis, students work in smaller subgroups with PhDs and professors.

Regarding policy development, MTP professors are involved in various standardisation initiatives. They are also involved in designing new research programmes and serve as RCN board member and in various committees. Aspects of societal transformation are addressed by MTP by providing expertise to the public sector. Regarding industrial transformation, MTP mainly contributes via research towards use of hydrogen as an energy carrier, and sustainable materials and manufacturing processes.

MTP runs an "Industrial Research School in Complex Systems" together with the University of Agder and the University of South-Eastern Norway, which allows students to work together with company partners toward an "Industrial PhD".

5. Relevance to society

Mechanical and industrial engineering are crucial pillars for the future development of Norway beyond the oil age. MTP's long-term contribution to Norwegian research and higher education is to conduct high-quality undergraduate and graduate study programmes in these areas, and to establish new ways of teaching and innovation. MTP does applied and innovation-oriented research with a close connection to industry. As the courses are research-based, they can serve to disseminate new concepts and innovations within the

society. MTP has been piloting novel ways to teach. Most significant are the integrated MSc programme (MTEK) of the institute, and the TrollLab. The latter has led to new teaching methods beyond the concept of project-based teaching and maker spaces, which are complemented by the necessary infrastructures. MTP has also been involved in projects with public sector. For example, the PQL group had PhDs funded by Trondheim municipality. Another example is a project involving the PM group and the Public Library in Trondheim.

The unit plays an important role in research on sustainable use of materials and production. Its research on novel material processing and manufacturing control is very relevant and in line with the long-term plan to address societal challenges and toward the SDGs. In this regards, MTP's active role in the multi-sectoral Project Norway has been crucial.

The unit is also active in the area of production automation but on a far smaller scale. While the quality of research and the publication outcome per researcher is sufficiently high the total volume of research output is low in particular for the RA and RAMS groups. This imbalance is due to the way the department was formed.

5.1 Impact cases

Comments on impact case 1: Seram Coating

Silicon Carbide (SiC) cannot be sprayed owing to its very high melting point. A new material was developed that does allow spraying, and a patent was filed in 2012. This material is now marketed under the name ThermaSiC by the start-up company Seram Coatings that was established in 2014. The development was initially funded in 2012 - 2014 by NTNU Discovery and FORNY2020, and later by research grants from RCN and from the EU. Additional financial support came from several innovation prizes and private investors.

This impact case is significant in its field, opens up new applications and is expected to have a significant market impact. It could also displace the use of Tungsten Carbide, with clear positive societal and environmental impacts.

Comments on impact case 2: NTNU Aluminium Product Innovation Centre (NAPIC)

NAPIC is a big research centre, collaborating with several institutions. It was founded in 2017 aiming to become a world leader in research-driven innovation for aluminium production. More than 20 research projects were conducted, more than 30 PhD/Postdocs were educated, and over 100 MSc students have been involved across different NTNU departments. NAPIC's research contributes to reducing costs and energy consumption, a reduced CO2e footprint, and improved product quality. NAPIC has contributed to realise low-maintenance bridges (Hangar-bridge), an all-aluminium battery for high-speed electric ferries (Medstraum), more efficient electric conductors for battery systems (Corcus busbars), flexible tooling for advanced metal forming processes in the automotive industry (Benteler), low CO2 bridge utilising clay-based concrete with post-consumer aluminium reinforcement (Grødøla), high stability roller-skis (IDT Solutions) etc. The DAM research group is involved in the centre contributing to alloy development, compensation metallurgy, through-process modelling as well as innovations allowing for material substitution.

The impact case has a clear impact to industrial development and environment in line with sustainability goals, such as the European Aluminium Industry's Sustainability Roadmap, towards reduced emissions and infrastructure costs.

Comments on impact case 3: Project Norge (Project Norway)

Project Norway is a permanent research centre established in 1999 and run by MTP. It has a funding of approximately 5 million NOK per year that is coming directly from the eight Norwegian universities and two research institutes involved. A large portfolio of research projects is running in parallel based on proposals from industrial partners from the public and private sector or research partners. The research projects have produced a combination of academic papers, research reports, master and PhD theses, popular-scientific reports, specific new processes, tools, etc. As a consequence, Project Norway has produced a large volume of practically-oriented research reports, many containing new processes, models, and other recommendations. They were adopted by enterprise partners on a large scale and had high impact on the development and execution of large and small projects across multiple sectors in Norway. Outcome of the projects are recommendation for industrial practice at large. The PQL group is contributing to this project with two professors and four associate professors.

Project Norway has a clear positive impact on the Norwegian industry and society. As a multidisciplinary project it has contributed to rather diverse sectors and on technical as well administrative levels. Its importance can be seen in the fact that it can deliver objective recommendations on a sectoral level from a variety of independent academic institutions.

Comments on impact case 4: Knuckle Boom Crane Payload Motion Compensation

A novel algorithm for damping undesired pendulum motion of knuckle boom crane payloads was developed in project conducted at the RA group in 2015-2019. This technology has been integrated into the commercial Anti-Sway Rotator product of the National Oilwell Varco (NOV) company. This has significantly enhanced the efficiency and safety of lifting operations, while also reducing operational costs. The technology has been adopted by industry leaders such as National Oilwell Varco and Transocean, showcasing its practical application and impact in real-world scenarios.

The impact is clear given the immediate applicability and the availability in the Anti-Sway Rotator framework of NOV. It is a good example of knowledge transfer that also led to six journal publications.

Comments on impact case 5: TrollLabs Innovation Case

From 2014 to 2018, RCN funded the TrollLABS project conducted by the DAM group. The aim was first to review established concepts of extreme prototyping, maker spaces, project/problem-based teaching and design thinking, and then to define new concepts for stimulating and organising design and engineering processes enabling extremely rapid exploration, prototyping and testing of novel technical ideas and concepts, spanning all problem relevant disciplines such as ME, CS, material, mechatronics, control systems, signal analysis etc. This project laid the foundation for a new ‘maker focused’ teaching approach at MTP and other labs at various other NTNU faculties, other global partners and in industry. TrollLABS has become a centre for conducting and researching experimental prototyping projects. Based on the results and insights gained, the department has in 2020-2022 invested substantial infrastructure funds in creating the most advanced and inclusive maker space student infrastructure at NTNU, which is the impact case considered here.

The TrollLabs project along with the subsequent investments into physical space and teaching programme has a significant impact on teaching university students as well as public outreach. It also resulted in a few startups and patents.

Methods and limitations

Methods

The evaluation is based on documentary evidence and online interviews with the representatives of Administrative Unit.

The documentary inputs to the evaluation were:

- Evaluation Protocol that guided the process
- Terms of Reference
- Administrative Unit’s self-assessment report
- Administrative Unit’s impact cases
- Administrative Unit’s research groups evaluation reports
- Bibliometric data
- Personnel and funding data
- Data from Norwegian student and teacher surveys (only for HEI’s)

After the documentary review, the Committee held a meeting and discussed an initial assessment against the assessment criteria and defined questions for the interview with the Administrative Unit. The Committee shared the interview questions with the Administrative Unit at least two weeks before the interview.

Following the documentary review, the Committee interviewed the Administrative Unit in an hour-long virtual meeting to fact-check the Committee’s understanding and refine perceptions. The Administrative Unit presented answers to the Committee's questions and addressed other follow-up questions.

After the online interview, the Committee attended the final meeting to review the initial assessment in light of the interview and make any final adjustments.

A one-page summary of the Administrative Unit was developed based on the information from the self-assessment, the research group’s evaluation reports, and the interview. The Administrative Unit had the opportunity to fact-check this summary. The Administrative Unit approved the summary with minor adjustments.

Limitations

The Committee judged that the Administrative Unit self-assessment report was insufficient to assess all evaluation criteria fully. However, the interview with the Administrative Unit filled gaps in the Committee's understanding, and the information was sufficient to complete the evaluation.

List of administrative unit's research groups

Institution	Administrative Unit	Research Groups
NTNU	Department of Mechanical and Industrial Engineering	Robotics and Automation, RA
		Reliability, Availability, Maintainability and Safety (RAMS)
		Design, Analysis, Materials Manufacturing (DAM)
		Project and Quality Management (PQL)
		Production Management (PM)

Terms of Reference (ToR) for the administrative unit

The board of the Faculty of Engineering, Norwegian University of Science and Technology (NTNU) mandates the evaluation committee appointed by the Research Council of Norway (RCN) to assess Department of Mechanical and Industrial Engineering (MTP) based on the following Terms of Reference.

Assessment

You are asked to assess the organisation, quality and diversity of research conducted by Department of Mechanical and Industrial Engineering (MTP) as well as its relevance to institutional and sectoral purposes, and to society at large. You should do so by judging the unit's performance based on the following five assessment criteria (a. to e.). Be sure to take current international trends and developments in science and society into account in your analysis.

a) Strategy, resources and organisation

b) Research production, quality and integrity

c) Diversity and equality

d) Relevance to institutional and sectoral purposes

e) Relevance to society

For a description of these criteria, see Chapter 2 of *the Mathematics, ICT and technology evaluation* protocol. Please provide a written assessment for each of the five criteria. Please also provide recommendations for improvement. We ask you to pay special attention to the following 5 aspects in your assessment:

1. As a department under NTNU's Faculty of Engineering, MTP follows common strategic goals and priorities from both a faculty level and centrally at NTNU, as well as on a departmental level. Relevant strategic documentation from NTNU has been listed under "Documentation". A revision of the Faculty of Engineering's Strategy Plan was completed in 2023, and made valid for the period 2018-2025, see link at page 3. The updates will come to show in the faculty main strategy.
2. MTP is responsible for two classical research domains in engineering science and education: Mechanical Engineering; and Industrial Engineering. These two domains are operationally organized into seven (sub)research groups, in which each has an appointed group leader, being part of MTPs operational management group and the extended management group. Due to the importance of research in the strategy of the department, the institute head has the dual function as 'head of research'. Three of the research (sub)groups belong to the field *Mechanical* (Engineering Design, Materials, Manufacturing), which will be denoted DAM, and requested assessed as one research unit/group. This is for the most part identical to the organization reviewed last time by RCN. Three research (sub)groups belong to the field *Industrial*, including Production Management and Logistics (PML), Project and Quality Management (PQM), and Reliability, Availability, Maintenance and Safety (RAMS). The last research (sub)group, Robotics and Automation (RA), falls research-wise and operationally between the two main domains. Overall, the MTP research (sub)groups operate, among others, within engineering science, natural science, management science, ICT, technology and manufacturing/industrial science.
3. MTP is a relatively new administrative unit. It was formally established in 2017, after the merger of two former NTNU departments (formerly known as the Dept. of Product

Engineering and Materials (IPM) and the Dept. of Production Management and Quality (IPK)), and a governmental-initiated merger with Dept. of Mechanical Engineering of a university college (HIST) in Trondheim. Physical co-localization of the department was later implemented in two steps; first the integration of HIST (2018) and then the integration of IPK (completed 2022). The latter has involved significant remodelling and upgrading of the entire infrastructure, including laboratories, and has been managed and (mostly) financed by the department. MTP has conducting substantial upgrades of research and teaching infrastructure, as well as work environment for employees and students, and appears today as one of the most up-to-date ones at NTNU.

4. As mentioned above, partly due to history, the research activities of the (sub)group covers a vast array of fields, spanning from natural science (material) to management science. This obviously leverages departmental robustness in terms of international and industrial networks, as well as balancing between downturns and upturns in different sectors, both industrial and academic ones. At the same time, this means that viable research strategies must be deployed down to the (sub) group level, and with this follows significant responsibilities on each research group. Therefore, to comply with the organization of the evaluation panels and the history, including the previous RCN assessment, MTP requests that the assessment is conducted with five full research groups/research units, including DAM, RA, PML, PQM and RAMS.
5. MTP means that some groups still do not fit well within the predefined categories of the panel. Therefore, we ask to consider this fact carefully in assigning panels and during the course of the assessment.

In addition, we would like your report to provide a qualitative assessment of Dept. of Mechanical and Industrial Engineering as a whole in relation to its strategic targets. The committee assesses the strategy that the administrative unit intends to pursue in the years ahead and the extent to which it will be capable of meeting its targets for research and society during this period based on available resources and competence. The committee is also invited to make recommendations concerning these two subjects.

Documentation

The necessary documentation will be made available by the mathematics, ICT and technology secretariat at Technopolis Group.

The documents will include the following:

- a report on research personnel and publications within mathematics, ICT and technology commissioned by RCN
- a self-assessment based on a template provided by the mathematics, ICT and technology secretariat
- strategic plans of relevance from NTNU and its Faculty of Engineering, (hyperlinks to NTNU-sites included): o NTNUs main strategy 2018-2025 (e)
    - NTNUs development agreement with the ministry 2023-2025 (n)
    - NTNUs wider contribution to innovation, (n)
    - NTNUs international development plan 2023-2025 (e)
    - NTNUs development plan for open science 2023-2025 (e)
    - NTNUs development plan for gender equality and diversity 2023-2025 (e)
    - Faculty of engineering main strategy 2018-2025 (n)
    - Faculty of engineering research strategy 2018-2022 (e)
    - NTNUs periodic plan 2023-2026 (n)
    - Faculty of engineering periodic plan 2023 – 2026 (n)

Interviews with representatives from the evaluated units

Interviews with the Dept. of Mechanical and Industrial Engineering will be organised by the evaluation secretariat. Such interviews can be organised as a site visit, in another specified location in Norway or as a video conference.

Statement on impartiality and confidence

The assessment should be carried out in accordance with the *Regulations on Impartiality and Confidence in the Research Council of Norway*. A statement on the impartiality of the committee members has been recorded by the RCN as a part of the appointment process. The impartiality and confidence of committee and panel members should be confirmed when evaluation data from the Dept of Mechanical and Industrial Engineering are made available to the committee and the panels, and before any assessments are made based on these data. The RCN should be notified if questions concerning impartiality and confidence are raised by committee members during the evaluation process.

Assessment report

We ask you to report your findings in an assessment report drawn up in accordance with a format specified by the mathematics, ICT and technology secretariat. The committee may suggest adjustments to this format at its first meeting. A draft report should be sent to the the Dept. of Mechanical and Industrial Engineering and RCN. The Dept of Mechanical and Industrial Engineering should be allowed to check the report for factual inaccuracies; if such inaccuracies are found, they should be reported to the mathematics, ICT and technology secretariat within the deadline given by the secretariat. After the committee has made the amendments judged necessary, a corrected version of the assessment report should be sent to the Faculty of Engineering, NTNU and the RCN no later than two weeks after all feedback on inaccuracies has been received from the department of Mechanical and industrial Engineering

Appendices

1. Description of the evaluation of EVALMIT
2. Invitation letter to the administrative unit including address list
3. Evaluation protocol
4. Template of self-assessment for administrative unit (short-version)

The Research Council of Norway

Norges forskningsråd
Besøksadresse: Drammensveien 288
Postboks 564
1327 Lysaker

Telefon: 22 03 70 00

post@forskningsradet.no
www.forskningsradet.no

Publikasjonen kan lastes ned fra
www.forskningsradet.no/publikasjoner

Design: [design]
Foto/ill. omslagsside: [fotokreditt]

ISBN 978-82-12-04162-2 (pdf)