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THE SWEDISH
Manufacturing
R&D Clusters

Swedish Manufacturing R&D Challenges towards 2040

- Continuity and change, requirements for global competitiveness

Edited by the management group of
the Swedish Manufacturing R&D Clusters:
Ulrika Brohede, Anna Davidsson & Lorenzo Daghini, Scania CV AB
Alf Andersson, Volvo Cars
Lena Moestam & Johan Svenningstorp, Volvo Group
Peter Bryntesson, FKG
Boel Wadman, RISE

Table of content

THE SWEDISH **Manufacturing R&D Clusters**

1 Introduction

The aim of this document is to give a description of the common need for future production research within Sweden. The document is strongly influenced from the agenda of the vehicle manufacturing sector, but with the ambition to include challenges from all companies with production in Sweden. It is compiled by the Swedish Manufacturing R&D Clusters, and this is the 10th edition of the document. The document is intended as an inspirational roadmap for manufacturing innovation and is open to be shared and implemented for example in education, strategies, and R&D projects.

1.1 *Background*

The Swedish Manufacturing R&D Clusters is an organization that was initiated in 2006 by the vehicle manufacturers in Sweden and the automotive supplier's group FKG. Initially, the aim of the clusters was to identify common areas for research initiatives that would strengthen the competitiveness of vehicle manufacturers and their suppliers in Sweden. Today, the scope is widened to include all manufacturing companies with production in Sweden.

The goal of the Swedish Manufacturing R&D Clusters is to develop environmentally, socially, and financially sustainable manufacturing systems capable of delivering future innovative products to the market. By this we strengthen Sweden's ongoing success as a sustainable industry nation.

After nearly twenty years of collaboration, the Swedish Manufacturing R&D Clusters have established a solid foundation for new research and innovation initiatives within manufacturing R&D. As Sweden's R&D resources are relatively limited, it is important that the resources are used efficiently. The cluster work serves as a means to join forces in areas of shared interest.

The cluster organization is a network of experts in manufacturing technology and processes from industry, research institutes, and academia. The cluster structure has evolved over time, and today there are eight clusters focusing on different manufacturing expert areas, see Figure 1. Four of the clusters cover manufacturing processes and four clusters cover areas that support manufacturing processes. The clusters are coordinated by a management group and are supported by a strategy board.

Each cluster is led by a chairperson from industry, supported by a coordinator from RISE. Since 2020, RISE has been assigned to coordinate the clusters, with added funds from the member program IVF Intresseförening Service AB.

The now eight clusters are continuously reviewing the industry relevant research needs in each specific area and initiate collaborative projects to fill the identified technology and knowledge gaps. The research needs described in this document are based on business intelligence and strategic discussions within the clusters.

The cluster organization is open to all manufacturing-related initiatives aiming at strengthening and developing the sustainability and the competitiveness of the manufacturing industry in Sweden, and all companies are welcome to learn from each other and to work together in the clusters.

Figure 1. Cluster structure.

By participating in a cluster, the following advantages can be gained:

- Insight into other industries' and companies' interests and ongoing production research
- Early information and invitations to participate in planned research and innovation projects
- Knowledge of project results through the cluster network
- Business intelligence and state of the art through other members of the network
- Opportunities to influence Swedish and international research agendas and calls
- Competence development
- Networking

More information, and this document, can be found on the Swedish Manufacturing R&D Clusters homepage **Sveriges produktionskluster—Kunskapsförmedlingen**

2 Overarching manufacturing systems R&D needs

The manufacturing industry has ambitious visions to meet the environmental and climate challenges, often anticipating new regulations for greatly reduced emissions. The visions include reducing the carbon dioxide emissions to 50% by 2030, fossil-free products and processes, 100% circularity, and zero emissions throughout the entire life cycle of the product. Many of these objectives are to be met already during the next decade. The visions encompass the entire industrial value chain, which accounts for a large part of Sweden's emissions of greenhouse gases.

The demands on minimizing the environmental footprint have led to vast investments in electrification and lightweight design, as well as in electrification of the manufacturing processes, fossil-free and biobased materials, and green electronic components.

Another strong trend is the development of digitalization of our products, services, and manufacturing systems. Here automation, sensor solutions and digitalization are utilized to improve our way of working. This influences manufacturing both by adding new components and by new enablers improving the quality and efficiency of the manufacturing system itself.

To be in the forefront, the production systems in Swedish industry need to be resilient and sustainable. New competences are required and the industry's ability to effectively organize the knowledge management is constantly being challenged. As we move towards a circular economy new partnership and collaboration models are expected. Strong relationships, new competences, solution-oriented development collaborations among partners, and data availability and transparency in the entire value network are notified as enablers for this transformation.

These trends and challenges will undoubtedly have a big impact on future manufacturing systems. Adaptability, with sustained and improved performance, will be crucial for success. In this document we highlight the challenges for globally competitive production in four main themes:

- Circular and resource efficient manufacturing
- Production methods meeting new products, functions, or features
- Digital continuity in the industrial eco-system
- Resilience and competence

2.1 *Circular and resource efficient manufacturing*

In the manufacturing industry there are rising demands connected to environmental sustainability and the development towards a circular economy. During the last years, fossil free production has become a target for many companies and the awareness of CO^2 emissions from different manufacturing processes has grown. Work to reduce the climate related gas emissions are on-going, but much more effort is needed to reach the Paris Agreement on climate targets.

One consequence of the development towards independence of fossil energy is the electrification of transports and manufacturing systems. The availability of electrical energy is then becoming a key issue. In just a few years' time a shortage of electricity is foreseen in many parts of Sweden as an effect of development needs of the infrastructure of energy distribution in combination of accelerating increased demands for electricity. And, even if the society in the future will be able to produce all the electricity needed, there are many reasons to be mindful when it comes to energy consumption in manufacturing systems.

The demands on sustainability in industry is pushed also in the financial system. As part of the efforts connected to the Green Deal objectives, the European Commission has developed a taxonomy to support green or sustainable investments. It is a standardized system aiming to create transparent reporting on environmental footprint of products and the connected manufacturing system. The first steps of implementing the EU taxonomy have been taken and the big companies have just started to see the effects of this. As we move further in time also smaller companies will need to adopt to this standard. At the time being, the EU taxonomy is focusing on climate related emissions, but further development is to be expected. The ambition for this taxonomy is that it will cover the full span of circular economy as well as protection and restoration of biodiversity and ecosystems.

Resource efficiency is somewhat of a traditional backbone of manufacturing engineering. However, views on what resources to prioritize will shift over time. The move towards a circular economy is anticipated to have a quite radical effect on the whole production system. As the global resources are limited, the use of primary materials will decrease and reuse, repair, refurbish, and remanufacturing activities are foreseen to grow significantly. The effects in the manufacturing systems are yet to be seen, but this is most certainly an area where the manufacturing engineering community has a large potential to drive change and innovation.

2.2 *Production methods meeting new products, functions, or features*

New customer values and ensuing mobility patterns meeting the climate goals will have a large impact on the business models and on the products and components to be produced. The introduction of new products and manufacturing processes will demand higher integration between design, purchasing and manufacturing departments. New preconditions such as supply chain disruptions will also influence the production system organization, to assure resilience in several scenarios.

High volume production of e-mobility components, such as transmission components with high surface demands will exist in parallel with flexible manufacturing, disassembly, and remanufacturing of used components.

New product and component types will demand increased integration between design, modelling, and production, as well as purchasing departments. Early decisions on design or process will affect the entire value chain to a larger extent, for example when casting large thin-walled parts or when integrating intelligence and services in components. Upscaling of new components: batteries, electrical motors, and inverters, will increase the complexity of the production site, which encompasses both process-industry activities and discrete manufacturing. The resulting higher inclusion of microelectronics and software in component systems will demand higher focus on software and sensor quality assurance and increase the need of clean production environments.

2.2.1 Battery manufacturing "Cell to Pack": Current and Future state

The main steps in the battery manufacturing chain are:

- Mining and Refining
- Materials production
- Cell production
- Battery production
- Vehicle production
- *Vehicle utilization*
- Recycling.

In this chain, the "Battery production" step covers several operations, from a supplied battery cell to a ready-made battery pack, transported and assembled into a vehicle.
For the "Battery production" cell to pack, a cluster theme has been established. Based on dialogues with all clusters about the cell to pack current state to a future production state, a number of challenges and R&D needs have been identified. The following is a structure of these:

Cell to pack manufacturing operations. From the supplied battery cells, operations are made like pretreatment, adhesive bonding, mechanical bonding, assembly into modules and/or directly into a battery pack box, assembly of bus bars, cables, box cover etc. Then transport of the battery pack for assembly and installation in a vehicle.
Challenges and R&D needs: E g health and safety for adhesives, fluids and lasers, restart of adhesive operations when interrupted, quality secured screw connection for soft materials. The combination of high speed and high precision in cell handling and assembly.

Manufacturing and supply of components. Like module boxes, bus bars, cables, connections, battery management system, cooling system, tray box with cover, screws.
Challenges and R&D needs: Are related to mechanical workshops capabilities now and in future, to produce components in the right material and with the right quality. Key words are efficiency, resilience and zero emissions. Both in house and in value chains/networks. E g forming and joining the tray box or parts of it, which can be made of steel, aluminium or polymers/composites.

Manufacturing of various designed battery cells and packs. Specific variables are the shape, size and characteristics of the battery cells, the design of the battery pack, with or without modules, design for circularity and future scenarios like battery cells to chassis.
Challenges and R&D needs: To design and prepare the manufacturing system and manufacturing cells for future battery designs and material flexibility.

Industry 5.0 perspectives. This means human-centric, resilient and sustainable. Key areas to apply in the cell to pack flow are agility, reduced cost, adapted education and training, empowered workers, system view on ergonomics and safety, digitalization, AI and robotics.
Challenges and R&D needs: To understand flexibility and agility demands for man, technology and organization on the cell to pack manufacturing flow: i) from a change of design perspective ii) from a change of production volumes, number to produce, perspective.

Test- and demo resources cell to pack. Pre-industrial evaluation, process qualification, education and training will be needed in many process steps. Drivers will be g be battery cell developments, new design of battery packs for circularity, changed or mixed use of materials, new joining techniques, needs for quality assurance etc.
Challenges and R&D needs: Define the actual and coming needs for test- and demo resources and competences in cell to pack manufacturing. Establish the resources in time. Examples are joining methods of newly designed products and smart disassembly processes.

2.3 *Digital continuity in the industrial eco-system*

Advanced digitalization in the manufacturing system is partly implemented in many large industrial companies. Today, however, much manual work in the product and service development is spent to rebuild data lost between functions and organizations. There still exists many mundane tasks that are well suited to be automated. Also, within the supply chain, the future supply loop, data is not transparent enough and the digital tread is broken, generating waste. Ensuring continuity within and between collaborating organizations is important, while maintaining high cyber and information security standards.

Short lead-times and efficient production systems are dependent on standardized digital connection between design, engineering, and operations with a detail level relevant for quality assurance. Traceability during the entire life cycle of the product and the production system will be important when the new Digital Product Passports are launched, including the value chains of materials and resources needed for manufacturing.

Cognitive aspects need to be considered related to automation and IT-development. Support from AI and machine learning can both improve prerequisites for advanced decision making and decrease unhealthy, dirty, dangerous, and under-stimulating working environments.

2.4 *Resilience and competence*

Based on future challenges and forecasts, manufacturing industries in a fast-moving environment need strategic, tactical, and operative approaches considering sustainability and resilient perspectives. Here, innovations, new competences, and good working conditions are essential elements. Manufacturing systems with a daily output of complex products constitute significant evidence of the human ability to organize. A multitude of influencing aspects need to be considered in parallel, and utilization of built-up knowledge and new knowledge creation are at the very core of these operations. To build a high-performing organization, a safe and healthy work environment incorporating inclusiveness and diversity is today seen as fundamental for long-term success.

Combined with the ability to sustainably manufacture products with increased change frequency, there is a need that production systems can manage changed business conditions in a resilient way. To meet the quickly changing demands requires an ability to not only to maintain the manufacturing system´s function before, during and after major changes, but also to have an ability to take advantage of new opportunities and emerge stronger after a crisis or major challenge. Thus, adaptability and a high ability for organizations to be agile and resilient is crucial. This became very evident during the Covid-19 pandemic and the supply chain challenges that followed. To have management strategies to be (and stay) agile and manage shifting competence needs and uncertainties and keep learning during changes is thus of vital essence.

How to create industrial ecosystems, for example for electrified vehicles and the batteries in specific, is very much discussed today. The notion of eco-system in this context is used to point out the need to build networks/systems with a wide range of partners and stakeholders where all involved organizations can contribute to finding ways to achieve truly circular value flows. To make this happen requires the partners to loosen up from current boundaries and identify the shared overarching mission and then support each other to find the role and business opportunities for each partner. In the end, the system must be effective, efficient, and flexible to become resilient and sustainable.

Some of the currently burning topics in the industry are lack of competence in automation, digitalization, artificial intelligence, and data analytics. Other urgent areas where competence needs to grow are environmental performance and how to transform to circular economy systems. Within these areas increased competence is needed broadly and integrated among all functions in organizations. Management competences also need to be developed to grow the ability to handle complexity and conflicting demands.

2.5 *Continuity and change – requirements for global competitiveness*

The public funding made possible by research programs such as FFI, Produktion2030, and H2020/Horizon Europe has been of vital importance in building up the project portfolio initiated in the clusters. By active collaboration between companies, public agencies, research institutes, and academic partners many high impact projects have been executed. Experience has been gained on how to collaborate and provide consistent input to R&D programs of relevance for the manufacturing industry. The Swedish Manufacturing R&D clusters' ambition is to secure continuity in the manufacturing R&D eco-system, regardless the source of funding. Some important aspects to consider are:

Swedish R&D competitiveness
The Swedish manufacturing companies, including the automotive industry (OEMs and their Swedish part and system suppliers) act in a highly competitive global market. To assure the development of

local competence and attract new talents, it is of equal significance that their Swedish R&D partners are globally competitive.

Collaboration and trust

The cluster cooperation has provided continuity within manufacturing R&D collaboration in specific areas of high relevance to industry. The non-competitive collaboration between companies has resulted in shared knowledge from projects with partners of the entire value chain. The clusters develop R&D strategy and project roadmaps, and by sharing the visions between cluster members the possibility increases for achieving common missions.

Knowledge & technology transfer

It has been beneficial that the R&D-projects have enabled the generation of education and training material to be used in industry and in education at different levels, starting from High School and reaching to PhD student level and life-long learning. State-of-the-art knowledge from recent manufacturing projects is demanded by the industry and may also motivate students to choose a Production Engineering education.

Continuity and long-term strategy

In manufacturing research, that often needs technical and research infrastructures, it takes time to build productive research environments and to achieve innovation. For this reason, it is beneficial with continuity in the organization and conditions for public funding. The cluster organization that develops R&D strategies and roadmaps provides a channel for industry input to new R&D programs, both nationally and internationally.

R&D and Technology infrastructure

To ensure an efficient use of resources the manufacturing companies of the clusters have an ongoing dialogue with universities, institutes, relevant networks, and organizations, such as the Swedish Production Academy, and competence centres etc. Demand driven industrial applied science can very often be combined with basic research and Ph.D. studies, as well as education and the science outreach mission of universities. The purpose with this dialogue is to decide how we should proceed jointly to build up a critical mass, avoiding duplication, to strengthen and further develop the existing competences and technology infrastructures that increase the global competitiveness of the universities and institutes.

3 Cluster specific R&D needs

In the following section, the cluster specific research & development needs are defined. For each cluster, it is described which technology areas the specific cluster area is connected to.

Further, the clusters prioritized R&D areas are described in terms of:

- Aim and Vision
- R&D Area description
- Identified R&D topics
- Wanted effects

Project ideas and project roadmaps addressing these R&D needs are continuously defined and updated by the clusters. Please contact the specific cluster of interest to you if you need more information. The coordinators and chairpersons of the cluster can be reached at www.produktionskluster.se.

3.1 *Component Manufacture*

The component-manufacturing cluster is devoted to advancing the manufacture of engineering components, mainly in metals, in a circular and resource efficient way. Focus is on development of sustainable, effective, flexible, and robust processing techniques used in manufacturing components, materials, tools, and machines. To this end coverage is given to a range of subjects from process and production planning to quality assurance.

Component manufacturing covers a range of technology areas that includes high performing materials, machining processes, casting processes, surface and heat treatment, additive manufacturing, quality assurance and evaluation, manufacturing tools, process fluids, process planning, non-conventional manufacturing technologies and remanufacturing for circular economy.

Prioritized R&D areas for the Component Manufacturing cluster:

1. Human
2. Line
3. Machine/Equipment
4. Tools and process planning
5. Process.

3.1.1 Human

Aim and Vision

Humans and manufacturing systems should be in balance. Humans need appropriate skills acquired through education and professional training. Every R&D-project should provide education and technology-transfer learning materials to be shared by academy and industry.

R&D Area description

The manufacturing systems need to be designed according to the humans' needs and skills.

We need updated knowledge transfer and educational/training materials about processes, new manufacturing methods, manufacturing equipment and systems for continuous improvement of competence and skills but also for re-training of personnel in case of technology shifts.

Identified R&D topics

- Knowledge transfer from R&D projects to the offices and workshops in industry as well as to schools and universities
- Human-adapted process environment in operation, set-up work, inspection, service, and maintenance.

Wanted effects

- Guidelines and demonstrators on how to design human friendly systems for component manufacture
- Cost-effective and up-to-date educational/training material for prioritized areas.

3.1.2 Line

Aim and Vision
Faster and more efficient development of sustainable production lines and processes with the ability to handle an increased number of variants and new types of products.

R&D Area description
For new products and fluctuating product volumes we need to be able to quickly change capacity and products with improved or maintained sustainability. The risk for investments in wrong technologies will increase and result in huge economic and resource waste. New powertrains with downsized combustion engines for alternative fuels and components for hybrid or electric powertrains must be manufactured in a sustainable way. We need better methods and tools for development and installation of the future production lines.

Identified R&D topics
- Develop technology, knowledge, and resources for new needs. Definition of principles for factories manufacturing a mix of components for electric and combustion engines.
- Demands of sustainability, robustness, and flexibility of new and existing production lines and processes
- Design of efficient production lines / product flow (e.g. type Lean Plant Design)
- Modular and reconfigurable production lines, flexible component fixtures
- Development of production prerequisites for electrical powertrains
- Flexible and cost-efficient line concept for entire product life cycle, including ramp-up and phase out.

Wanted effects
- Sustainable manufacturing with reduced CO^2-footprint
- Lead time to purchase and install new or modified lines reduced by 30%
- Time for trimming during installation of new system decreased by 50%
- Ramp up time of new system after installation decreased by 30-40%
- Build world class competence in manufacturing of electrified and hybrid vehicles
- Efficient methods and KPI´s for follow up and continuous improvement and maintenance of running systems.

3.1.3 Machine/Equipment

Aim and Vision
Low life cycle cost and verified accuracy, stability, and reliability to be able to secure product quality and capacity and minimize/eliminate rework and manufacturing of scrap.

R&D Area description
Robust and flexible production equipment and non-destructive testing in-line. The ability to evaluate and control the accuracy and capability of the manufacturing equipment (including the tools) during the life cycle is fundamental for advanced component manufacturing. Evaluation of complex machining systems is very complex. There is a need for better testing and analysis methods that can be used for industrial applications and to prolong machine lifetime.

Identified R&D topics
- Quicker feedback and corrective actions if problems should occur to minimize the possibility of machine or product failure
- Characterization of machine tools and manufacturing equipment

- Minimization of resources and energy
- Robust and reliable systems for in-line measurement of the manufacturing equipment/process, such as capability and equipment condition trends.

Wanted effects:

- Lower total cost and environmental impact/produced component, during the life cycle of the equipment
- Practical machine tool test methods for static, dynamic, kinematic, and thermal stability
- In-line measuring techniques in pace with the process cycle time that withstand the production environment and can be used in industrial applications
- Machines and equipment with embedded monitoring and trend following systems (connected to networks) for efficient and robust production and maintenance (e.g. condition-based maintenance)
- High predictability of part quality through analysis of empirical data and process dependencies
- Effective re-use and flexibility of machines/equipment.

3.1.4 Tools and process planning

Aim and Vision

Shorter lead-time in the introduction of new products/processes and faster ramp-up time by introducing new methods and tools for creating, analysing and verifying sustainable manufacturing.

R&D Area description

Process planning, methods and tools for modelling and verification of manufacturing processes. The objective with process planning is to find the best solution to manufacture a component. It is also important to be able to store experiences and secure intellectual property regarding manufacturing knowledge. New IT tools for process planning and virtual manufacturing processes will make it possible to test and verify ideas at an early stage and reuse and spread knowledge to new generations of process planners. Typical processes are casting, machining, heat treatment and additive manufacturing.

Identified R&D topics

- Implementation of model driven work procedures for process planning. Establish best practices in commercial software, including methods to manage models of machine tools, fixtures and tools based on international standards
- Virtual manufacturing processes with process chain analysis capability for process planning to be introduced in industry in significant scale
- Awareness, utilization, and influence of international standardization within STEP Manufacturing and other relevant committees.

Wanted effects

- Reduced lead time for product realization. Minimizing time for generation and editing process plans by 50%
- Reduced time to ramp up time by using virtually verified critical processes based on accurate and realistic material and manufacturing process models
- Reduced cost for investment and implementation of systems by using standards.

3.1.5 Process

Aim and Vision
To support sustainable product design and increase competitiveness by new manufacturing technology and rationalize the manufacturing of new materials and material combinations.

R&D Area description
New materials and environmentally friendly manufacturing technology for traditional and future powertrains. New materials are enablers to further develop vehicles with less weight and environmental impact. The components should be optimized regarding the strength/weight ratio to improve energy efficiency and performance. Innovative manufacturing processes open opportunities for production with reduced environmental impact and for products with improved properties. Manufacturing processes gives restrictions (or possibilities) on design and product properties. A combination of different materials into one structure will give positive product properties but could cause severe manufacturing problems. New manufacturing technology could make it possible to manufacture materials with improved product properties, or more tailored properties.

The impact on environment and health inside and outside of the factory must be minimized. We need new processing liquids with decreased impact on environment and health and implementation of dry machining or minimum quantity lubrication for cutting operations where applicable. Chemicals used for detergents, process gases and quenchants in connection to heat treatment need to be minimized or replaced by environmentally sound alternatives. Improved handling and treatment of residues and recycled materials from both the machining of components as well as casting is important.

Identified R&D topics

- Heat treatment
  - Influence on distortion
  - Influence on fatigue properties and optimization of residual stresses
  - Continuous verification connected to process control
- Cutting
  - Machining, grinding and fine finishing of high strength hardened steel
  - Machining light-weight materials, e.g. aluminium, magnesium, composites, and combined materials
  - Methods for minimizing burrs and improved methods for efficient deburring
  - Ability to predict and manage the machinability due to material batch variations
  - Machining of near-net-shape components
  - Machining of additively manufactured components
  - Machining of gears for electric powertrains
- Surface integrity
  - Tailor-made engineered surfaces
  - Abrasive- and "non-conventional" finishing processes
  - Machining impact on surface integrity
  - In process metrology of surface integrity
  - Optimization of the complete manufacturing process to attain required surface integrity
- New advanced materials
  - Casting and machining of high strength cast materials like CGI and ADI
  - Combinations of different materials in joint structures and components
  - Ultra clean steel for high performance transmission components
  - Laser welding of powertrain components and additively manufactured materials

    - Coatings for powertrain components
    - Machinability of combined materials and new materials, e.g. magnetic steels (electric powertrains), powder metals and AM-manufactured components
- Sustainable and circular manufacturing processes
    - Cold forming of powertrain components
    - New cutting fluids, minimum quantity or dry lubrication, cryogenic machining. Industrially viable cleaning methods and adoption to REACH
    - Sustainable quenchants in heat treatment
    - Development of improved handling of waste and rest materials
    - Reduction of energy usage in idle machines
    - Regain the energy used for melting and heating of the material
    - Simulation and evaluation of the overall life cycle assessment (LCA) of manufacturing process chains from an environmental perspective.

Wanted effects

- Reduced environmental impact of materials, liquids, and processes
- Reduce the amount of energy/produced component
- Reduced weight and energy losses in powertrains
- Increased productivity and decreased production costs
- Assured quality and minimization of scrap
- Methods and tools for life cycle assessment (LCA)
- Solutions for manufacturing of electric powertrain components.

3.2 *Forming & Joining*

The Forming & Joining cluster covers research topics within the technology areas forming and joining processes as well as related materials, manufacturing systems and process modelling.

The four main themes of challenges for globally competitive production, introduced in section 2 of this document, are drivers for change with significant effects on the research and development in the areas forming and joining.

The four main themes of challenges for globally competitive production:
1. Circular and resource efficient manufacturing
2. Production methods meeting new products, functions, or features
3. Digital continuity in the industrial eco-system
4. Resilience and competence.

Tables in the following sections show how the cluster activities are targeting different aspects of the themes above.

Factors such as digitalization of society, electrification of vehicles and an increased focus on sustainability and resilience lead to new conditions and expectations for the manufacturing industry. With increased environmental driving forces, new product design solutions based on new and recycled materials and manufacturing technologies will be needed. Consequently, forming and joining technologies are facing major challenges as this transition requires development and validation of new robust manufacturing concepts able to handle materials with varying properties and supplier flexibility.

Prioritized R&D areas for the Forming & Joining cluster:
- System level challenges related to forming and joining
- Forming and shaping technologies
- New and combined joining technologies, including simulations.

3.2.1 System level challenges related to forming and joining

Flexible and cost-efficient production systems including dies, tooling, fixturing, pre-process, in-process and post-process quality controls, maintenance and minimized and cost-effective changeover of today's manufacturing processes in existing workshops for the products of tomorrow. Holistic solutions for cost efficient and sustainable production systems including forming, heat treatment and joining, as well as other related processes.

Aim and Vision
Flexible and cost-efficient production systems with changeover successfully accomplished to manufacture the sustainable products of tomorrow.

R&D Area description
Moving towards new structures within the automotive sector over a 20-year period will put high demands on creating production systems and manufacturing processes that can handle a large spectrum of material types, including recycled materials, or are capable of gradual transformation. The research area includes strategies for choosing manufacturing processes and production equipment with material flexibility. The manufacturing process shall be flexible and adaptable to also

produce future re-designs with minimal CAPEX and process changes. This will require increased knowledge in component properties with recycled and mixed materials.

Identified R&D topics

Table 1. Identified R&D topics and which of the themes for globally competitive production they address.

	1	2	3	4
Material flexible production systems	x	x	x	x
Virtual verification of new materials and production concepts	x	x		
Handling & fixturing equipment for new materials	x	x		
Strategies for choosing manufacturing processes and production equipment			x	
Re-engineering & remanufacturing strategies related to forming & joining	x		x	x
Data collection and process analysis to support decision making	x		x	

Wanted effects

- A significant productivity increase in the production processes
- Production systems with flexibility in volumes and materials
- Re-engineering & remanufacturing capabilities

3.2.2 Forming and shaping technologies

Light-weight solutions for material scenarios such as hybrid materials and structures, composites, light-metals, and ultra-high strength steels. Improved prediction accuracy for forming simulations.

Aim and Vision

Shorter time for introduction of new materials and material concepts for light-weight automotive structures with high passive safety. Safe introduction of new materials and manufacturing processes supported by effective simulation methods.

R&D Area description

Production of components of new advanced sheet materials, such as composites, ultra-high strength steels or light-metals, requires building new competence on how to use the materials to their full potential. The required knowledge needs to be formulated as manufacturing driven product design rules to enable product designs that offer cost efficient production.

Together with simulation tools, tests of the forming properties of different material systems, are required to provide the support needed for mechanical design. While some of the basal tests could be carried out in collaboration with other vehicle manufacturers and suppliers, also full-scale forming tests of typical parts are required to verify feasibility of the design prior to production.

Several of the new materials available are still immature when it comes to large volume production, why continuous development of the forming technology and its implication on the design and evaluation process is expected for the near future. The latter could include cost modelling to evaluate different concepts, as well as multifunctional optimization, aiming to optimize the process not only based on best forming outcome. In many cases, the target might be to explore the capabilities of an improved method or to improve an existing method.

Forming simulations are used extensively today. However, the introduction of new materials and new process conditions require new material models. The forming operation itself might require testing and evaluation of different simulation techniques. Robustness studies are required to study the impact of, for instance, the variation of the mechanical properties of the incoming material and different process parameters, such as increased temperature. In addition, the expected increase in usage of recycled material will likely increase the variability in mechanical properties of the sheet material. The possibility to simulate friction and wear of dies will increase the possibility to introduce new, low-cost die materials. Approaches including the use of AI and Machine Learning (e.g. Physics Informed Neural Networks) are expected to speed up this development.

Identified R&D topics

Table 2. Identified R&D topics and which of the themes for globally competitive production they address.

	1	**2**	**3**	**4**
Material testing of new materials	x	x	x	
Formability of advanced sheet materials	x	x		
Innovative forming technologies	x	x		x
High volume manufacturing processes for new automotive materials	x	x		
Manufacturing driven product design		x		x
Simulation of spring-back in forming	x	x	x	
Robustness studies of processes	x			x
Sequential simulation of process chains, including final geometry		x	x	
Effective material models for new materials and process conditions	x		x	
Simulation of press and die dynamics	x		x	
Simulation of wear in dies	x		x	x
Efficient methods for including variation in material models		x	x	x
Handling forming simulations with varying material properties	x	x	x	

Wanted effects

- Product design utilizing manufacturing driven product development enabling cost efficient and sustainable forming processes.
- Fulfilment of the product demands such as lower weight and increased passive safety.
- Fulfilment of the styling demands which require more complex shapes, sharper radii, advanced forming methods, whilst new materials and processes are being introduced.
- Capability to handle more variation in material properties in simulations and processes and identification of methods to minimize these variations.
- A significant productivity increase including lead time reduction in the product development process with a special focus on manufacturing engineering.
- Fulfilment of the styling demands which require more complex shapes, sharper radii, advanced joining methods, whilst new materials and processes are being introduced.

3.2.3 New and combined joining technologies, including simulations

For future combinations of materials and shapes for material scenarios such as hybrid materials and structures, composites, light-metals, and ultra-high strength steels. Challenging and increasing use areas include for example battery applications. Combination of joining technologies to ensure cost effective production while maintaining sufficient joint properties.

Aim and Vision

Implementation of optimized joining processes, which enable volume robust, high productive and flexible production of advanced materials and material combinations. Safe introduction of new materials and manufacturing processes supported by effective simulation methods.

R&D Area description

New and improved joining methods need to be identified and evaluated continuously. The industry needs a significant amount of information in order to design parts for new joining methods, such as how the manufacturing process should be outlined, what is required to simulate the process, reliability of simulation results, what type of equipment is needed, which production volume the new method is suited for, etc. In many cases, the target might be to explore the capabilities of an improved method or to improve an existing method while ensuring that all specified requirements are met regarding joint properties.

Joining simulations are not used as extensively today as forming simulations. There is a large need for reliable joining simulations to study the processes, the properties of joints, e.g. crashworthiness, and also the consequences of, for instance, a welding scheme on the quality output and geometrical conformance of subassemblies (virtual pre-matching). Data mining from manufacturing is increasingly interesting to analyse with AI assisted systems to identify problem areas and suitable solutions to increase reliability and sustainability.

Identified R&D topics

Table 3. Identified R&D topics and which of the themes for globally competitive production they address

	1	**2**	**3**	**4**
Joining techniques with small degradation of materials and with small distortion of components	x	x		x
Joining techniques with good surface appearance	x	x		
In-process monitoring for higher quality	x		x	
Adaptive control of joining to increase joining robustness	x	x		
Manufacturing driven product design		x		x
Optimization of joint configurations to reduce manufacturing cost at specified joint strength	x	x		
Hybrid joining	x	x		x
Cost efficient and volume flexible processes	x			x
Joining simulation	x	x	x	x
Improved CAE models for crash properties of joints, e.g. mechanical joints, and adhesive joints	x	x	x	
Robustness studies of processes	x	x		x
Sequential simulation of process chains, including final geometry		x	x	
Effective material models for new materials and process conditions	x	x	x	
AI assisted systems for improved robustness and sustainability	x	x	x	x

Wanted effects

- Product design utilizing manufacturing driven product development enabling cost efficient and sustainable joining processes.
- Fulfilment of the product demands such as lower weight and increased passive safety which require new processes.
- Fulfilment of the styling demands which require more complex shapes, sharper radii, advanced joining methods, whilst new materials are being introduced.
- Production of different bodies/cabs for different types of powertrains in the same manufacturing system.

- New joining technologies introduced that deliver higher productivity, flexibility, and cost efficiency.
- A significant productivity increase including lead time reduction in the product development process with special focus on manufacturing engineering.
- Fulfilment of the styling demands which require more complex shapes, sharper radii, advanced joining methods, whilst new materials and processes are being introduced.
- Joining processes with improved robustness and sustainability, supporting re-use and recycling of components.
- Predictability of mixed-material joint properties and their effect on the structure including safety and fatigue.

3.3 *Surface Treatment & Paint*

The Surface Treatment and Paint cluster focus on development of the surface treatment materials, methods, and processes to meet the future demands on surface treatment, such as mixed materials, electrification of vehicles, sustainability, and economy. Virtual tools to simulate surface treatment processes are developed to reduce try-out time and the need for physical testing to achieve optimized results.

The Surface Treatment and Paint cluster develop process technologies which significantly reduce the energy use, environmental impact, and consumption of resources. It also develops process technologies which reduce process steps in the paint shop, surface treatment to support the development and implementation of multi-material solutions and light weight electrified vehicles, corrosion protection technologies with improved performance and increased sustainability, manufacturing engineering tools which support shorter process development time and reduced requirements for physical prototype testing. The cluster also develops the Paint Centre at RISE, to be used for improved development, tests, and verifications as well as for education and training.

The area is dependent upon the following technology areas:

- Materials technology (including paint, sealers, BiW materials)
- Pre-treatment processes, wet and dry
- Corrosion: Development of accelerated corrosion tests correlating to long-term corrosion performance of different coating systems and applications
- Paint formulation: Development of new paint formulations which can lead to reduction of environmental impact and increased performance
- Virtual Manufacturing Engineering and Paint Process Simulation tools for optimizing the paint shop processes (such as spray application and curing)
- Process equipment
- Heat treatment and geometry assurance technologies (Paint thermal processes and adhesive curing during oven curing can cause significant distortions).

General targets for paint application are significantly reduced chemical and paint material consumption, reduced energy consumption and environmental impact, increased paint shop capacity and Virtual Paint Shop simulation for reduced development time, reduced physical trials, and optimized processes.

General targets for pre-treatment are reduced energy consumption, reduced material consumption, less waste, and a total reduction of the environmental impact.

Prioritized R&D areas for the Surface Treatment & Paint cluster:

1. Process enhancements for reduced environmental impact and cost reduction
2. Materials and processes for the next generation surface treatment of vehicles with new combined materials and electrical drivelines
3. The Virtual Paint Shop

3.3.1 Process enhancements for reduced cost and environmental impact

Aim and Vision
Process technology is implemented that reduces energy and water consumption, environmental impact, and waste production.

R&D area description
Today's paint shop is the single largest consumer of energy, water and chemicals and produces the largest amount of waste within the vehicle manufacturing plant. It is also responsible for a significant share of emissions to water and air from the factory. Approximately 80% of the water and 40% of the energy consumption at the vehicle manufacturers come from the paint shop. The highest energy consumption in the paint shop is from the ovens. Air ventilation and heating process baths come on second place. The energy consumption from treatment of solvent effluents from the air can vary depending on which technology that is used. The pre-treatment process is responsible for more than 2/3 of the water consumption.

There is a need for reducing the number of process steps in the paint shop and to minimize manual work e.g. masking. Paint loss when spraying wet paint is often causing high costs and negative environmental impact. Electrostatic spraying is one method to reduce paint loss. When spraying non-conductive materials like polymers, electrostatic painting is not used today. The complete virtual paint shop is an enable to facilitate analysis and optimization of the paint process in an approach which has not been possible previously.

Identified R&D topics

- Ventilating air management including recirculation and use of heat exchangers.
- Low energy and water consuming pre-treatment processes.
- Oven design, heating zones and nozzles.
- Efficient heating technology (IR, UV, induction heating).
- Solvent free paints to phase out the need for solvent combustion.

Wanted effects

- The paint shop at the vehicle manufacturers will be able to reduce the energy consumption with 50%.
- Decreased water and chemical consumption.
- Swedish sub-suppliers to the automotive industry shall be able to meet the environmental and energy demands set by the automotive industry.

3.3.2 Materials and processes for the next generation surface treatment of vehicles with new combined materials and electrical drivelines

Aim and Vision
Processes and materials can be introduced that reduce environmental impact and material consumption.

R&D area description
Today's technologies, zinc phosphate and electro dip coating were developed when mild steel and zinc plated steel were the only materials used. Zinc phosphate is expensive to monitor and generates large amounts of waste especially from aluminium surfaces. An alternative is required since it is more common that the substrates used in the vehicles are of different materials such as steel, zinc plated

steel, aluminium, composites, and plastic materials. High-tensile strength steel of different grades has extensive use, and different materials are combined in multi-material designs.

There is a need to establish an alternative to the commonly used zinc phosphate pre-treatment. The electro dip coating could be expanded to other applications also outside the automotive industry. The ability to coat composite and plastic components will also be included. These alternatives shall meet new requirements on the product, function for new material combinations and give better results regarding energy, environment, and resource utilization. There is a desire to reduce the solvent content in waterborne paints. Powder paint is used to some extent on truck chassis, as a primer on cabs and on components from subcontractors. There is also a need to evaluate where water-borne paint can replace solvent borne paint. Technology for reducing the emission of VOC (Volatile Organic Compounds) for all paint systems needs to be established. Efforts have been made to reduce the number of paint layers by combining layers, e.g. pre-treatment with ED-coat and primer with base coat. Low temperature curing paints are of interest for all paint systems as well as for multi-material constructions. Evaluate alternative heating systems for boosting curing (IR, UV, induction) for shorter and uniform heating. Also, there is a need to be able to evaluate how different choice of materials and process affect the environmental impact.

Identified R&D topics

- Test and verification of pre-treatment methods
- The sustainable surface treatment process – tools and evaluation methods to compare different processes to choose the process with least environmental impact.

Wanted effects

- Reduction of energy consumption on site with 25% and a 50% reduction of material consumption in the pre-treatment area.
- 75% less waste and reduction of the environmental impact for pre-treatment processes.
- A reduction of solvent content from 15% to 5% in waterborne paints.
- A new approved pre-treatment method with the associated environmental benefits shall be implemented by at least one vehicle manufacturer in Sweden.

3.3.3 The Virtual Paint Shop

Aim and Vision

User friendly systems and tools will be introduced that shorten implementation and reduce the usage of resources and physical try-outs needed.

R&D Area description

The paint shop is a very large investment and therefore it is essential to maximize its utilization during its full lifetime, which typically covers multiple generations of products. Upon product or material changes a full validation of a complete body-in-white (BIW) is necessary.

There is a need to eliminate the need for try-out testing of a full BIW and reduce the implementation time in a vehicle manufacturer's process via enabling technologies such as simulation of various surface treatment processes combined with physical testing at a component level. To achieve this far-reaching goal, all available competences need to be gathered, and complementary research shall be identified, collated, and implemented. When subsequent analysis identifies a gap, new research projects are to be initiated.

Programming spray painting robots is time-consuming and costly for small series. There is a need for self-programming systems with automatic path planning and selection of paint brushes based on the demands on paint thickness and the geometry of the product.

Identified R&D topics

- Simulate process parameters such as electrical fields in process baths and penetration and evacuation of solution in cavities, build-up of paint thickness upon spraying, adhesion, etc., as well as simulation of the process flow through the factory. Virtual testing becomes more and more important as space and time for test bodies in the production flow is reduced.
- New methods for education both from a pedagogical perspective as well as from a practical implementation of the new virtual tools must be developed and assessed in order to meet the requirements the automotive industry has on both new and present employees.

Validation methods are important for the R&D topics mentioned above.

Wanted effects

- Implementation of new education methods.
- Robot painting of complex 3D products without pre-programming of the robot.
- Simulation of the oven heating and paint curing for both water- and solvent-borne paints.
- Optimization of paint curing by optimized heating.

3.4 *Assembly*

The manufacturing industry is continuously facing challenges that need to be met and adapted to, such as new technological advancements, new competitors, global sourcing, sustainability, and industry restructuring. Within assembly the major aspects to consider when dealing with these challenges are, see Figure 2, 1) developing of innovative products, 2) process development and automation as an enabler for more efficient and flexible assembly, 3) the people within the assembly system, 4) digitalization that supports assembly and 5) interoperability (when two or more systems or components exchange and use information).

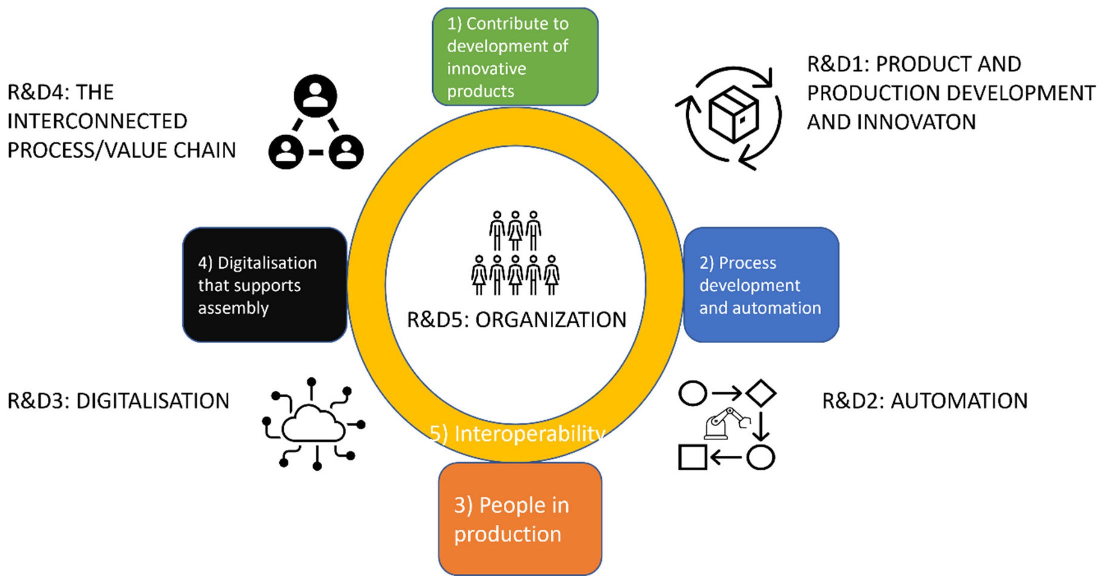


Figure 2. The assembly cluster focus areas 1-5 and prioritized R&D areas (R&D1-5).

The current trends affecting industry, not only the highly competitive automotive industry, but also their suppliers throughout the supply chain, are the electrification, introduction of new materials, and digitalization including automation. New, vital automotive components like batteries are blurring historical borders between discrete and continuous manufacturing processes and restructuring established supply-chains. In consequence, several companies are facing the question of how to plan and execute the change required to adapt to these trends and thus stay competitive. Therefore, there is a need to enhance industrialization and focus efforts that contribute to a more sustainable manufacturing through circular economy and life-long learning. With the increased digitalization, we are becoming increasingly connected, the number of different systems is increasing, the amount of data is increasing and with it the complexity. The assembly cluster recognizes that the combination and interconnection between systems is an important and huge challenge. This is realized in assembly and consequently it has a lot of application issues.

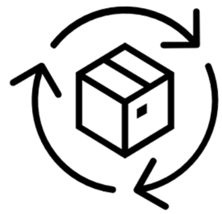
Newly identified issues

- Welding and gluing are today popular in the production processes. From a recirculation and disassembly perspective the assembly cluster would like to highlight that this might be moving the wrong direction. Processes such as taping or other flexible joining methods is preferable.
- Mega-casting and heavier components could be complicated for manual assembly work.

Prioritized R&D areas for the Assembly cluster:

1. Product and production development and innovation
2. Automation
3. Digitalization
4. The interconnected process/value chain
5. Organization.

3.4.1 Product and production development and innovation



Aim and Vision

Product- and production development are run as parallel activities (concurrent engineering) to achieve an effective implementation of new innovations in product and/or production processes. The aim and vision are to develop and implement methods, standards and technologies required for these activities to become even more effective than they are today. These product should be design for assembly, dis-assembly and circular flows.

R&D area description

New challenges such as mass customization of products, and a higher level of automation all contribute to increased demands on the design of product- and production systems. Changes in customer demands, law- and regulation, products, technologies, and materials require new ways to design not only the future products, but also the future assembly systems. Thus, it is vital that assembly is represented in the design of new products and production systems.

The following characteristics contribute to the R&D need:

- New lightweight materials, material combinations and functions together with requirements and varying levels of automation in green/brown-field settings. This creates new requirements on all aspects of production, such as how to design, realize and perform assembly or disassembly including joining methods
- Design optimization through modelling, simulation, or visualization: as product development times are reduced and hardware prototypes are eliminated, visualization techniques are required for simulating everything from factory resources, production processes and flows and human operations e.g., through virtual tools such as simulation and modelling
- Geometry/Quality: virtual pre-matching, improved measurement methods, in-line measurements
- Next generation power train. Including battery and electric components. New risks and safety requirements
- Radical reduction of components to assemble e.g. due to mega-casting technologies.

Identified R&D topics

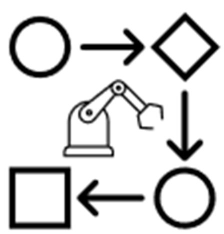
- What effects do new materials, such as lightweight materials, styling-proposed exclusive materials etc., have on future assembly processes?

- How does radical reduction of components to assemble, e.g. due to Mega-casting technologies, change assembly systems? Including disassembly and re-work, repair
- How to ensure that increased product variants have no negative effect on assembly quality and productivity?
- What effects do new propulsion systems, electrification, self-driving vehicles, and enhancement of infotainment systems and associated software etc., have on future assembly processes?
- How can R&D support the re-thinking within product- and process development?
- How should product- and process development be managed and integrated to achieve high quality in product and process?
- How are platform-based services changing product and production development? Platform providers like Microsoft and Amazon Web Services provide or host a broad range of services that are useful for companies, e.g., AI, ML, storage, business models, sustainability assessments etc. How can available services be efficiently used so that the Cluster projects do not need to reinvent the wheel?
- How could practice, methods and production equipment be developed/adapted so that it supports flexibility within the assembly system?
- Way of working/practice and methods within Design for X (Automated Assembly) e.g., Design for Ergonomics
- Standardized methodology for downloading of software in support of product variation.

Wanted effects

- Highly effective assembly, best-in-class
- Flexible production processes within assembly
- Quick and cost-efficient change-over in manufacturing for production of multiple variants and alternative propulsion systems
- Efficient collaboration between product and process development
- Products that are designed for assembly, disassembly and our planet.

3.4.2 Automation



Aim and Vision

Cost efficient and productive assembly processes with a flexibility that manage new conditions put on the production system by the introduction of new materials, modularization of products, new types of propulsion systems, etc. utilizing automation as an enabler. Low cost and flexible automation by collaboration between operator and robot could facilitate ergonomic production solution as well as reduce the set-up time.

The product modularization will have a significant impact on future assembly where e.g., recession or prosperity in the global economy can affect the assembly system and its processes. The system must be able to manage this with a suitable combination of manual, semi-manual, semi-automated, and automated assembly stations that can be chosen and exchanged depending on the production demand. The vision is to develop strategies for production, such as how to design a product for efficient utilization of technologies in the production system (i.e. hard points etc.) and technologies for assembly systems that meet the future manufacturing technologies, such as human-robot collaboration, additive manufactured components, digitalization and how the logistic system should be a part of the assembly system. The potential of automation through Artificial Intelligence (AI) for decision support, supervisory control, and process prediction needs to be fully leveraged in future assembly systems.

R&D area description

Automation in manufacturing process cover a broad span of areas and technologies. Within assembly the industrial robots, AGVs (driverless industrial trucks) & advanced external sensor systems are the most critical areas. And all of these are in combination developed into future assembly systems (highly depended on developments in the digitalization area). The last decades the development of external sensors have enabled the new area of Human Robot Collaboration to develop through power and force limiting robot systems. These are now merged with AGVs into Mobile Manipulators (MoMa) where a power and force robot are moved on the factory floor to perform assembly activities where it is most required.

The advanced external sensor systems are also used to create a whole new field of flexible automation applications. One can imagine robots rather than dedicated hardware marrying the BIW and chassis, automated guided carts loading and unloading parts on standard pallets or automated recognition of a specific alternative propulsion system or equipment automatically sensing the variant and choosing the correct fuel to be delivered to just that vehicle. There also exists the entire field of variant recognition and process control systems which, given the current IT development, should be able to deliver wireless technologies and programs developed in such a way as to be easily reprogrammed based on which modular components or operations are needed. This then opens the possibility for remote diagnostics of production equipment by experts or suppliers at long distance.

The following characteristics contribute to the R&D need:

- Cost, flexibility, and adaptability of automated systems
- Safety, design, and use of collaborative automated or digitalized applications
- In-factory logistics, Kitting, material supply and in-house transportation
- Manual assembly. Co-operating and balancing flexibility. Interaction human and technology. Optimal distribution of tasks between humans and robots
- Cognitive automation through Artificial Intelligence, e.g. decision prediction through OpenAI/ChatGPT.

Identified R&D topics

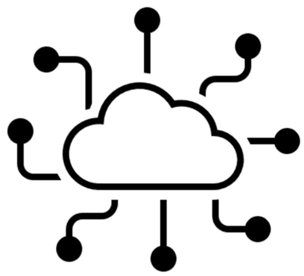
- What are the best automation strategies by which automation will enable effective and flexible assembly systems?
- Collaborative robot applications including i.e. technology, station design, strategy, and safety issues
- New types of assembly operations resulting from electrification, e.g. batteries, cables, and connectors. New automation to avoid risks related to batteries and electrification
- How should an assembly system be designed to avoid system losses?
- How can automation be a way to reduce increasing manual handling connected to assembly as well as kitting and sequencing of material?
- How to design modular and pluggable system that can be very rapidly reconfigured to accompany market requirements?
- The system perspective: How to design a robust adaptive assembly process as a whole
- Automation of in-house logistics, kitting transportation, and material handling

- Humans and machines (HRC) working together side by side or together.
- How can the potential of Artificial Intelligence be leveraged in assembly?

Wanted effects

- Reduced assembly cost per product with innovation implementation of automation
- Increased capability to assemble multiple product variants in each assembly line
- Significant reduction of the ramp-up and changeover/set up times
- Increased delivery precision from assembly lines
- Flexibility
- Adaptability.

3.4.3 Digitalization



Aim and Vision

Digitalization is gaining speed today, not only in society, but within the manufacturing industry as well. It will create lots of new opportunities, both through the development and introduction of modern technology, but also through finding new applications of existing ones. The future envisions smart factories where everything is connected. For example, there will be digital twins of the physical assembly system, enabling further improvements by iterating between physical and digital reality.

R&D area description

This R&D area is broad and includes everything from the product, process, staff, and infrastructure, thus embracing all parts directly and indirectly having an impact on the assembly system. In this sense, digitalization as an R&D-area is viewed as an enabler of modern technology, as well as of new applications for existing ones, all used to further improve the assembly system. To be able to reach an elevated level of digitalization and to implement the enabling technologies, industry needs to create strategies and road maps for digitalization.

The following characteristics contribute to the R&D need:

- Effectiveness, efficiency, and traceability of digitalization
- Interoperability, security (IT and cyber), design, and development of digital systems
- Utilize the power of digitalization in product preparation and execution, e.g., work instructions, on-line monitoring

Identified R&D topics

Digitalization is a huge research area, and as such, it is impossible to address the full extent of the future content that will have bearing on assembly. Therefore, R&D-topics within the area of digitalization are exemplified by, yet not limited to:

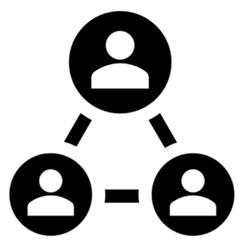
- Digital models and virtual tools
- Enabling technologies for digitalization e.g.
    - Digital twins/model-based design
    - xR-technologies such as Virtual- and Augmented Reality (VR/AR

  - Big data
  - Artificial intelligence
  - Connected equipment, OT/IT-systems
- Cognitive Automation – Support systems for information and instructions.
- Digital factory/Simulation
- Digital maturity and strategies
- Interaction human and machine, including IT tools, assembly instructions, HMI etcetera
- Digital technology to facilitate efficient and objective ergonomics assessments.

Wanted effects

- Connected systems that will provide not only faster and easier integration of modern technology, but also increased process control
- Relevant data visualized in a way that provides us with the opportunity to act on an expected deviation before it occurs
- Augmentation of human capabilities and compensation of potential human weaknesses enabling older and younger workers to work on equal terms
- Modern technology that enables improved assembly systems
- High up-time and profitable assembly process
- Fast, efficient simulation enables the ability to design, plan, optimize and validate all assembly operations without the need for physical hardware
- Ability to sort correctly, and relevant information in unique processes
- Worker well-being for all operators.

3.4.4 The interconnected process/value chain



Aim and Vision

End-to-end communication and interconnected circular value chains.

R&D area description

With the increased digitalization, we are becoming increasingly connected, the number of different systems is increasing, the amount of data is increasing and with it the complexity. The assembly cluster recognizes that the combination and interconnection between systems are an important and huge challenge. This is realized in assembly and therefore it has a lot of application issues. New challenges are seen such as new business models.

Keys to achieving the success of the future interoperability:

1. Very important to be able to set the right requirements specification
2. It is important that the supplier has full control of their own systems!
3. Involvement of operators and staff
4. It is important to think about systems and complete solutions and not just technology.

Please see the assembly cluster report on Interoperability[1].

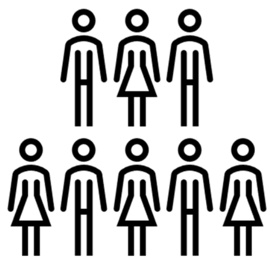
Identified R&D topics

- End-to-End communication
- Cyber-security
- Collaboration along whole value-chains based on multi-sided platforms
- Manufacturing and sustainability/circularity as platform-based services
- Organizational transformation to leverage the interconnected value chain.

Wanted effects

- Highly effective assembly, best-in-class.
- Flexible production processes within assembly.
- Quick and cost-efficient change-over in manufacturing for production of multiple variants and alternative propulsion systems.
- Increased sustainability and circularity of whole supply-chains
- Efficient collaboration between product and process development.

3.4.5 Organization



Aim and Vision

Manufacturing systems with a corporate culture where development and improvement are a part of the daily work. Technology used (automation, digitization etc.) in cooperation with co-workers. Work that characterizes the co-worker's context, competence, and independence. The work must be sustainable, developing, safe and with good ergonomics.

R&D area description

The user in a new world of digitalization and automation: As digitalization will provide the development and use of modern technology, the user environment will most likely change. In consequence, there will be a need of new competencies, new roles/responsibilities, and new practices in the future. Support for people in production, such as, assembly instructions, instructions, verifications.

The following characteristics contribute to the R&D need:

- To reach the goal of superior quality and productivity in assembly it is imperative to understand how to design systems where both human and machine capacities are utilized in the best way, i.e., Industry 5.0. In addition, up/re-skilling and support for life-long learning is relevant
- Ergonomics, stress, and work environment in assembly systems
- Productivity, quality, cost, and safety through standardization of work
- Agile work for managing variation and support resilience

Identified R&D topics

[1] interoperabilitet-sa-har-jobbar-vi-i-kluster-for-montering-2021-06-15.pdf (kunskapsformedlingen.se)

- Learning organization, organization skills development through individual learning and career development
- Organization and leadership for development and improvement as well as being able to utilize and use people's acquired skills
- Ergonomics aids, Cognitive ergonomics, Physical ergonomics
- Human-centred work design (i.e., Industry 5.0 priority)
- Up-skilling and Re-skilling of personnel
- Communication and visualization with humans and/or between/with machines
- Leadership and work organization includes relationships with other activities such as maintenance and logistics.
- Ergonomics and safety, workplace design
- Change management
- Competence, development, skills to drive, maintain and develop the future production system.

Wanted effects

- All people have control over the machines and systems affecting them
- Attractive work and work satisfaction
- Optimal allocation of work-tasks between humans and technologies
- Flexible production systems that are continually developed and improved by utilizing the human experience and skills
- Taking advantage of skills of employees
- A safe environment and workplace design
- Improved ergonomics.

3.5 *Geometry and quality*

Geometry and quality assurance in product realization comprise tasks during design and development of products and productions system as well as in manufacturing, as shown in Figure 3. Of main importance is the assurance of product function for the customer. Important for a cost and resource efficient product realization are the tools and methods for tasks, such as simulation, evaluation, verification, and monitoring. A key enabler for industrial operation lies is the standards specification and verification of products and processes. To reach the goals, it is vital to keep up with technology development through education and training. Additionally, circularity must be an integrated part of product and process design to promote sustainability, traceability, reusability, and end-of-life.

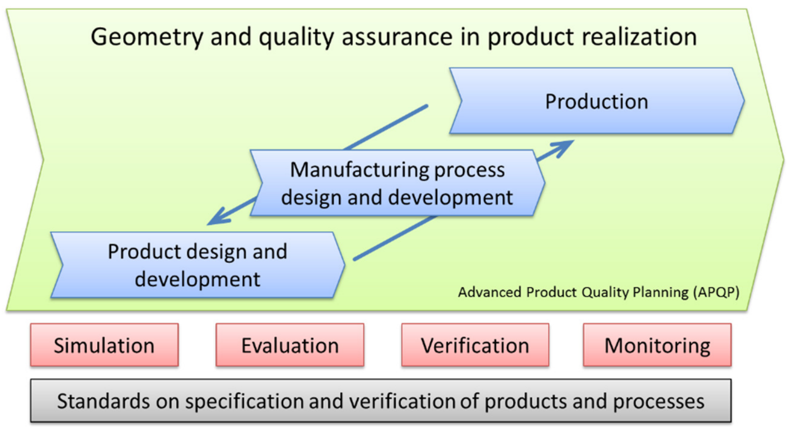


Figure 3. The scope of geometry and quality assurance in product realization.

Prioritized R&D areas for the Geometry and quality cluster:

1. Product and process specifications and requirement management
2. Tools and methods for measurement and quality planning
3. Verification technologies and quality control.

3.5.1 Product and process specification and requirement management

Aim and Vision

For product functional assurance the product and process specification and requirement management are crucial. Furthermore, it is important to gain knowledge, skills, and tools to be able to define specific demands of the product, consequently also for the process, which produces the products. By correct definitions on demands: quality, cost efficiency and robustness will increase while the lead time decreases due to improved products and processes.

R&D Area Description

Development of technologies and strategies to optimize product and process design for manufacturing efficiency. Digital models of products, processes and resources are key assets that increase in value through the understanding of its representation.

Identified R&D Topics

- Managed model-based 3D engineering, e.g., MBD (Model Based Design), PMI (Product Manufacturing Information), GD&T (Geometric Dimensioning and Tolerancing).

- Smart manufacturing enablers for the integration of processes and resources e.g., standard for GPS (Geometrical Product Specification), STEP (Standard for the Exchange of Product data).
- Requirement break down and dependency management.
- Specification risk management (balance between function, quality, and cost)
- Circularity and life cycle dependencies.
- Tolerance analysis on components, in-process parts, and assemblies.
- Surface integrity (topography and surface layer characteristics) e.g., functional correlation in surface areal specifications, characteristics interrelationship between macro form and micro surface.
- Product and process design for circularity.

Wanted Effects

- Robust design of product and processes, concerning geometry and other quality aspects will help in reducing rework, minimizing scrap.
- Traceable design rational for products and processes.
- Smart manufacturing enabled by industry common standards
- Ensure surface performance and early identification of potential functional errors
- Minimizing environmental impact sustainability in products and processes.

3.5.2 Tools and methods for measurement and quality planning

Aim and Vision

Efficient tools and methods in measurement and quality planning are vital in integrated product and process development cycles. The tools and methods use and create coherent information carried by digital models.

R&D Area Description

By developing efficient tools and methods used in engineering processes it is possible to already in the project phase develop robust products and processes with short lead time to start of production. It is important to foresee the effects of new material- or process- choices and by this verify effects in new projects. Development of cost models for on-going processes and product outcome gives the possibilities to take the correct actions for improving processes and products. Hereby the most cost-effective solutions can be chosen to eliminate quality deficiencies.

Identified R&D Topics

- Simulation driven engineering
  - Virtual process analysis (study of variation and quality on product, process, and tools)
  - Inspection engineering and work method simplification (offline programming, preparation etc.)
  - Visualization of tolerances and variation.
- Measurement planning
  - Measurement method simplifications (introducing method uncertainty)
  - Control plan integration and communication.
- Quality management systems – application of
  - Advanced Product Quality Planning (APQP)
  - Production Part Approval Process (PPAP)
  - Requirements for automotive production and relevant service parts organizations (IATF 16949)
  - First Article Inspection Requirement

- Cost models for quality deficiencies.

Wanted Effects
- Increased operational dependability in quality control
- Common understanding of products and processes design intent
- Easy communication of measurement and quality control plans.

3.5.3 Verification technologies and quality control

Aim and Vision
Development of efficient verification techniques will supply the manufacturing process with tools for rapid adjustment of the processes and fast reaction to variation in both incoming material and process variations. Smart manufacturing enabled by increased digitalization and connected devices.

R&D Area Description
Focus on enhancing verification techniques to leverage the quality of both product and process, as well as product performance. By doing so it will lead to better identification of deficiencies in processes, resources and products. Additionally, the production development is moving towards increased intelligent utilization of measurement data to better understand process behaviour and early detect deviations from standard practices. This will enable reduction of scrap and energy consumption of on-going processes which is environmental beneficial.

Identified R&D Topics
- Requirement verification
- Characterization of
    - material properties
    - mechanism kinematics and dynamics
    - acoustics
- In-line and in-process measurements
- Non-destructive testing – NDT (such as optical, x-ray, or ultrasonic measurement)
- Data processing and analysis e.g., Radiography, Tomography, Photogrammetry Variations and trends, Pattern recognition, Correlation and causality, Big data
- Root-cause analysis
- Self-calibration
- Optical measurement
- Cleanliness verification
- Leak testing
- Tool wear detection
- Measurement result visualization and communication
- Uncertainty assessment e.g., Measurement method uncertainty analysis, Measurement System Analysis (MSA) data utilization.

Wanted Effects
- Improved performance in verification and quality control
- Increased resource efficiency by improved control of products and processes with reduced scrap and rework
- Improved visualization and communication of measurement results for humans understanding of process behaviour and control
- Development and easy adoption of emerging technologies
- Smart data utilization in quality control – evaluation and monitoring of
    - Capability

- Predictability
- Robustness
- Controllability.

3.6 *Logistics*

Logistics can be seen as a part of the whole supply chain. Logistics, especially production logistics, is also an integrated part of the production system, in which customer expectations and market competition demand huge numbers and variety of parts being supplied through the supply chain and effectively being exposed and available. It is also a key contributor to environmental and social sustainability, being cost efficient, ensuring materials availability, supporting quality, and allowing flexibility and agility, while still being robust and resilient.

The logistics cluster handles production logistics internally and externally in the supply chain, see Figure 4.

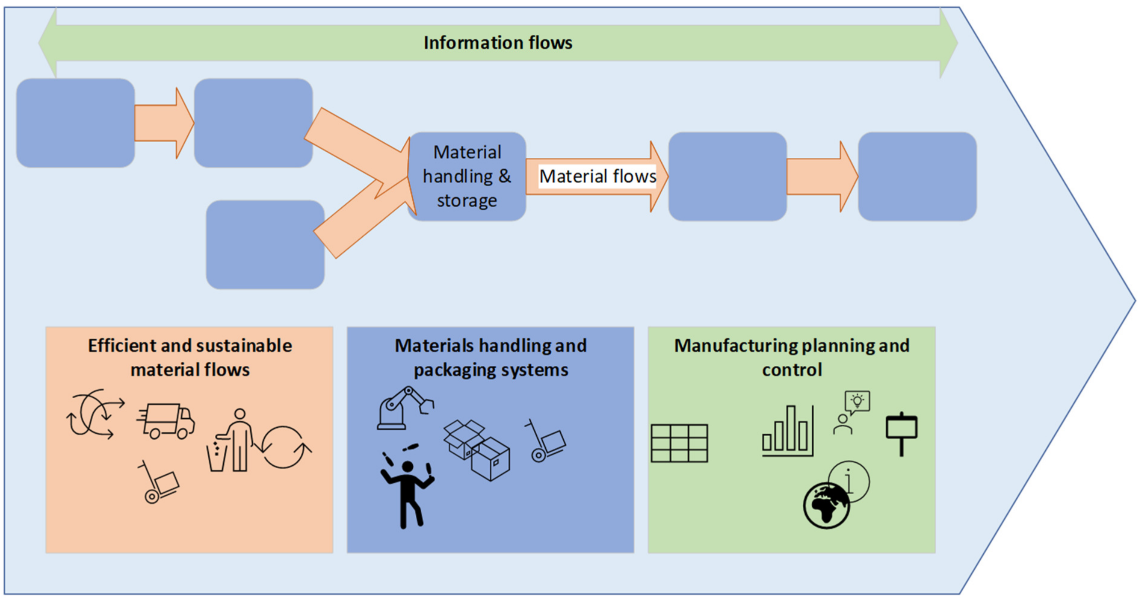


Figure 4. The logistics cluster handles production logistics internally and externally in the supply chain.

Prioritized R&D areas for the Logistics cluster:

1. Efficient and sustainable material flows in the supply chain
2. Materials handling and packaging systems
3. Manufacturing planning and control.

3.6.1 Efficient and sustainable material flows in the supply chain

Aim and Vision

The vision is to create environmentally sustainable and competitive supply chains that increase productivity, responsiveness, and resilience, where decisions are made based on their impact on health, safety, and the environment. The aim for 2030 is to achieve cost efficiency, high flexibility, and low environmental impact throughout the supply chain, from order-to-delivery processes to circular flows.

R&D Area description

The supply chain consists of the information, monetary, and materials flow throughout the order-to-delivery process. Supply chain management is essential for the efficient and effective processing of materials and related information and circular flows. The distribution of spare parts is an area that requires high service levels without incurring high distribution costs or large amounts of tied-up capital. The supply chain design is interdependent on the production system design, and the location of a particular production or materials handling activity can be performed in-house, at logistics centres, component suppliers, or third parties.

Today's supply chains face various challenges, including competition, increased disturbances, product platform variations, high flexibility demands, environmental sustainability, and regulations. Additionally, technological advancements, such as digitalization, electrification, and autonomous driving, are changing supply chain conditions. Therefore, there is a need for competencies to make this transition. Research is necessary to understand the fit between the supply chain and production system design to improve efficiency, meet requirements, and adhere to production principles. Development of performance measurement and management systems in relation to supply chains and material flows is necessary, including assessment methodologies and decision support tools. Moreover, aspects related to sustainability and the interplay between human, environment, and technology should be integrated early on in the design phase. For example, sourcing involves choosing between nearby and long-distance suppliers and selecting between single-sourcing, dual-sourcing, and multi-sourcing. Long-distance transportation presents challenges, such as increased risk and uncertainty, and environmental sustainability concerns.

Today, these aspects have been given increased attention in decisions regarding the supply chain configuration. To achieve long-range Supply In Line Sequence (SILS) deliveries of components, information of the final assembly sequence needs to be available to suppliers before shipping, and potentially before production at the supplier site. Improved information sharing between the assembly plant and supplier may be necessary. Access to high-quality information is a key issue for competitive advantage. Information sharing is vital to maintain reliable and resilient supply chains and improve decision and support system functionality. However, sharing information across the supply chain may lead to decreased information security and discussions on conflict of interests, calling for new ideas and models for managing and sharing information.

Identified R&D topics

Research will focus on the challenges and needs identified above, contributing to the effective design of supply chains by focusing on both the design process and the normative system characteristics. The research effort will be devoted to achieving highly efficient and effective supply chains that support core value-adding production activities. and understand how to manage changing requirements.

- Improved conceptual and applied supply chain design processes
- Understanding of the effective application of new technology and digitalization in supply chains
- Efficient integration of external materials nodes and warehouses and the location of activities in the supply chain
- Flexibility and management of supply chain disturbances, especially for distant suppliers
- Adaption of the supply chain to the mass customized concept
- Circular component streams and recycled material streams for regular production purposes
- Integrated Supply chain cost/environment/lead-time analyses
- Information management and sharing throughout the supply chain.
- Integration of sustainability aspects and the interplay between human, environment, and technology early in the design phase.
- Impact assessments of the implementation of new regulations/laws.

Wanted effects

- Performance measurement systems taking a supply chain perspective and integrating environmental performance
- Increase the knowledge of how different production situations and contexts affect the choice of materials supply method, while also implying suitable combinations of different materials supply methods, approaching mass customized logistics
- Increased flexibility, responsiveness, and product quality throughout the SC
- Increase the knowledge of the main driving forces behind using cross docks, external warehouses, etc., and the main barriers and gains of using them
- High volume, mix and product flexibility in the assembly systems and in the entire supply chain.
- Cost analysis frameworks for new or refined supply chains, for OEMs as well as suppliers
- Enabling Circularity by understanding and overcoming challenges posed by circular material streams
- Faster and higher quality of relevant information exchanged between actors of the supply chain
- A collection of well performing material supply system cases to show their benefits and incorporate it into educational material.
- Integrating sustainability aspects and the interplay between human, environment, and technology early in the design phase can significantly enhance the efficiency and sustainability of material flows by optimizing resource use, reducing environmental impact, enhancing human well-being and improving system resilience
- Policymakers can make more informed decisions by using data and evidence from impact assessments, leading to regulations that are better suited to address current and future challenges

3.6.2 Materials handling and packaging systems

Aim and Vision
The vision is to achieve sustainable and high performing material handling systems that hat enable future circular, digital manufacturing processes The aim is to develop systems where the design of operations, equipment and packaging enables high efficiency, quality, flexibility, and robustness, as well as good ergonomics. The aimed progress within the materials handling and packaging systems area should be aligned with the development in the material flow and planning and control areas.

R&D Area description
The material handling and packaging systems area includes handling and transport of materials in facilities such as factories, warehouses, and depots. There is a close relation to production workstation operations and their requirements on materials handling and exposure. Also, the assembly operators often act in the materials supply process. The area includes packaging and load carriers needed. The processes studied comprise various forms of materials preparation required in supply of, or distribution from manufacturing. Also, management, administration and organization of these processes are covered by the research area.

The research area needs to consider the fast development in technology. Material handling will be a key factor in enabling circular production systems. Important topics include the use of information technology and digital tools, as well as the use of automation. In what situations and for what processes is automation appropriate to use? Applications concern a wide range of equipment from support of manual operations to fully automated handling and transport.

At a strategic level, knowledge needs to be developed regarding the strategic choices and related designs of in-plant materials handling systems and plant layout, considering the related supply chain strategies and production planning and control practices. This is required to form internal logistics strategies that allow stepwise development and provide a basis for continuous improvements. Competence development connected to the R&D area includes programming of robots and AGVs Performance in this area has traditionally referred to measures such as cost- time- space- and environmental-efficiency, product quality and human factors, which are still important, but also environmental sustainability needs to be highly considered.

The packaging serves several purposes and functions of great importance for efficiency (cost-, time- space- environmental- efficiency), flexibility, human factors, and environmental performance of the production system. Choice of packaging is central in materials handling. The packaging effects on picking of material to and from a package as well as that transportation and handling of complete packages is important. The development towards increased levels of automation, especially in transportation, handling and picking, puts pressure on the development of packaging. The digital progress develops the packaging possibility of displaying and carrying information. New packaging standards need to be formed, as existing are inadequate and restrict development in the area. Naturally, packaging systems constitute a vital and integrated part of the supply chain and influence material flow (3.6.1) and planning and control (3.6.3) areas. Globalization and supply network performance make the decision between one-way and returnable packaging important. Further, the use of special packaging is an emerging problem area due to product development choices resulting in modular product architecture and enlarged supply networks.

Identified R&D topics

Based on the aim and area description, several research topics have been identified. In focus is the operations in factories, warehouses, and logistic centres in contrast to the R&D area Efficient and sustainable material flows (3.6.2) which concerns material flows in supply chains, connecting and synchronizing factories, warehouses, and logistic centres, as well as the location of activities in the chain:

- Contextual effects on the performance of material feeding and material preparation processes.
    - Sustainability and resource efficiency
    - Flexibility and variant handling
    - Resilience and robustness
    - Cost efficiency
- Production system design, combinations of methods and processes concerning
    - engineering, information technology,
    - organization, and management.
- Sustainable and efficient material handling as solution for circular production systems
- The effective application of automation and digitalization in materials handling processes.
    - Data collection with sensors, IoT, vision, multimodality.
    - Connectivity and interoperability.
    - Advanced analytics, AI, ML, image processing.
    - Automation integration, management systems integration, digital twin capability and autonomy
    - Visualisation, operator interface and interaction.
- 2way human machine communication and interaction in human centred digital material handling solutions
- The next generation of smart packaging systems, considering the production workstation and plant efficiency, at both customer and supplier. This is closely linked to the area of Efficient and sustainable material flows in the supply chain, as presented in section 3.6.1.

Wanted effects

On an overall level, the area strives to contribute to sustainable material handling processes, including handling of tools and maintenance materials, considering environmental, economic, and social sustainability. This includes the following wanted effects:

- Material handling processes that support efficient assembly of an increasingly large product variety.
- Connected material handling processes that support alignment and control within the supply chain.
- Safe and attractive workplaces in materials handling and production.
- Efficient handling of direct and indirect materials tools and maintenance.

3.6.3 Manufacturing planning and control

Aim and Vision

The aim and vision is to achieve resilience and sustainability through high-performing and user-friendly planning systems that can manage uncertainty and flexibility, at all levels of the planning hierarchy in real-time. A development aim is to increase flexibility and service level, decrease tied up capital and lead-times in the supply chain, through an improved information flow and proper control of the material flow. Research in the area focuses on planning methods, planning process and organization, planning information, information system support, and the interplay between these issues.

R&D Area description

Manufacturing planning and control involves managing all aspects of manufacturing and warehousing, including managing materials and capacity, scheduling machines and people, managing materials buffers, and coordinating capacities and material flows from suppliers and to customers, on strategic, tactical, and operational levels. It spans from strategic/tactical sales and operations planning to daily shop floor execution and control, thereby relating to ERP, APS, and the MES systems.

The situational impact e.g., demand characteristics, product, supply, and material flow characteristics, on planning and control strategies is of great importance for design of a planning and control system that matches the supply chain and production capabilities. The same is true for the interplay with the design of products, and production and materials handling systems. The specialization and globalization make it important to address issues relating to the planning and control of production networks and entire supply chain planning methodologies. A key here is the ability of organizations to accurately forecast and visualize demand at all levels of the supply chain. The quality of demand forecasts and delivery schedules has a direct and consequential impact on the overall planning process. Potentially new and innovative solutions are developed by employing cross-functional and inter-organizational planning approaches, within the company as well as in the whole production network (incl. suppliers), and new advanced information and planning systems, access to and advanced analytics of big data to visualize, predict and prescribe demand requirements and supply needs. The demand and supply uncertainty, partly driven by the ongoing globalization and distant supplier selection, puts further requirements on flexibility and resilience and, thereby, on dynamic and advanced planning. In a lean production context, manufacturing and supply chain planning should focus on designing and aligning pull systems with material supply, materials handling, packaging, and production systems.

Lack of proper planning information is a serious problem in the supply chains today, resulting in higher freight costs, stock outs, long lead-times, tied up capital, and high administrative costs, involving external actors, internal functions of the company, and data from external parts. It takes too long for demanded information to be properly distributed upstream in the supply chain. Increased visibility and involvement in 2nd and 3rd tier suppliers improve these conditions. This problem can be addressed by exchanging high-quality information automatically, synchronizing demand and stock level information in the chain, and creating alerts for critical situations. Planning information quality is also crucial, with short- and long-term variation in demand information and supplier capacity visibility being key factors.

Planning and control in production networks and supply chains must enable planning system support for creating planning visibility for supply chain design, coordinated planning in production networks and dyads of customer and supplier firms, and scenario- and event-based planning and control. This ensures proactive adaptation to flexibility and variational demands. Planning and control systems for mass customized products at mixed-model assembly lines require order schedule stability and flexibility to accommodate disturbances in supply and production and respond to customer demands. This calls for a planning system able to produce long term stable plans and re-plan at shorter notice by reconfiguring resources. The efficient execution of logistics and production operations require planning parameters to be updated and the planning taking up-to-date information into account. Planning of every part must take the actual circumstances into consideration, e.g., referring to the choice of packaging, routes, and safety stocks. This is problematic when there are vast number of active parts in the operation. Methods and techniques should be developed for a dynamic optimization, approaching planning of every-part-every-day. Also, information produced by the planning system must be easily understood and utilized for pro-active actions in the materials flow and materials handling systems.

Manufacturing planning and control is equally crucial for managing circular component and material flows. The supply network of component suppliers requires known and manageable uncertainties regarding supply of remanufactured components and recycled raw material. This is essential for increasing the competitiveness of recycled materials, thereby supporting circular business models, and assuring the supply of critical components. Advancements in e.g. additive manufacturing and similar technologies, possibly driving more decentralized production and changing planning conditions, are important developments to have under observation. Readiness to benefit from new technologies once introduced is important.

Identified R&D topics

Research is not needed only about designing new planning approaches, but also about implementing and using them, as feasibility has proven to be both problematic and important, especially for the detailed short-term planning. The same is true for pull system control, especially in inter-organizational settings, e.g., making efficient use of supplier Kanban systems.

In order to meet the challenges mentioned research is needed for:

- Research on the use and applicability of modern information technology, e.g., real-time information sensoring and big data analyses.
- Planning information in supply chains: to overcome e.g., higher freight costs, stock outs, long lead-times, tied up capital, and high administrative costs.
- Impact of information quality, explaining the causes to and flexibility requirements and management of information quality deficiencies in planning processes.
- Demand communication upstream the supply chain, increased visibility and involvement in 2nd and 3rd tier suppliers.
- Automated and synchronized high-quality information exchange of demand and stock level information, to decrease tied-up capital and lead-times.
- Explore the use and applicability of modern information technology, such as real-time information sensing and big data analyses, in improving information flow and control of material flow.

- Planning information quality is another important area to improve impact on planning processes and supply chain performance.
- Planning and control systems that enable planning visibility, coordinated planning in production networks, and scenario- and event-based planning and control to adapt to flexibility demands.
- Development of methods and techniques for dynamic optimization to approach planning of every-part-every-day, important when dealing with vast numbers of active parts in the operation.

Wanted effects

- Reduced risks increased pro-activeness and resilience through, e.g., scenario-based and inter-organizational planning.
- Improved responsiveness and flexibility through information visibility and event-based planning and control.
- Developed planning approaches and processes for supporting circular component and material flows.
- Reduced tied-up capital through collaborative planning approaches and pull control.
- Reduced lead time throughout the value chain for increased MPC responsiveness and planning quality.
- Increased service-level, with sustained costs and tied-up capital, with new MPC solutions.
- Higher information quality throughout the supply chain (relevance, timeliness, etc.)
- Understanding of the opportunities driven by technology, e.g., sensors and big data analysis.
- Reduced environmental footprints through better resource utilization, increased integration of green transport (modes) and integrated material flow across the supply chain.

3.7 *Digital Manufacturing*

The cluster facilitates the advance of Digital Manufacturing (DM) in Sweden by channelling and supporting research efforts according to the research strategy. The aim is to guide different stakeholders, such as:

- **Funding organizations**: National reference document in the planning of R&D funding initiatives
- **Researchers**: Guide for researchers in identifying relevant industrial needs, thereby supporting the project creation process
- **Clusters**: Guide for the planning of workshops, seminars, activities etc.
- **Industry**: Support for industry to benchmark and improve their own strategic digital manufacturing processes and R&D portfolios, and to find industrial collaboration partners.

Collaboration is key, as information and digital solutions are central for all manufacturing clusters' research, see Figure 5. Therefore, the digital manufacturing strategy is created and updated by network meetings, workshops and results from R&D projects, status reports and future scenarios studies. This work follows a yearly-based activity plan.

Digitalization is an integral part of product development, production development, products, production systems, supply chains, and business relationships. Digital Manufacturing is an approach to manufacturing that is centred around the ever-increasing use of digital technologies and related methods and processes. It is seen as a crucial approach for meeting high requirements of efficiency, cost, time, flexibility, and – in an ever-greater importance – sustainability and circular economy and ecosystems. Digital manufacturing aims at providing a fully integrated, collaborative production system that responds in real time to meet changing requirements and conditions in the factory, in the supply network and in customer needs.

Industry needs to introduce new solutions for designing, optimizing, and maintaining manufacturing systems, both at detailed and at system levels. The whole life cycle span must be considered – from (re)design modelling, simulation and verification, via installation and commissioning, production ramp-up, to execution, control and maintenance and finally circularity, re-use etc.

Digital manufacturing has a vital role for reducing environmental impact, by providing various solutions for use over the entire life cycle of manufacturing systems and products. This can reduce emissions and energy consumption, as well as increase re-use and remanufacturing of both products and the manufacturing system and equipment. In addition, the circular economy sets new requirements, introduces new business models and provides new solutions to be used. Digital manufacturing must be developed and utilized while considering the sustainability benefits from adopting digital solutions (carbon handprint), as well as the negative impact of digitalization (footprint).

Generative AI is poised to revolutionize digital manufacturing by automating simulations, generating design alternatives, and predicting process behaviours. It will enhance simulation accuracy, automate design alternatives, and optimize processes for faster time-to-market. It automates data modelling, uncovers patterns for real-time decision-making, and improves process flexibility. AI also creates adaptive interfaces to streamline human-machine interaction and reduce training. Additionally, AI optimizes material use and waste reduction, advancing sustainability and circular economy goals

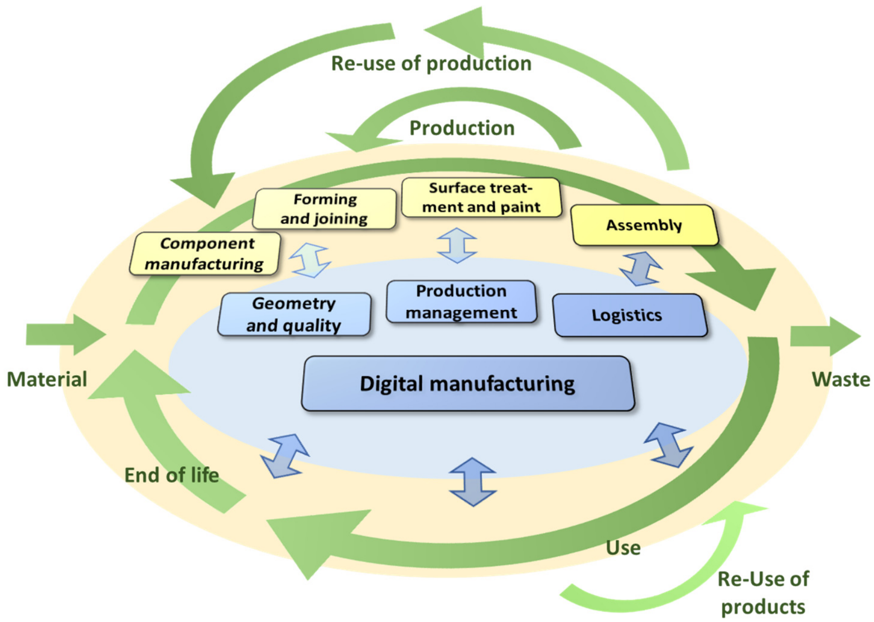


Figure 5. Four of the clusters (in blue) support and provide solutions to four manufacturing process related clusters (yellow). Digital Manufacturing strongly relates to and provides solutions to all clusters. The clusters need to consider the whole life cycle and need for circularity of both products and production systems.

Objectives

The overall objective of the digital manufacturing cluster is increased economic, social, and environmental sustainability. To achieve this, the aims are to enable:

- Efficient, data-driven work procedures over the life cycle, by extensive use of Digital Twins and Digital Thread solutions
- High quality, reduced lead time and costs in engineering, by daily use of user-friendly tools and data for modelling and analytics
- More accurate and efficient simulations, including also social and environmental analyses
- Up-to-date, coordinated, and usable digital information from various digital sources, that are easy of access, trace, manage, and standardized
- High degree of flexibility and efficiency in production, with best use of human capacities
- Solutions promoting environmental sustainability and circularity for production development and operation
- Support to manufacturing enterprises in digital manufacturing by information R&D results, testbeds, competence development initiatives.
- Efficient digital transformation process based on as-is maturity towards a desired to-be future state.

Digital Manufacturing involves many sub-systems, processes, and life cycle phases, and must be developed and implemented under consideration of industrial needs and preconditions, human needs of users and other stakeholders, work processes, products, manufacturing processes, materials, waste and energy from systems and processes, etc.

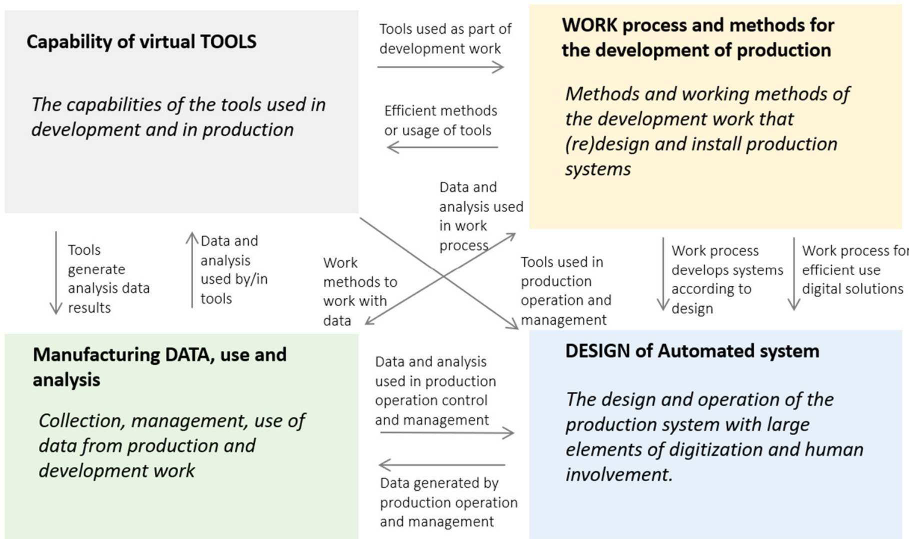


Figure 6. The four prioritized R&D areas in the digital manufacturing cluster are interrelated.

Prioritized R&D areas for the Digital Manufacturing cluster:

1. Work process and methods for the development of production systems
2. Capability of virtual tools
3. Design of Automated Systems
4. Manufacturing data use and analysis.

In all four R&D areas, see Figure6, the following general challenges are important:

- **Sustainability**: Digital manufacturing needs to increase sustainability and circularity, including to measure effects of solutions by simulation and optimization, using simple KPIs, making it easier to right, increasing awareness.
- **Education and training**: Competence development is key for industry, including flexibility, multidisciplinary, lifelong learning support, collaboration between large companies / SMEs / academy / institute, test / demo support, software training, etc.
- **Digital transformation**: Digital manufacturing needs to include management of the change towards a future state (to-be goal) by strategies, effects, handling different as-is maturity and competence levels, etc.

Resource efficiency and resilience by Digital Manufacturing

To achieve the goals of resource efficiency and resilience, a shared vision and strategy between industry, academia, and government is essential to support digitalization and sustainable manufacturing. Investments in education to address the skills gap, along with creating standards for data sharing and interoperability, are also crucial. A culture of innovation and clear sustainability metrics are needed to track progress towards Net Zero.

There are significant opportunities to improve sustainability, resource efficiency, resilience, and flexibility in production systems through digital tools like digital twins and AI. These tools can also support circularity goals. To drive innovation and adoption, developing measurable sustainability metrics, new business models (e.g., equipment leasing), and strengthening industry collaboration is key.

Current challenges in digital manufacturing include uneven progress, especially for SMEs, with a lack of unified digitalization strategies and transformation management knowledge. There's also a gap in integrating sustainability into product design and production, as well as challenges in implementing circular economy models. Tools like digital twins and AI are underutilized, and issues with data integration, standardization, and cybersecurity hinder the effectiveness of digital solutions.

Moving forward, digitalization and automation should align with circularity and climate neutrality goals, implementing digital twins and threads across product lifecycles to reduce energy use and CO_2 emissions. A coordinated roadmap for sustainable manufacturing, educational programs, and testing new technologies before full implementation are vital steps for a sustainable transition.

3.7.1 Work process and methods for the development of production systems

Methods and working methods of the development work that (re)design and install production systems.

Aim and Vision
Future production systems will be fully designed and modelled digitally as Digital Twins of physical systems. Advanced engineering tools will shorten lead times, enable more verifications, and optimize solutions.

The Swedish manufacturing industry aims to adopt the latest modelling, simulation, AI-based analysis, and optimization technologies to enhance profitability and sustainability. This includes increasing energy efficiency, reducing waste, and shortening lead times. Low-cost high-performance computing will enable cost-effective simulation and optimization, benefiting the industry. Circularity of production equipment, through increased reuse and extended lifetime, is also a key goal.

In the future, generative AI technologies will support engineers by autonomously producing design alternatives, simulation scenarios, and decision recommendations. This will complement traditional engineering tools by reducing manual modelling effort and expanding the solution space exploration.

R&D Area Description
Implementing automated production solutions requires extensive verifications to ensure they perform as predicted by Digital Twins. Many verifications can be made offline using virtual simulations, but a comprehensive end-to-end work process solution is still needed.

This area focuses on developing solutions for planning and developing production systems in a fully digital model, including layout, flow, equipment control, safety, and personnel competence. The goal is a holistic and flexible development process. Digital Twins should encompass product and process life cycles, including remanufacturing, environmental footprint, and support for circularity.
Decision makers need advanced decision support tools that enable efficient work by providing prompt, trustable, and accurate answers. Usability, availability, and understandability are of importance for organizations' benefit and commitment to use these tools. Generative AI also enables rapid generation of models, configurations, and optimization alternatives based on goals and constraints, supporting human designers with explainable and flexible solutions.

Production systems must be continuously optimized to adapt to changes in product mix, volume, and sequencing. Self-Adaptive Cyber-Physical Systems—such as Digital Twins—offer significant potential to meet this need. These systems depend on effective data collection, decision support based on well-structured mathematical models, intelligent optimization tools, and robust management.

Technologies like the Industrial Internet of Things (IIoT), Artificial Intelligence (AI), Machine Learning (ML), and Big Data can enhance traditional methods and support physics-based modelling and simulation.

Identified R&D Topics

Specific scouting areas (with identified technology R&D initiative needs):

- How to design production systems right from scratch and increase utilization of digital solutions
  - Expand the use of digital solutions for simulation, analysis, and optimization to streamline planning, design, setup, and verification of production systems. Key focus areas include interoperability, digital thread efficiency, user interfaces, data trustworthiness, and holistic modelling and simulation.
- Strategies and approaches towards production transformation
  - Develop strategies for production transformation, including digital tools for sustainability simulation, optimization, and material traceability to enable circular supply chains.
- R&D technology topics to be addressed, include:
  - Maintain up-to-date digital representations of production systems using 3D scanning, photogrammetry, and CAD, covering facilities, resources, and tooling.
  - Integrate data from diverse sources to enable seamless model exchange between suppliers and stakeholders and ensure complete verification workflows.
  - Enhance simulation and AI performance through efficient programming and High-Performance Computing, enabling more testable models and reducing set-up and commissioning times.
  - Model functions, data structures, and formats across various levels of the production system to support system-wide consistency.
  - Drive the effective use of simulation tools and methods for continuous, cross-functional analysis and optimization, supporting both technical and organizational change.
  - Apply simulation and optimization technologies for informed decision-making at all organizational and supply chain levels.
  - Embed simulation-based, multi-objective optimization into process development and production management to maximize operational impact.
  - Leverage data from data lakes, information backbones, and legacy systems to improve machine learning, simulation, and optimization outcomes.
  - Explore the use of generative AI to automatically generate simulation models, process configurations, layout alternatives, and control code based on goals, constraints, and input data.
  - Utilize synthetic data generated by AI models to support training of ML algorithms, virtual commissioning, and rare event simulations.
  - Develop interactive generative AI assistants to support engineers in analysing data, navigating digital twins, and producing documentation and decision materials.

Wanted Effects:

- Efficient planning and simulation with Digital Twins throughout the process development life cycle, reducing resource use and optimizing solutions.
- Improved productivity, energy efficiency, quality, lead times, and ramp-up speed.
- Robust, optimized manufacturing systems and processes across organizational levels.
- Rapid adaptation to change, reliable support for continuous improvement, and sustainable decision-making.

- Integration of sustainability and circularity in manufacturing simulations to reduce environmental and climate impact.
- Increased efficiency and innovation in system development through AI-generated design and simulation alternatives, combined with interactive and explainable AI tools that support engineers and decision-makers throughout the workflow.

3.7.2 Capability of virtual tools

The capabilities of the tools used in development and in production.

Aim and Vision:
Virtual tools for manufacturing support engineering from product development to production development to production operations whereby gained experience is fed back along the whole life cycle of products and production systems. Digital tools are seamlessly integrated, require little training, and provide capabilities and qualities that support decisions. Integrated models of various purposes and scope define the system and drive the development process. The physical production plant is mirroring the models. The models are part of the Cyber Physical Production System. Generative AI offers new opportunities for virtual tools, including automated generation of simulations, layouts, and control logic based on data and engineering intent. It can support model creation and verification and reduce manual effort and improving quality. Integrated explainable AI can provide real-time support to users, enhancing decision-making in complex development tasks.

R&D Area Description:
Virtual tools are essential for manufacturing support engineers, both for developing and operating production systems and for addressing manufacturing-related aspects of product development. One key challenge is ensuring that tools have the right capabilities for specific tasks. While commercial tools exist for many applications, others remain active areas of research, as new capabilities are needed to meet emerging demands—some of which may align with topics in other clusters. Another challenge lies in how well these tools support engineering methods and processes. For instance, just because a tool can simulate a particular aspect does not mean it is effective or practical in real-world workflows. Research is needed at the intersection of methods, processes, and tool capabilities. A further related challenge is the integration of various models and the need for traceability and model management. Engineering processes depend on multiple interconnected models and tools that must work together seamlessly.

Identified R&D Topics:
Specific scouting areas (with identified technology R&D initiative needs):

- How to realize the increased potential in the capabilities and quality of the digital tools
    - Develop intuitive, user-friendly tools and interfaces for assembly processes, with improved functionality and automation tailored to user needs. Emphasize faster software, cloud-based data storage, and robust cybersecurity. Leverage emerging technologies like AI, AR, VR, and IoT to enhance production efficiency and safety.
    - Enhance the efficiency, usability, and creativity of virtual engineering tools through generative AI—for automatic creation, refinement, and evaluation of models, layouts, and control logic—and by integrating interactive, explainable AI assistants and adaptive interfaces that provide real-time, context-aware support and reduce training needs.
- How to secure seamless information flow to/from digital tools
    - Emphasize the role of terminology, legacy content, and standards in digital models for production system digitalization. Address implementation aspects such as tool capabilities, usage practices, working procedures, and cost considerations.

- How to secure user friendly solutions, related to the two previous bullet points above
  - Optimize work instructions and digital data management by developing adaptable instructions, standardized digital interfaces, and clear identification of information needs. Emphasize ethical data handling, user-friendly interfaces, and 3D modelling to improve communication and usability.
- Key R&D Technology Topics:
  - Tools for modelling, simulation, and optimization of product-process-resource interactions.
  - Modelling methods and formats that enable effective data transformation and communication.
  - Evaluation of layout configurations.
  - Planning of control systems and virtual commissioning.
  - Efficient use of visualization, immersive technologies, motion capture, and ergonomic assessment.
  - Reduced manual modelling and engineering workload through AI-assisted generation and refinement of virtual models and simulations.
  - Increased innovation and solution space exploration enabled by generative AI suggestions in early design phases.
  - Enhanced user confidence and efficiency through AI-based real-time support and recommendations within virtual engineering tools.

Wanted Effects

- An organization that naturally integrates virtual tools into daily work, using comprehensive, accurate, and detailed virtual models to support decision-making.
- Improved mental models for engineers, enhancing understanding and awareness.
- Reduced time spent on model creation and more efficient data transfer between simulations.
- Greater sustainability and resource efficiency across the entire project life cycle, with reduced downtime and cycle time.

3.7.3 Design of automated systems

The design and operation of the production system with large elements of digitization and human involvement.

Aim and Vision

To improve competitiveness and sustainability, Swedish industry must adopt automation for low-volume, high-product mix scenarios. Flexible and energy-efficient systems should combine hardware, software, machines, and humans, utilizing Cyber Physical Production Systems. Modular and programmable equipment will create adaptable, reusable systems with self-diagnostic features and user-friendly human-machine interfaces. This will improve work environments and allow for safe collaboration between humans and robots. The goal is to develop safe and efficient information system architectures for production systems.

R&D Area Description

To cope with the increasing demand for customization and shorter time-to-market, Swedish industries need flexible and modular automated systems. This will allow them to quickly reconfigure and adapt to changes, while also supporting the transformation into lean manufacturing. New materials and product technology will also put requirements on materials handling, fixturing, and joining methods.

Collaborative robots and new safety systems present opportunities for creative solutions in automation. However, as automation systems become more complex, end users need simplified and intuitive human-machine interfaces (HMIs) to manage them, as well as the ability to handle unusual events or failures. Recent advances in generative AI offer new possibilities for automating the design, simulation, and configuration of automated systems. These include AI-generated control logic, layout proposals, and interaction scenarios between humans and machines. Integrating explainable generative AI into human-machine interfaces can support operators and engineers with real-time guidance, troubleshooting, and knowledge sharing, even in complex or unfamiliar situations. The development of new technologies such as augmented reality and mixed reality can also provide new communication and information solutions. This research area aims to increase sustainability, reduce perceived complexity, lower workload, and increase system awareness and safety for end users. It also focuses on information system architectures, modular solutions, and upskills to improve the performance of production systems.

Identified R&D Topics

Research sub-areas:

- Design of sustainable systems for automated manufacturing
- Human-machine collaboration.

Specific scouting areas (with identified technology R&D initiative needs):

- Solutions for minimized downtime:
  - Utilize business modelling, model-based engineering, sensors for data collection, and AI-driven analytics to optimize system design based on stakeholder needs.
- Root Cause Analysis for predicting dynamic systems:
  - Develop AI-based work procedures and software for data collection, analysis, and visualization to identify root causes in complex systems.
- Automated quality assurance
  - Leverage AI, data fusion, sensors, and 3D vision for anomaly detection, traceability, and improved reliability, while addressing data ownership and result interpretation challenges.
- Efficient and flexible Information system:
  - Implement Industry 4.0 technologies, resolve communication issues between legacy and new systems, and ensure cybersecurity, cloud integration, and alignment with semantic models.
- Human robot collaboration / Flexible automated system:
  - Tackle challenges in human-robot collaboration, including communication, safety standards, productivity, and non-permanent tasks like assembly, with a focus on collaborative end-effectors.
- Use of generative AI for adaptive system design and decision support:
  - Explore how generative AI can automate system layout generation, control logic design, and dynamic reconfiguration. Develop AI-based assistants that support operators and engineers with real-time insights, simulation, and training scenarios.
- R&D Technology Topics:
  - Develop cost- and energy-efficient systems combining collaborative robots, safety features, and flexible automation for rapid production ramp-up.
  - Ensure safe integration and competency across diverse automation types, including collaborative robots and human operators.
  - Create modelling techniques and ontologies for modular, reconfigurable, and reprogrammable systems.
  - Explore new manufacturing processes like 3D printing, low-volume automation (Karakuri), and sustainable reconfigurable solutions.

- Integrate Cyber-Physical Production Systems and advanced sensors for enhanced process monitoring, control, and safety.
- Leverage wireless and 5G technologies to reduce time-to-market, lower costs, and improve commissioning and operator training.
- Develop software solutions that enable easy modification without coding.
- Streamline project management, manufacturing, and tracking of parts using digital twins, 3D scanning, and progress monitoring for end-user environments and installations.

Wanted Effects

- Reduce energy consumption over the lifetime of automation systems.
- Boost efficiency through flexible handling of varying product types and volumes.
- Enable rapid reconfiguration and programming without external experts.
- Enable operator use without advanced automation skills, supported by personalized guidance and real-time information.
- Standardize interfaces and modular systems for easy reuse and adaptation.
- Improve design cycles, maintenance, and virtual commissioning for faster, cost-effective, high-quality execution.
- Cut project lead times, floor space, and tied-up capital.
- Use model-based design for efficient low-volume production and better system integration.

3.7.4 Manufacturing data use and analysis

Collection, management, and efficient use of data from production and development work.

Aim and Vision

Efficient management of industrial data is crucial for digitalization of the manufacturing industry. Data collected throughout life cycle from various data sources, such as factory design, product design, process planning, simulations, production, and follow-up can be coordinated through a common information framework. The vision is that digital information is easy to access, trace and manage, using standardization of data format and interfaces as a tool. This will improve the efficiency, sustainability, and adaptability of manufacturing systems, as well as enable circularity approach. The overall vision is to enable analysis and decisions based on up-to-date, coordinated, and usable digital information from various sources.

R&D Area Description

A key challenge in this area is managing scalable capabilities to create, collect, store, model, process, trace, share, analyse, and visualize data in industrial applications. This involves handling vast amounts of data and data streams related to materials flow, capacity analysis, product design, process planning, factory installations, production data, quality control, operation, and maintenance.

Virtual engineering tools should be used throughout the product life cycle, with models interoperable with data from various stakeholders. Integrating and securing engineering and operational data is crucial. Future research will focus on IoT, edge computing, cloud solutions, blockchain, big data analysis, and stream-based processing. Data analysis, AI and machine learning will be used for industrial analytics, predictive maintenance, and data-driven decision-making, aiming for resource-efficient data use to enhance manufacturing systems' efficiency, sustainability, and adaptability. Recent advances in generative AI offer new capabilities for data-driven manufacturing. This includes AI-generated insights, reports, and predictive scenarios based on large, heterogeneous datasets. Generative AI can assist in automatically building or refining data models, suggesting relevant analysis paths, and enabling intuitive access to data through natural language interfaces.

These technologies support more efficient, consistent, and explainable decision-making in dynamic production environments.

Facilitating the sharing of models and data among stakeholders, regardless of application or system (such as those in product design, manufacturing, and production equipment supply), is crucial. These models should be used throughout the system's lifecycle and be compatible with component models, including functions, dimensions, tolerances, kinematics, and dynamics. This ensures the integration of simulated and operational data, exemplified by digital twins.

Identified R&D Topics

Research sub-area

- Management of production-related life cycle data
- Utilizing data to enhance efficiency, sustainability, and adaptability.

Specific scouting areas (with identified R&D needs):

- How to choose, collect, process and present data in the era of big data?
  - Ensure data availability, quality, security, and effective analysis. Establish guidelines and standards to create value from digital infrastructure and information.
- Enabling Sustainable Use of Data as a Resource?
  - Conduct holistic analysis of sustainability and circularity. Manage the life cycle of product and manufacturing system data, from design to production and service remanufacturing/recycling. Leverage data for industrial analytics, predictive maintenance, and data-driven decision-making to improve production processes, including adaptation of work processes and methods.
- Managing Information in Complex, Evolving Systems?
  - Develop models (e.g., digital twins) to capture and interconnect aspects of products, business, and production systems during their life cycles. Define methods to trace model dependencies (e.g., digital thread) and manage change in large, interconnected systems. Create reference models linking manufacturing activities with the data types and qualities used.
- Applying generative AI for data synthesis and decision support
  - Investigate how generative AI can support synthesis of insights from diverse data streams, enhance model completeness, and generate predictive scenarios. Explore AI assistants that support users with tailored insights, documentation, and simulation-based suggestions.

Wanted Effects

- Continuous data flow for acquisition, storage, management, sharing, reuse, and recycling, with standardized formats for efficient sharing.
- Enable access to relevant, synchronized data for fast, informed decisions, with intuitive interaction with digital models.
- Standardized, adaptable information frameworks and generic models to define data needs across stages, supported by demonstrators for PLM implementation, especially in remanufacturing.
- Enable efficient data collection and use for sustainability and circularity in product development, including service and take-back.
- Improve remanufacturing, recycling, and aftermarket support to enhance serviceability and reduce lead times.
- Simplify product assembly, maintenance, and reassembly while lowering life-cycle costs and environmental impact.

3.8 *Production Management*

The Production Management cluster is a Swedish R&D collaboration focusing on the role of production in the industrial transformation and the ability to proactively manage challenges such as green, digital, and competence transitions in parallel. Our vision is to enable the development of production systems that create sustainable benefits for people, the environment, and the economy in a landscape of rapid changes and uncertainties. This requires a holistic perspective on sustainability considering economic, environmental and social aspects, and emphasis on production strategies, production system design and industrialisation, as well as daily operations.

To realise the vision of sustainability and resilient goals, including net zero targets, the manufacturing systems are acknowledged as the core of industrial transformation. The desired future state includes manufacturing systems designed for low emissions, strong environmental accountability, and leadership at all levels. Integration across organisational functions and the systematic use of digital solutions are critical enablers – together with an empowered and sustainability-literate workforce. Scenario-based decision-making and system-level strategies are necessary to foster resilience and sustainability across both global and local contexts. The Production Management cluster focuses on industrial issues and R&D areas related to:

i. Production Strategies (Planning what to do),
ii. Production System Design and Industrialisation (How to do it), and
iii. Daily Operations (How to manage, control, and improve).

Current state of practise varies across companies and sectors. There is high awareness and ambition, but organisations often lack integrated structures to translate strategies into practice. There is a need to embed sustainability in operational routines, clarify terminology, and foster bottom-up engagement on the shop floor. Realising sustainability vision within companies requires new forms of collaboration across traditional functional and organisational boarders, competence development, and systematic use of existing knowledge and tools.

Production systems also play a key role in regional development, education systems, and labour market resilience. As such, sustainable production must contribute not only to competitiveness and environmental goals, but also to inclusive growth and the long-term attractiveness of industrial work in society.

Core perspectives and the strategic importance of the Production Management research area for a sustainable industry

Future competitiveness and climate-neutrality depend on how we design, manage, and operate production systems. Core perspectives, forming the foundation for the Production Management cluster's research agenda covers:

- *Sustainable systems must include economic, environmental, and social goals:* Strategic alignment and system design must enable regenerative business models that support circularity, resource efficiency, and good working conditions.
- *Integration, adaptability, and broad engagement are key enablers:* Digital tools, human-centred design, and active learning cultures that foster continuous skills and competence development are essential for successful transitions.
- *Production systems shape both competitiveness and societal development:* Their role extends beyond factories – influencing education, regional growth, and the long-term industrial attractiveness

These perspectives form the foundation for the Production Management cluster's research agenda.

The following R&D areas reflect how production strategies, system design, and daily operations must evolve to support sustainable industrial transformation. Each area addresses specific capabilities, and knowledge needs critical to achieving circularity, resilience, and competitiveness in a rapidly changing industrial landscape.

3.8.1 R&D Area: Production Strategies

Aim and Vision

Innovative processes and dynamic strategies are needed to meet the increased speed of change in a global market affected by major challenges. Supported by strategic decision processes involving scenario-based planning, methods, guidelines and roadmaps. These strategies must also enable the transition towards sustainability and resilient goals by actively promoting and supporting the product and production development practices. This includes a balanced approach to global and local production, strategic investments in renewable energy and electrification, circularity, and ensuring leadership across all organisational levels. Strategic roadmaps should adopt a system perspective that includes technological aspects, environmental responsibility and emission reduction, as well as organisational and human factors such as skills and competences – thereby embedding sustainability at the core of strategic decision-making.

R&D area description:

Manufacturing companies and suppliers in Sweden operate on a global market, and to remain competitive, they must be intelligent and innovative in this constantly changing environment. However, increasing global uncertainties related to climate change and changes in foreign policy have made global supply chains more vulnerable. Therefore, it is crucial to consider new business opportunities and sustainability dimensions of local versus global manufacturing.

Strategic coordination across different functions and actors is increasingly important to achieve environmental sustainability targets. Integrated efforts across the value chain, with joint planning and scenario-based strategies, are required to handle uncertainty and guide investment decisions. Technology roadmaps should connect short-, medium, and long-term sustainability efforts to measurable emission reductions, utilising digital and data-driven tools.

R&D topics

Strategic planning & transitions

- Scenario-based planning
- Coping with "twin/triple transitions"
- Alignment of sustainability strategies with core business planning
- Integration of emission reduction targets in production planning

Business models & global/local balance

- Balancing of global and local production
- Business models to enable circular economy transformation
- Production strategies and innovation processes

Collaboration and leadership

- Strategic stakeholder collaborations
- Leadership development for sustainable transformation

Competence and digital enablers

- Competence supply strategies within new fields
- Systematic use of digital tools in strategic decision-making

Expected impacts
Sustainability and industrial competitiveness through innovation and transformation ability. A well-developed production strategy enables companies to scale sustainable practices from pilot projects to full implementation. It also strengthens their ability to respond to external demands, such as environmental reporting and traceability requirements. The result is a more resilient, adaptive, and future-ready industry, with production systems aligned to sustainability and resilience goals and global benchmarks.

3.8.2 R&D Area: Production System Design & Industrialisation

Aim and Vision
Establishing resilient and sustainable production systems requires the integration of holistic and long-term perspectives. The goal is to ensure optimal use of resources, minimal waste, and a focus on the human dimension in product realization processes. System design should also support sustainability goals by enabling circular material flows, low-emission operations, and energy efficiency across the production life cycle. This includes strategies for reuse, upgrading, and longevity of production equipment, as well as integration of maintenance, digital infrastructure, and traceability solutions already from the design stage.

R&D area description:
The design phase of the production system is critical to enable cost-efficient, resilient, and sustainable production with circular economy prerequisites in the value chain. Factories need to be designed for flexibility and fast transitions due to swift changes in society and market needs. Thus, methods and tools need to support a system perspective in the design of factories, production flows, and workplaces.

There is a need for flexibility for manufacturing of product variants, primary products and secondary products for potential businesses, customisation, tests and possibilities for scaling, training, education, and communication with internal and external stakeholders. Also, early development phases require a constant interaction and mutual understanding related to the product design, advanced information systems, and manufacturing system design.

The system perspective is key – production systems must be designed to meet both current and future demands while supporting sustainable value creation. There is a growing need for digital twins and simulation tools to support lifecycle-oriented decisions and enable proactive redesign as sustainability targets evolve. Designing for sustainability also requires early integration of energy supply strategies, environmental monitoring, and data infrastructure that supports continuous learning and improvement. Furthermore, future production systems must be integrated across organisational and technical domains – from product development and manufacturing to logistics, energy infrastructure, and end-of-life processes – to enable coherent value chains aligned with circularity, net zero, and long-term sustainability goals.

R&D topics

System design for sustainability and flexibility
- Design of production systems for present and future business value
- System design for low-emission operations and energy efficiency
- Flexible infrastructure to scale new production needs and business models
- Circularity in system and equipment design (reuse, upgrade, lifespan extension)
- Human-centred design, competence development

Digitalisation & data integration
- Digitalisation, data management and cyber security

- Digital twins and simulation for sustainability impact assessment
- Integration of sustainability KPIs and data tracking from design phase

Collaboration & flow
- Solution-oriented collaboration in end-to-end flows
- Strategic maintenance: design, AI, traceability, management

Entrepreneurial & systemic innovation
- Entrepreneurship and intrapreneurship
- Integration of environmental and social/human aspects in production system design

Expected impacts
Resilient and sustainable production systems that can efficiently manoeuvre during unpredictable and swift changes in both local and global markets. Products and production systems are jointly developed enabling circularity, flexibility, high performance, efficient scale- and ramp-up, predictability and advanced decision support, intelligent maintenance, and socially sustainable work and workplaces.

Designed-in sustainability enables organisations to bridge the gap between pilot projects and large-scale transformation, increasing their ability to scale circular and low-carbon solutions. With systematic digital support and interconnected infrastructure, production systems will be capable of adapting over time, fostering continuous innovation and alignment with sustainability and resilience goals.

3.8.3 R&D Area: Daily operations

Aim and Vision
Competitiveness through recruiting, developing, and maintaining talents to the industry with empowered, motivated, healthy, and skilled workforce at all levels over time. To contribute to the sustainability transition, daily operations must be rooted in a holistic culture of sustainability and continuous improvement, with employees actively engaged in achieving environmental and operational goals. Empowering the workforce with "green skills" and promoting bottom-up engagement, competence development, and role evolution are key levers for accelerating change and fostering innovation on the shop floor.

R&D area description:
To run a flexible production system of large scale is a challenging task that requires competent, motivated, and healthy people from different fields of expertise and organisations to join forces, efficiently and effectively. There is a need to attract young talents and to create prerequisites for individual and organisational development. New approaches, methods and tools are needed to support leadership and agile work practices.

Although many companies today have sustainability experts, these roles are often not fully integrated into operational and development work. There is a growing need to align sustainability efforts with everyday production practices, including structured involvement of operators and technicians. Furthermore, organisations must manage the increasing pressure from external demands, such as environmental reporting and traceability, which require daily data input and quality.

Addressing competence gaps is becoming critical – particularly the need to combine domain/process knowledge with digital and environmental skills. The industry must invest in continuous workplace learning and make use of digital technologies to support inclusive upskilling and reskilling, while also maintaining well-being, safety, and long-term attractiveness of industrial work. Daily operations must also support continuous organisational learning and adaptability. This includes enabling employees to take active part in changes and development work, cultivating a culture of active and shared ownership, and building capabilities to manage transitions in complex and uncertain environments.

R&D topics

Leadership, engagement & learning

- Leadership and employee development
- Hybrid work and coaching leadership managing complexity
- Green skills development and lifelong learning for sustainability
- Methods for fostering employee engagement, skills and competence development in transition processes

Digital tools & data in daily operations

- Utilisation of big data, real-time data, AI, data ethics
- Digital tools for real-time environmental monitoring in operations
- Utilization of digital technology for competence supply practices

Culture & collaboration

- Inclusive culture, seamless collaborations, autonomous teams
- Workplace innovation
- Cross-functional team building for collaborative improvements
- Human-Technology-Organisational interaction

Work environment & sustainability

- Physical, organisational, and psycho-social work environment
- Socially sustainable work
- Industrial labour relations
- Integration of sustainability in daily routines and shop floor practices
- Sustainable development in organisations

Expected impacts

A key capability for resilient operations is the ability to identify and manage critical work practices — those activities and interactions that become decisive in times of rapid change or operational pressure. By making these practices visible and supported, organisations can strengthen their ability to act, adapt, and learn during transitions and implementation of changes. Efficient production systems and workplaces are characterised by continuous improvements and innovation, diversity and inclusiveness, cultural efficiency, empowerment, individual and team development. Skilled, healthy, and motivated people. Systems in place for competence management to attract, recruit, develop, and retain talented people. Employee empowerment, active engagement, and innovative development. Working life balance, attractive work and strong company branding.

A strong operational culture that supports sustainability goals will improve companies' ability to move from pilot testing to full-scale implementation. By fostering employee engagement, tracking relevant KPIs, and investing in resilient competence strategies, companies will be better positioned to lead sustainable industrial transformation. In the long term, this enables a future-ready workforce, improved retention, and a production environment aligned with sustainability and resilience goals.