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THE SWEDISH
Manufacturing
R&D Clusters

Swedish Automotive Industry Needs of Manufacturing R&D towards 2030

- Continuity and change, requirements for global competitiveness

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1 Introduction

The aim of this document is to give a description of the Swedish Automotive Industries common need for future production research. It is put together by the Swedish Manufacturing R&D Clusters and this is the 8th edition of the document.

1.1 Background

The Swedish Manufacturing R&D Clusters is an organization that was started in 2006 by the vehicle manufacturers in Sweden and the automotive suppliers group. The trigger was the MERA program (Manufacturing Engineering Research Area) that was setup to support vehicle industry in Sweden (search for MERA at www.vinnova.se). 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.

After more than ten years of collaboration, the Swedish Manufacturing R&D Clusters, have become a sound platform for initiating new research activities within manufacturing R&D. As Sweden's R&D resources are relatively limited, it is important that these scarce resources are used efficiently. The cluster work is a way to join forces in areas where there are shared interests.

The cluster organization is a network of experts in manufacturing technology and processes, from industry, institutes and academia. The cluster structure have evolved over time and today there are 9 clusters focusing on different manufacturing expert areas, see Figure 1. Four of the clusters cover main manufacturing processes and five clusters covers areas that support all manufacturing processes. The clusters are coordinated by a management group and are also supported by a strategy board.

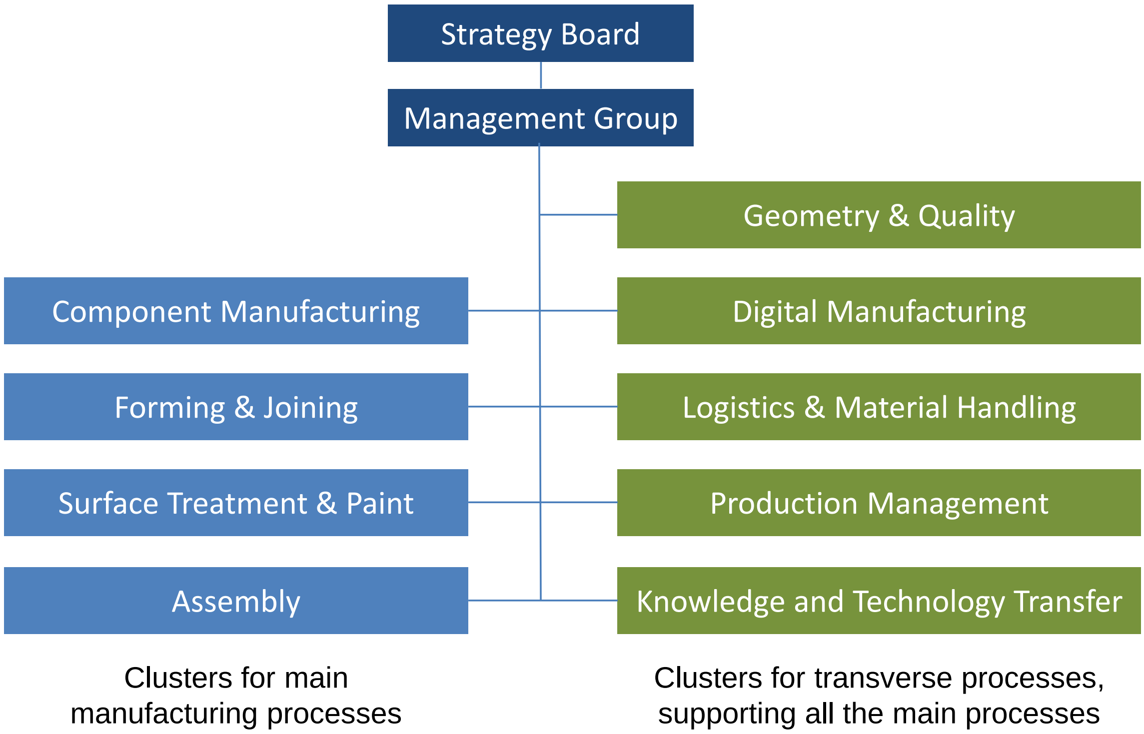

Figure 1 Cluster structure.

Each cluster is led by a person from industry, supported by a coordinator from an institute or university. These clusters are continuously reviewing the research needs in each specific area. The programmatic needs described in this document are based on work conducted by these clusters.

The cluster organization is open to all manufacturing-related initiatives aiming at strengthening and developing the competitiveness of automotive and other industry in Sweden, and we welcome other companies to learn from each other and work together with us on this. More information, and this document, can be found on the Swedish Manufacturing R&D Clusters homepage www.produktionskluster.se.

2 Overarching Automotive Manufacturing R&D Needs

Some of the most frequently occurring words describing the development trends in industry today are Digitalization and Automation. In vehicle industry Electrification can be added to the list of dominating trends. The demands on minimizing the environmental footprint have led to vast investments in development of driveline technology and lightweight design. Another strong trend is the development of safe traffic solutions and vehicles. Here the use of automation and digitalization is utilized to find new smart safety system solutions.

Other well-known challenges in the western world are demographic unbalance with an aging population and problems to attract young people to jobs in industry. Equality related to gender, age, culture and other aspects will remain important.

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 three main themes:

- *Resouce efficient manufacturing for decreased environmental impact and strengthened competitiveness*
- *Robust and efficient production of new products, functions or features*
- *Smart manufacturing engineering/industrialization process*

2.1 Resource efficient manufacturing for innovative companies, attractive workplaces, decreased environmental impact and strengthened competitiveness

To reach full integration of economic, ecologic and social sustainability in development of production the entire production system, including all manufacturing processes, needs to have high productivity, high quality and delivery precision, short lead-times, as well as high flexibility to manage a high number of variants and variation in volumes. Moreover, the capability to continously improve operations and work on innovations is crucial.

The vision is that the complete production system is environmentally neutral and that there are closed loops for waste and energy, as well as for manufacturing equipment. There shall be methods and manufacturing technology solutions to constantly decrease the amount of material, media and energy. Waste in all forms shall be eliminated.

To secure long-term availability of skilled work force the plant processes shall be developed to fit the human being prerequisites. The human qualities shall be utilized for the right things. Life-long learning and a healthy working environment with supportive organisational structures shall be promoted. This needs to go hand in hand with the automotive industrys requirements on mass customization and productivity improvements without sacrificing quality aspects. To meet this put high demands on well functioning logistic systems and production planning combined with flexible and efficient manufacturing with high space utilization rate, low manufacturing costs, and efficient supply of components. The entire manufacturing system, including the supply chain, must be included.

Digitalization within this area focuses on on-line equipment and systems to enable data analyses, planning and control to optimize the manufacturing system. A connected manufacturing system shall also be able to provide tools to create a flexible set-up quickly adjustable to meet new market demands.

2.2 Robust and efficient production of new products, functions or features

To support the offer of new customer values is an obvious and necessary capability for manufacturing systems to sustain competitiveness. Independent of how this customer value is created - new products, new business models, new material or new software – the manufacturing system need to manage this with sustained level of efficiency and quality. Methods to radically reduce manufacturing ramp-up time for new material and material combinations needs to be developed. Furthermore, the ability to set up product plans and business models to ensure high life cycle efficiency will be decisive for success.

The manufacturing system also needs to be flexible in terms of what design materials it needs to handle and be open for integration of new technologies related to these customer values. This means for instance that when more new material is introduced, the development need of all technologies and processes needed to create competitive manufacturing systems will follow. There is also a need to develop new alternative solutions in case of situations of raw material shortages. To get a sustainable society is also about making recycling and reuse of products feasible on industrial scale.

To produce high quality premium products methods for quality assurance will continue to be important. Each step of the manufacturing process need to be controlled and manouvered to get predictable outcome. Ways of working, methods and tools need to be developed to include new materials, features and functions.

In parallel to increased software content in the vehicle and its components, the demands in production to manage ”assembly” of these in an efficient and quality proof way. This includes raising need of competence, strategies and methods for correct software download and verification of function.

2.3 Smart manufacturing engineering/industrialization process

The challenge is to design a production system that meets the manufacturing process requirements of today, yet opens up to adjust to new future demands. This needs to be met without jepordizing productivity, lead-time and the human work environment. As prerequsites and limitations are set early in the desing process, it is importand to consider these aspects from start.

Short lead-time from product/concept idea to market is crucial for competitiveness. The development of an efficient manufacturing system is a vital part of this process. It is important to early on be able to assess manufacturing aspects of the product design. To give high quality feedback early in the process that enables manufacturing adaption of new product concepts is a key factor to achieve efficient and effective manufacturing. Extensive testing and long ramp-up can be substantially reduced if all manufacturing aspects are included already when the manufacturing system is specified and designed.

Computer support and virtual tools are fundamental to enable development of future production systems in a smart and efficient way. The vision is that no physical test objects or manufacturing processes will be needed. This requires that all affecting factors needs to be included by virtual methods (Design for X – DFX). Efficient and user friendly virtual tools are needed to make complete assessments to develop an optimized production system with as few prototypes as possible. Tools and methods to optimize work station design need to be included to assess all aspects of manufacturing and effects on the humans in the manufacturing system, physical as well as cognitive.

To realize this digitalization and automation of data flows, processes, methods, tools and engineering work will have a big impact. Digitalization of the different steps drives automation by connection of steps and automation of work processes. By combining different sources of information, calculations, visualisation and analysis new and improved decision support are created. Artificial intelligence can be used to support decision making when a large spectra of solutions can be studied to find the most optimal choices.

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 main 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 as a result of these R&D needs are continuously defined and updated by the Clusters. Please contact the Clusters if you need information about this.

3.1 Component Manufacture

The component-manufacturing cluster is devoted to advancing the manufacture of engineering components, mainly in metals. Focus is on development of 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:

- New high-performing materials and tailored material properties under specific manufacturing processes.
- Machining processes such as turning, milling, drilling, boring, grinding, and finishing methods (including abrasive finishing).
- Forming and casting processes, including cold and hot forming and sintering.
- Surface and heat treatment processes such as case- and induction-hardening, plasma and ion spraying, texturing and shot peening.
- Additive processing and joining technologies.
- Robust manufacturing (including quality assurance and statistical process control).
- Performance characteristics of machine tools and process-machine interactions.
- Industrial robots.
- Cutting tools, forming tools, grinding tools and abrasives.
- Handling of tools, pallets and components in the manufacturing system.
- Process fluids such as lubrication-, cooling- and cleaning-fluids.
- CAM, preparation of work instructions and human machine interfaces (HMI).
- Process planning including modeling, simulation, evaluation and optimization of processes for optimal selection of manufacturing methods and equipment.
- Digital manufacturing technologies: gathering, storing and analysis of machine and process data
- Measuring technology and metrology for dimensions, shapes, surfaces and material properties.
- Approaches to added value through geometrical/microstructural precision.
- Factory design.
- Remanufacturing for Circular economy

Prioritised R&D needs and targets for component are identified within following competence areas:

3.1.1 Human

Aim and Vision: Humans and manufacturing systems should be in balance.
Humans have to have appropriate skills acquired through education and professional training. Every R&D-project should provide education and technology-transfer learning materials in collaboration with the Knowledge & Technology Transfer cluster.

R&D Area description: The manufacturing systems need to be designed according to the humans needs and skills.

We need an 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 shift.

Identified R&D topics are:

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

Expected impacts:

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

3.1.2 Line

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

R&D Area description: With shorter product life cycles and fluctuating product volumes we need to be able to quickly change capacity and products. The risk for investments in wrong technologies will increase and result in huge economic wastes. New powertrains with downsized combustion engines for alternative fuels and components for hybrid or electric powertrains have to be manufactured. We need better methods and tools for development and installation of the future production lines.

Identified R&D topics are:

1) Identify the strategic components for future powertrain that could be suitable for manufacturing in Sweden, as for example hybrid powertrains. Develop technology, knowledge and resources for future needs. Definition of principles for factories manufacturing a mix of components for electric and combustion engines.
2) Development of factory design processes supported digital models with standardised formats. Interfaces between systems to be able to reuse, communicate and share models from different sources.
3) Demands of robustness and flexibility of new and existing production lines.
4) Design of efficient production lines / product flow (e.g. type Lean Plant Design). Modular and reconfigurable production lines. Flexible component fixtures and transportation systems (e.g. handling between machines).
5) Development of production prerequisites for electrical powertrains.
6) Flexible and cost efficient line concept for entire product life cycle, including ramp-up and phase out.

Expected impacts:

- 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 continuously improvement and maintenance of running systems.

3.1.3 Machine/Equipment

Aim and Vision: Low lifecycle cost and verified accuracy, stability and reliability to be able to secure product quality and capacity and minimize/eliminate 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 analysing methods that can be used for industrial applications.

Identified R&D topics are:

1) Quicker feedback and corrective actions if problems should occur to minimize the possibility of machine failure.
2) Characterisation of machine tools and manufacturing equipment.

3) Robust and reliable systems for in-line measurement of the manufacturing equipment, such as capability and equipment condition trends.

Expected impacts:

- Lower total cost/produced component, during the lifecycle 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. These should be able to use in industrial applications.
- Machines and equipments 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 of machines/equipment in case of technology shift.

3.1.4 Tools and Process Planning

Aim and Vision: Shorter lead-time in the introduction of new products and faster ramp-up time by introducing new methods and tools for creating, analyzing and verifying manufacturing processes.

R&D Area description: Process planning and 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 also reuse and spread knowledge to new generations of process planners. Typical processes are: casting, forming, machining, heat and surface treatment.

Identified R&D topics are:

1) 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.
2) Virtual manufacturing processes with process chain analysis capability for process planning to be introduced in industry in significant scale.
3) Awareness, utilisation and influence of international standardisation within STEP Manufacturing and other relevant groups.

Expected impacts:

- Reduced lead time for product realisation. Minimising 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 product design and increase competetiveness by new manufacturing technology and rationalise the manufacturing of new materials and material combinations without harming the environment.

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. Examples of such technologies are metal shaping processes as a replacement for metal removing processes. Raw material consumption can be reduced as well as the need for process liquids and its handling is simplified together with improved performance properties of the final product.

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 fit properties.

The impact on environment and health inside and outside 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 are:

Forming topics

1) Forming of powertrain components.
2) Micro and macro structure influence on shape and performance.

Heat treatment topics

1) Influence on distortion.
2) Influence on fatigue properties and optimization of residual stresses.
3) Continuous verification connected to process control

Cutting topics

1) Machining, grinding and fine finishing of high strength hardened steel.
2) Machining light-weight materials, e.g. aluminium, magnesium, composites and combined materials.
3) Methods for minimizing burrs and improved methods for efficient deburring.
4) Ability to predict and manage the machinability due to material batch variations.
5) Machining of near-net-shape components.
6) Machining of additively manufactured components
7) Machining of gears for electric powertrains.

Surface integrity topics

1) Tailor-made engineered surfaces.
2) Abrasive- and "non-conventional" finishing processes.
3) Surface treatment technology.
4) Machining impact on surface integrity.
5) In process metrology of surface integrity.
6) Optimization of the complete manufacturing process to attain required surface integrity.

New advanced materials

1) Casting and machining of high strength cast materials like CGI and ADI.
2) Combinations of different materials in joint structures and components.
3) New steels for induction hardening of transmission components as a replacement for carburising steels.
4) Ultra clean steel for high performance transmission components.
5) Laser welding of powertrain components and additively-manufactured materials.

6) Coatings for powertrain components.
7) Machinability of combined materials and new materials, e.g. magnetic steels (electric powertrains), powder metals and AM-manufactured components.

New combined processes

1) Forging of cast materials.
2) Hot forming and hardening of tubes.
3) Laser welding of components in different materials.
4) Abrasive water-jet machining combinded with for example milling or grinding.
5) Isolation, impregnation and winding of electric powertrain components.
6) Handling higher demands on cleanliness for electric components.

Environmentally friendly (sustainable) manufacturing processes

1) Cold forming of powertrain components
2) New cutting fluids, minimum quantity or dry lubrication, cryogenic machining. Industrially viable cleaning methods and adoption to REACH.
3) Environmentally sound and sustainable quenchants in heat treatment.
4) Development of improved handling of waste and rest materials.
5) Reduction of the amount of energy in idle machines.
6) Regain the energy used for melting and heating of the material.
7) Simulation and evaluation of the overall life cycle assessment (LCA) of manufacturing process chains from an environmental perspective.

Expected impacts:

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

3.2 Forming & Joining

This area is dependent upon the following technology areas:

- Cost effective changeover of manufacturing processes - transforming existing workshops into manufacturing of tomorrow
- Materials technology including formability and joinability of ultra-high strength steels, light-metals and composites
- Stamping dies manufacturing with focus on the complete tribological system
- Forming technologies for sheet metals, extrusions, composites and hybrid materials
- Joining technologies for different materials, material combinations and component geometries
- Forming and joining technologies including equipment, tooling and fixturing
- Non-destructive, in-line testing technologies for forming and joining
- Repair technologies for new materials introduced for forming and joining
- Forming and joining simulations, including robustness studies and sequential simulation of the manufacturing process
- Design for manufacturing, in order to design cost efficient components in advanced materials
- Adaptive in-process monitoring and control of forming and joining

Forming and joining technologies are facing major challenges, as a consequence of the introduction of new, innovative materials leading to significantly reduced body weight. This transition requires new manufacturing concepts.
With increased environmental driving forces, new product design solutions based on new materials and manufacturing technologies will emerge:

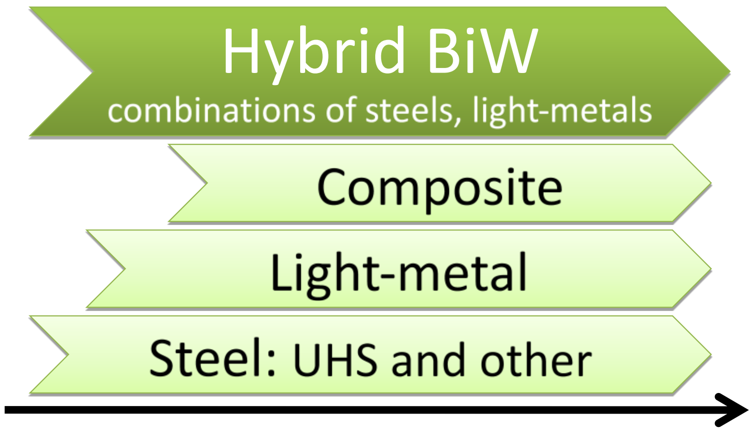

Figure 2 Important areas with need of research.

Prioritized R&D areas and targets selected to support this industrial transition in forming and joining technologies are:

1) Changeover: Minimized and cost effective changeover of today´s manufacturing processes in existing workshops for future generation products.
2) Forming and joining simulations: Improved prediction accuracy for ultra high strength steels, light metals and composites.
3) Forming and shaping technologies: Light-weight solutions for all four material scenarios: hybrid materials and structures, composites, light-metals and ultra-high strength steels.
4) New joining technologies: For future combinations of materials and shapes for all four material scenarios: hybrid materials and structures, composites, light-metals and ultra-high strength steels.
5) Flexible and cost-efficient production systems: Including dies, tooling, fixturing, pre-process, in-process and post-process quality controls and maintenance.

The following programmatic needs and proposals for these areas are identified:

3.2.1 R&D Area: Changeover

Minimized and cost effective changeover of today´s manufacturing processes in existing workshops for the products of tomorrow.

Aim and Vision: Changeover successfully accomplished.

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 or are capable of gradual transformation. The research area includes strategies for choosing manufacturing processes and production equipment with a material flexibility. The manufacturing process shall be flexible and adaptable to also produce future re-designs with minimal CAPEX and process changes.

Identified R&D topics are:
- Material flexible production systems
- Virtual verification of new materials and production concepts
- Handling & fixturing equipment for new materials
- Strategies for choosing manufacturing processes and production equipment

Wanted effects:
- A significant productivity increase in the production processes.
- Production systems with flexibility in volumes and materials

3.2.2 R&D Area: Forming and joining simulations

Improved prediction accuracy for ultra high strength steels, light metals and composites.

Aim and Vision: Safe introduction of new materials and manufacturing processes supported by effective simulation methods.

R&D Area description: Forming simulations are used extensively today. However, 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 spread in the mechanical properties of the incoming material and different process parameters, such as increased temperature. The possibility to simulate friction and wear of dies will increase the possibility to introduce new, low-cost die materials.

Joining simulations are not used as extensively today as forming simulations. There is a large need for this type of simulation, both to study a single joint and also the consequences of, for instance, a spot welding scheme on the quality output and geometrical conformance of subassemblies (virtual pre-matching).

Identified R&D topics are:
- Simulation of spring-back in forming
- Robustness studies of processes
- Joining simulation
- Sequential simulation of process chains, including final geometry
- Effective material models for new materials and process conditions
- Simulation of press and die dynamics
- Simulation of wear in dies

Wanted effects:

- 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.

3.2.3 R&D Area: Forming and shaping technologies

Light-weight BiW-solutions for all four material scenarios: hybrid materials and structures, composites, light-metals and ultra-high strength steels

Aim and Vision: Shorter time to introduction of new materials and material concepts for light-weight automotive structures with high passive safety

R&D Area description: Production of components out 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 in order to enable product designs that offer cost efficient production.

Together with simulation tools, tests on the forming properties of different material systems, are required to provide the support needed for the 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 the feasibility of the design prior to production.

Several of the new materials available are still immature when it comes to large volume production, wherefore 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.

Identified R&D topics are:

- Material testing of new materials
- Formability of advanced sheet materials
- Innovative forming technologies
- High volume manufacturing processes for new automotive materials
- Manufacturing driven product design

Wanted effects:

- 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.

3.2.4 R&D Area: New joining technologies

Future combinations of materials and shapes for all four material scenarios: hybrid materials and structures, composites, light-metals and ultra-high strength steels

Aim and Vision: Implementation of joining processes, that enables volume robust, high productive and flexible production of advanced materials and material combinations.

R&D Area description: New and improved joining methods need to be tested and evaluated continuously. The industry needs significant amount of information in order to design a part for a new joining method, such as: how the manufacturing process should be outlined, what is required to simulate the process, how much one can rely on the 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.

Identified R&D topics are:

- Joining techniques with small degradation of materials and with small distortion of components
- Joining techniques with good surface appearance
- In-process monitoring for higher quality
- Adaptive control of joining to increase joining robustness
- Optimization of joint configurations to reduce manufacturing cost at specified joint strength
- Hybrid joining
- Cost efficient and volume flexible processes

Wanted effects:

- 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.

3.3 Surface Treatment & Paint

This area is dependent upon the following technology areas:

- Materials Technology (including paint, sealers, BiW materials).
- Corrosion: Development of accelerated corrosion tests correlating to long-term corrosion performance of different coating systems.
- 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 (off-line programming, paint spray & sealant application).
- Equipment and paint material.
- Heat treatment and Geometry assurance technologies (Paint thermal processes and adhesive curing during oven bake cause significant distortions).

R&D areas

- Future Process materials for the Next Generation Surface Treatment of Vehicles with New Combined Materials
- Process Enhancements for Reduced Environmental Impact and Cost Reduction
- The Virtual Paint Shop

Description in General:

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

General targets for paint application:

- 20 % decreased chemical and paint material consumption.
- Reduced energy consumption and environmental impact.
- 10 % increased paint shop capacity.
- Virtual Paint Shop simulation and reduced development time

General targets for pre-treatment:

- 25 % reduction of energy consumption.
- 50 % reduction of material consumption.
- 75 % less waste and a total reduction of the environmental impact.

The following programmatic needs and proposals for these areas are identified:

3.3.1 R&D Area: Future Process Material for the Next Generation Surface Treatment of Vehicles with New Combined Material

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

R&D area description: Today's technique, zinc phosphate and electro dip coating was 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 aluminum surfaces. An alternative is required as it's more common that the substrates used on the vehicles are different materials such as steel, zinc plated steel, aluminum,

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 on truck chassis, as a primer on cabs (Scania) and on components by subcontractors.
There is a need to evaluate where solvent based paints could be used and be an advantage compared to water-based paints. Technology for reducing the emission of VOC (Volatile Organic Compounds) for all paint systems needs to be established.
There are efforts 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.

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 a total reduction of the environmental impact.
- A reduction of solvent content from 15% to 5% in waterborne paints.
- One new approved pre-treatment method with the associated environmental benefits shall be implemented by one vehicle manufacturer in Sweden.

3.3.2 R&D Area: Process Enhancements for Reduced Environmental Impact and Cost Reduction

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 far most amount of waste within the vehicle manufacturing plant. It is also responsible for a significant amount 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 comes from ovens. Air ventilation and heating process baths come on second place. The energy consumption from combustion of solvents from the air can vary a lot due to which technology is used. More than 2/3 of the water consumption comes from the pre-treatment process.

There is a need for reducing the number of process steps in the paint shop and also to minimize the amount of manual work e.g. masking.
Paint loss when spraying wet paints is often causing high costs and negative environmental impact. Reduction of paint loss is done by using electrostatic spraying. When spraying non-conductive materials like plastic materials electrostatic painting is not used today.
The complete virtual paint shop is an enabler to facilitate analyzing and optimizing the painting process in an approach which have not been possible previously.

Identified R&D topics are:

- Ventilating air management including recirculation and use of heat exchangers.
- Low energy and water consuming pre-treatment processes.
- Oven designs and energy 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%.
- Water consumption will be reduced to zero.
- Swedish sub-suppliers to the automotive industry shall be able to meet the environmental and energy demands set by the automotive industry.
- Masking to prevent adhesion loss when gluing windshields can be avoided.

3.3.3 R&D Area: The Virtual Paint Shop

Aim and Vision: User friendly systems and tools will be introduced that shorten implementation and reduce the usage of resources.

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 lab testing of a full BIW and reduce the implementation 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. In order to achieve this far-reaching goal, all available competences need to be gathered and complementary research shall be identified, collated, and implemented. In those cases where subsequent analysis identifies a gap, new research projects are to be initiated.

Programming spray painting robots is time-consuming and costly when the series are small. 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 are:

A. Simulate process parameters such as penetration of chemicals in a cavity, build-up of paint thickness upon spraying, adhesion, etc., as well as simulation of the process flow through the factory. Virtual testing is becoming more and more important as space and time for test bodies in the production flow is reduced.
B. Simulating the heating process in the ovens and its effect on curing of the paint and adhesives as well as the impact on the geometry of the parts.
C. 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 vehicle industry has on both new and present employees.

Validation methods are an important part of both part A, B and C.
Spray paint simulation is needed for all types of paints and all types of spraying equipment. That includes wet paints and powder paints and spray guns and rotating bells both with internal and external loading.

Measurable goals / Expected Results:

- The project shall enable a 15% reduction of paint usage via a more even application and reduced spillage as well as a 10% increased capacity in an existing paint shop. This shall eliminate the need for testing on full BIWs (at the suppliers) with a reduced try-out time at the vehicle manufacturers. The target is that each participant shall complete one trial.
- 40 new trained operators using the new education methods.
- Robot painting of complex 3D products without pre-programming of the robot.
- Simulation of paint film build-up can be done for all types of paints and spray paint equipment.
- Simulation of the oven heating and paint curing for both water- and solvent-borne paints.
- Possible optimization of paint curing.

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 and industry restructuring. 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 digitalisation including automation. 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. Within assembly, some of the major aspects to consider when dealing with these challenges are the people within the assembly system, automation as an enabler for more efficient and flexible assembly, digitalisation that supports assembly, as well as to contribute to the development of new innovative products and assembly systems.

Assembly is connected to the following technology areas:

- Digitalisation enabling effective and efficient assembly.
- Automation: As the cost for automation equipment is continuously decreasing and the performance at the same time is increasing, the benefits regarding flexibility when using for example robots instead of dedicated equipment is becoming economically justifiable.
- In-factory logistics focusing material supply and production flow.
- Human-Machine Interaction: in order 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.
- Material Technology: New lightweight materials, material combinations and functions together with varying levels of automation creates a new field of requirements on all aspects of production, such as how to design, realize and perform new joint methods.
- 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.
- Software downloads/validation: product differentiation is moving from hardware based to software functionality based.
- Geometry/Quality: virtual pre-matching, improved measurement methods, in-line measurements.
- Work organisation and how to manage assembly systems.
- Standardization of work process: Increase productivity, quality, cost and safety.

The main areas for R&D needs within assembly are:

1) Automation and process development
2) Digitalisation supporting assembly
3) People in production
4) Contribute to the development of innovative products and assembly systems

3.4.1 R&D Area: Automation and process development

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 large 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.

R&D area description: There is a continuous improvement of the existing assembly processes which can generate records of invention and singular ideas which any program needs to be open for and encourage. There is also a question on how to further optimize assembly with automation. With the falling prices and improved performance of industrial robots that can be combined with new advanced external sensor systems, a whole new field of flexible automation application has opened up. 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 up the possibility for remote diagnostics of production equipment by experts or suppliers at long distance.

Identified R&D topics are:

- What are the best automation strategies by which automation will enable effective and flexible assembly systems?
- Collaborative robots including i.e. technology, strategy and safety issues.
- How should an assembly system be designed in order 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?

Wanted effects:

- Reduced assembly cost per product with innovation implementation of automation.
- Increased capability to assemble multiple product variants in a given assembly line.
- Significant reduction of the ramp-up and change over/set up times.

3.4.2 R&D Area: Digitalisation supporting assembly

Aim and Vision: Digitalisation 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 new 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, enabling further improvements by iterating between physical and digital reality.

Due to the relatively high manual work and high cost of labour in combination with immense requirements on up-time, assembly is a vulnerable part of the manufacturing system. As such, it is important that engineers and R&D-staff within assembly grasp the opportunity that comes with digitalisation and capture its possibilities in order to further improve the assembly systems.

R&D area description: This R&D area is very 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, digitalisation as an R&D-area is viewed as an enabler of new technology, as well as of new applications for existing ones, all used to further improve the assembly system.

Identified R&D topics are:
Digitalisation 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 digitalisation are exemplified by, yet not limited to:

- Laboratory experimentation and validation: An important topic related to digitalisation is the opportunity to experiment and validate new technology and applications in a laboratory environment. Therefore (as in line with current trends nationally and internationally) testbeds, (or similar) needs to be promoted as an enabler as to how, what and when digitalisation should be integrated into everyday manufacturing and assembly.

- Big data: We know that there will be more data available and accessible in the future. Therefore, we need to learn how to utilise the data in the best possible way within assembly. Also, it is crucial to view this as a whole where everything is connected, and that the creation of such a system goes beyond just connecting components to a network. Within this area, a few examples of assembly-related challenges are:
    - Define relevant information so that the correct data is collected
    - The collection points and intervals
    - The information model for the data
    - The supporting IT infrastructure and overall connected system

- Virtual- and Augmented Reality (VR/AR): As both augmented reality and virtual reality are gaining speed, assembly should capture possibilities from these technologies. As VR/AR becomes cheaper and the technology solutions will be better it will most likely become a standard tool. Examples of application within assembly are:
    - Visualization of instructions
    - Contextual information
    - Training and preparation
    - Ergonomics/evaluation

- Artificial intelligence: New functionality will come as advanced algorithms are developed. This will move towards increased system autonomy. Within assembly, it needs to be defined if and how it should be captured.

- Digital twins/model based design: By having a digital twin the management of data will be better as there will be a common model for all process activities such as design, logistics, production, sales, and aftermarket. As data are put into the model, it will always be available in the latest/updated version. This will also improve the concurrent engineering since everybody working with development simultaneously can see the same information, resulting in i.e. improved product quality and shorter development time.

- The user in a new world of digitalisation: As digitalisation will provide the development and use of new 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.

- Digital factory/Simulation: Implementing the smart factory by using Production and Process simulation tools:
    - How can line balancing tasks be supported by virtual tools so that this task can be performed, if necessary, on a daily basis and enable assessment of how balancing alternatives affect operators' ergonomic conditions?
    - How can simulations tools be developed so that they can calculate the most likely or best path that a human and/or assembly equipment, like for

example industrial robots, will take to assemble a part, separately or in collaboration?
    - How can the simulation tools be linked to and used for efficient off-line programming of assembly equipment?
    - How can simulation tools be developed to support the design and evaluation of the cognitive interaction between humans and information sources in the manufacturing environment?

Wanted effects:

- Connected systems that will provide not only faster and easier integration of new technology, but also increased process control.
- Relevant data visualised in a way that it provides us the opportunity to act on an expected deviation before it occur in reality.
- New 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.
- Able to sort only, correct and relevant information in unique processes.

3.4.3 R&D Area: People in production

Aim and Vision: Manufacturing systems with a corporate culture where development and improvement is a part of the daily work. Technology used (automation, digitization etc.) in cooperation with coworkers. Work that characterizes the co-workers context, competence and independence.

The work must be sustainable, developing, safe and with good ergonomics.

R&D area description:

- People in production
- Interaction human and machine, including IT tools, assembly instructions, HMI etc.
- Humans and machines (HRC) working together side by side or together.
- 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
- Competence, development, skills to drive, maintain and develop the future production system

Identified R&D topics are:

- Collaboration between humans and machines (HRC)
- Digital models and virtual tools
- 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
- Support for people in production, such as, assembly instructions, instructions, verification

Wanted effects:

- People control machines
- Attractive work and work satisfaction
- 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

3.4.4 R&D Area: Contribute to the development of innovative products and assembly systems

Aim and Vision: Product- and production development are run as parallel activities (concurrent engineering) in order to achieve an effective implementation of new innovations in product and/or production processes. The aim and vision is to develop and implement methods, standards and technologies required for these activities to become even more effective than they are today.

R&D area description: New challenges such as new business models, a great customization of products, and a higher level of automation all contributes 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.

Identified R&D topics are:

- What affects have new materials, such as light-weight materials, styling-proposed exclusive materials etc., on future assembly processes?
- How to ensure that increased product variants have no negative effect on assembly quality and productivity?
- What affect have new propulsion systems, self-driving vehicles, enhancement of infotainment systems and associated software etc., 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 in order to achieve high quality in product and process?
- 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)
- 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.

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 (Figure 3). Of main importance is the assurance of product function for the customer. Important for a cost and resources efficient product realization are the tools and methods for task as simulation, evaluation, verification and monitoring. A key enabler for industrial operation are the standards on specification and verification of products and processes.

Geometry and quality is connected to the following technology areas:

- Product design and variant management
- Precision engineering and metrology
- Measurement planning and quality control
- Uncertainty management
- Computer aided design and manufacturing
- Work organization & competence

The main areas for manufacturing R&D needs within Geometry and quality are:

- Product and process specifications and requirement management
- Tools and methods for measurement and quality planning
- Verification technologies and quality control

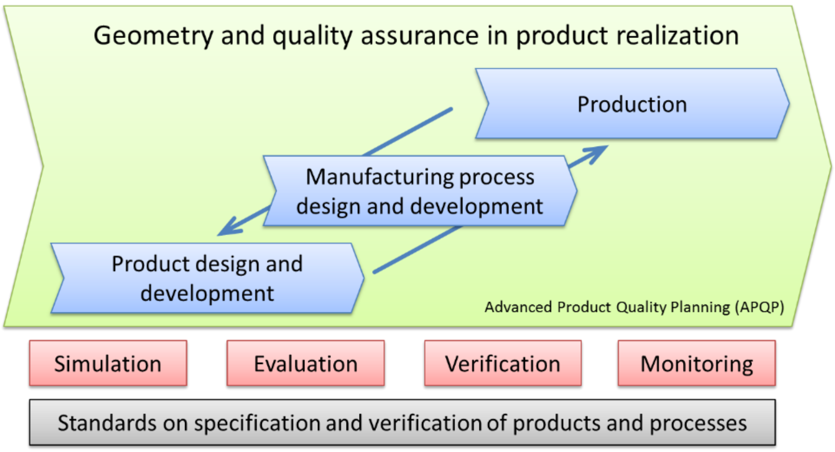

Figure 3 The scope of geometry and quality assurance in product realisation.

3.5.1 R&D Area: Product and process specification and requirement management

Aim and Vision: For product functional assurance are the product and process specification and requirement management crucial. Therefore, it is very important to have both the knowledge and the tools available to define specific demands of the product and as a consequence also for the process which produce the products. By correct definitions of the demands, both quality, cost efficiency and robustness increases while the lead time decreases due to improved products and processes.

R&D Area Description: Development of technologies 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
  - MBD – Model Based Design
  - PMI – Product Manufacturing Information
  - GD&T – Geometric dimensioning and tolerancing
- Smart manufacturing enablers for the integration of processes and resources
  - Standard for Geometrical Product Specification (GPS)
  - Standard for the Exchange of Product data (STEP)
- Requirement decomposition and dependency management
- Specification risk management (balance between function, quality and cost)
- Tolerance analysis on components, in-process parts and assemblies
- Surface integrity (topography and surface layer characteristics)
  - Functional correlation in surface areal specifications
  - Characteristics interrelationship between macro form and micro surface

Wanted Effects:

- Robust design of product and processes
- Traceable design rational for products and processes
- Smart manufacturing enabled by industry common standards

3.5.2 R&D Area: 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 process 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 effect of new material or process choices and by this verify the introduction 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 in order 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 R&D Area: 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: By improving verification techniques, the quality of both the product and process and the product performance will increase due to improved possibilities to identify deficiencies in processes, resources and products. Increase smart utilization of measurement data for the understanding process behaviour and early detection of deviations from the normal. Reducing the amount of scrap and energy consumption of on-going processes which is environmental beneficial.

Identified R&D Topics:

- Dimensional metrology
- Characterisation of
  - material properties
  - mechanism kinematics and dynamics
  - acoustics
- In-line and in-process measurments
- Non-destructive testing – NDT (such as optical, x-ray, or ultrasonic measurement)
- Data processing and analysis
  - 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
  - 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 Digital Manufacturing

(In this edition, *Digital Manufacturing* includes the previous *Automation* and *Virtual Engineering* cluster areas).

Digital Manufacturing is an integrated approach to manufacturing that is centred around the use of computerized systems. It is an essential part of current and future sustainable production system design, process planning, simulation and verification, production execution, control and evaluation. *Digital Manufacturing* has become central with the ever increasing use of digital systems in manufacturing. As more automated tools are used, it is necessary to model, simulate, and analyse all of the machines, tooling, and materials in order to design and optimize the manufacturing process in detail and at system level.

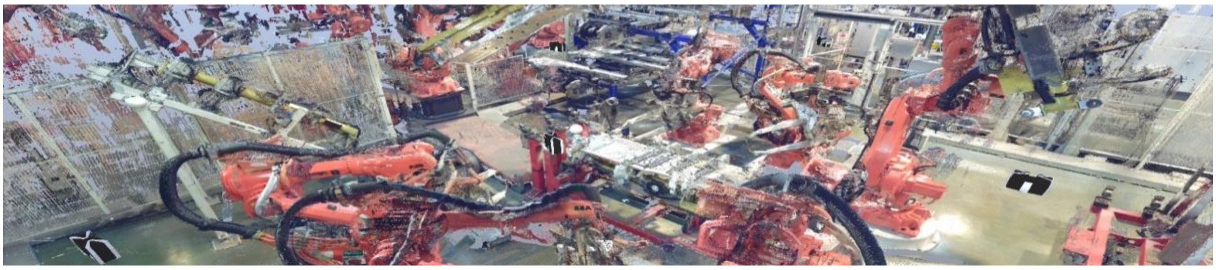

Figure 4 Digitalized 3-D model of an existing automation production cell (point cloud).

Digital Manufacturing includes technologies and their related methods, tools and processes to create and use information and data in digital format over the whole life cycle. The design and engineering covers the development of efficient automated production solutions, with its hardware and software, support for automated modelling and programming, simulation and verification, commissioning and ramp up. In the perspective of mass customisation, there are big challenges to increase the efficiency and effectiveness to manage high flexibility and variability in short lead times. This also has a similar impact and challenges in the production operation life cycle phase, to manage an increasing amount of variants and its associated information and data. To make use of the full potential of the concepts for "Smart Manufacturing" based on new techniques for connectivity and analytics, it is essential to design value driven and user adapted methods and solutions, and implement them to maintain a leading industrial position.

In view of sustainability, one important perspective is that, during the different life cycle phases, the solutions need to be adapted with human aspects in mind, to a wide range of users and their tasks. There is also a strong connection to and synergies with other cluster areas.

Digital Manufacturing is based on and associated with the following technology areas:

- Digital Twin
- Cyber-Physical Systems
- Smart and connected manufacturing (IIoT)
- Cloud-edge based manufacturing
- Data lakes, Big Data management and analytics
- Artificial Intelligence and Machine Learning
- Intelligent apps and analytics
- Blockchain – in industrial applications
- Automation and robotics
- Virtual Commissioning
- Simulation and Optimization
- 3D scanning and modeling of production environment
- Visualization and immersive experience (VR/AR/MR)
- Human-robot Collaboration / Collaborative Robots
- Methods and tools for decision support
- Life cycle data management (PLM/ALM/MES/MOM)

For the concepts of digitalization and smart industry to be a reality (Industrie 4.0 in Germany, Smart Manufacturing Leadership Council in the US, Made In China 2025 etc.), cooperation is required. This means cooperation between people and also between the technical applications involved in the value chains that a product relates to (design idea to product, raw material to recycled product, order to product etc.). Cooperation requires international standards to enable the combination of and communication between various solutions. The development of these standards is ongoing both at a national and international level and it is important for Swedish industry and academy to influence this work, making sure that new standards reflect the needs of Sweden.

The main areas for R&D needs within Digital Manufacturing are:

1. Design of sustainable systems for automated manufacturing
2. Efficient planning, set-up and verification of automated systems
3. Human-machine, collaboration, communication and adaptive control systems
4. Development and integration of virtual manufacturing engineering tools
5. Management of production related life-cycle data
6. Simulation, analysis and optimization of manufacturing systems
7. Re-use of data and simulations for efficient service, maintenance and end of life activities

The logic for the formation into the seven areas is illustrated in Figure 5 below. It is based on different tasks and needs during the life cycles of creating, installing, operate, maintain, and phase out a production system. There are however, more or less overlap and dependencies between two or several areas.

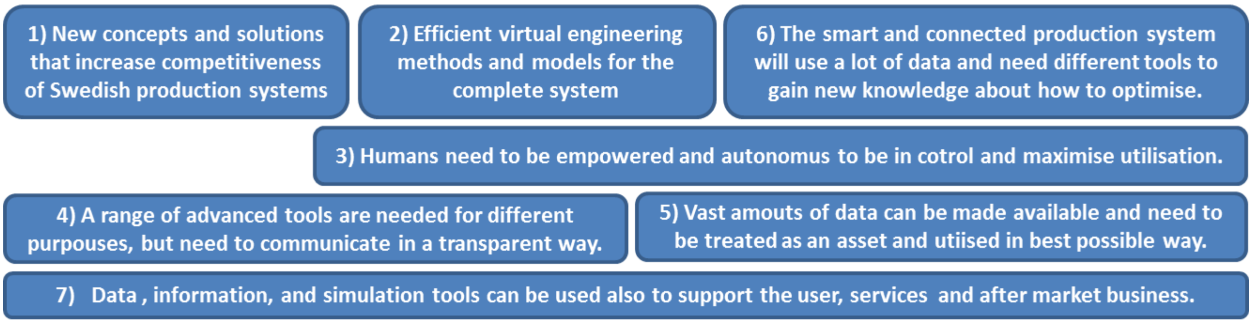

Figure 5 Illustration of the logic for the formation of the seven areas and their relations.

3.6.1 Design of sustainable systems for automated manufacturing

Aim and Vision: To improve Swedish industry competitiveness, automation will play an important role, especially to make it viable for low volume and high product mix. Therefore, energy efficient, flexible manufacturing systems that utilize the best combination of hardware and software, as well as the best combination of machines and humans to fulfill the tasks, are important. Such systems are adaptable and re-useable through modular and programmable equipment utilizing the principles of Cyber Physical Production Systems (CPPS).

R&D Area Description: To be able to deal with the expected increased mixture of different material, models and powertrains, the automated systems must become less rigid. New product technology will also put requirement on materials handling, fixturing and joining methods. Further, the increased demand of a short time to market calls for equipment that can be reconfigured. A sustainable way to solve this is to increase the reusability of the systems by making them more modular and increase their ability to adapt to changes. The development of new types of robot applications (collaborative robots) and the related safety systems opens up great opportunities to find creative solutions for the future automation solutions. This approach will support the ongoing transformation into lean manufacturing by adding simplicity to the change process thus giving production personnel improved tools to apply continuous improvement also to automated systems.

Identified R&D Topics:

- How to create cost- and energy efficient systems using the best combination of machines and humans to accomplish goals of flexible and adaptable systems.
- Modeling techniques for generic definition of resources, their data structure and format to be able to create systems that are modular, re-programmable and reconfigurable (semantics/otologies).
- How to use the emerging technologies, e.g. Cyber Physical Production Systems and advanced sensor systems for various applications (process monitoring, control, safety, etc.).
- Mixed type of automation, using collaborative robot applications and issues related to safety systems, integration, and competence.
- Technologies that will enable higher flexibility for faster setup and ramp-up of production.

Wanted Effects:

- Ability to handle increased variations in products and volumes without increased costs of investments and man power.
- Lower life time energy consumption caused by automation equipment.
- Enabling higher level of flexibility, adaptability and production control will increase total system efficiency.
- Short lead time product change through re-configurations and programming rather than hardware changes.

3.6.2 Efficient planning, set-up and verification of automated systems

Aim and Vision: The production system and its resources will in the future be completely designed and modeled in a digital format, as the Digital Twin of the physical system. Engineering systems, methods and tools that shortens lead time and ramp up, makes it possibly to perform more verifications then previously and thereby makes it possible to compare and determine the most optimized solutions.

R&D Area Description: To implement a complex automated production solution demands several different types of verifications in order to make sure that the implemented solution will run as smooth as possible in physical production. Some of these verifications can today be done "off-line" using different tools, for ex. virtual simulations can be used to design the physical work cell, placement of equipment's, design of equipment's etc. Also, tools exist today to verify the sequence of the work cell as well as behavior when it comes to events such as emergency stops or break downs (PLC-code). However the end to end solution to design, develop and verify a production solution does not exist, not down streams nor upstream. The purpose in this area is to identify and develop solutions which make it possible to work efficiently with planning and development of production solutions in a complete 100% digital model. This should also include aspects related to safety and competences of shop floor personnel. The goal is to determine how the set up should look like, it´s layout and the flow in the value stream, equipment control etc. to create a holistic and flexible approach to the development process.

Identified R&D Topics:

- 3D scanning, photogrammetry, CAD modeling and related technologies of the production system facilities, resources and tooling etc. to support up to date physical models.
- Modeling of functions, data format and structure etc. at different system levels (components, machines, cells, shop floor system).
- Seamless data integration from different sources in order to efficiently perform complete verifications.

- Seamless exchange of equipment models between suppliers and manufacturing stake holders.
- Develop tools and set up in order to increase how many optimized solutions can be developed.
- Create a solution which ensures a full, highly verified production solution, including safety, collaborative solutions etc.
- Programming methods that reduce the need for engineering time both in the setup and commissioning of the production system.

Wanted Effects:

- Reduce number of needed resources in relation to how many optimized solutions can be developed.
- Increase quality on implemented production solutions meaning have less detected errors in the physical equipment and also a faster ramp up time to full production.
- With a "Digital Twin" at hand, different scenarios can be simulated and planned change-overs can be programmed and verified with short lead time.

3.6.3 Human-machine, collaboration, communication and adaptive control systems

Aim and Vision: Research and development of hardware/software solutions that can be setup and handled by other than experts. The overall vision is to hide complexity from the end user with the help of human machine interfaces and adaptive, self-diagnostic systems. The work environment will sometimes be a collaborative process between humans and robots. The goal is to investigate and develop requirements and specifications for safety and information system architectures in automotive production systems.

R&D Area Description: Todays' automation solutions consist of many different hardware and software systems that need to share and process data but also display information to end users and request input. Future systems will also include many situations where machines, robots and humans work in a collaborative environment. As the complexity of the systems increase the end users need to process more information and have better knowledge about the systems. This can be solved by encapsulating complex systems in simplified and intuitive HMIs, but also in the case of unusual events or failures must possible to manage. Up skilling of competence to adapt to the now conditions for automation is an important issue. The development of new technologies for e.g. augmented reality or mixed reality has also great potential for new type of information and communication. The aim of this research area is to investigate and develop solutions that can reduce the perceived complexity, lower the workload and increase the system awareness and safety for the end user. The research area will also focus on the requirements and specifications of information system architectures and how standards and modularized solutions can increase the performance of the production system.

Identified R&D Topics:

- How can human machine interfaces help reducing the perceived complexity in automation solutions for manufacturing?
- How can the current status of automation equipment be visualized and how can visualization help in failure recovery?
- How can adaptive and self-diagnostic control systems help the end user with the daily work?
- How can changeovers and setup times be reduced with the help of human machine interfaces and expert systems?
- How can immersive tools be used for information and decision support.
- How can standards and module based system architectures help improve the performance of the production system and what requirements are there on such systems?

Wanted Effects:
- Ability to cope with product changes without external experts.
- Possibility to employ operators without the need for high competence in automation.
- Standardized and well defined user interfaces that can be reused between different automation solutions.
- Standardized and modularized information systems that can evolve over time and easily be changed to suit new demands in the production system.
- Create equal opportunities for individualized support and situational information.

3.6.4 Development and integration of virtual manufacturing engineering tools

Aim and Vision: Engineering tools for virtual manufacturing enable multidisciplinary information sharing and decision support. Combining various sources of information, calculating, visualizing and analyzing the information gives decision makers more understanding on the decisions to be taken, and thus make the decisions more accurate in an early phases. The long term goal is to be able to model the functions, logic, kinematics, dynamics etc. for the processes and the complete system, to become a Digital Twin and use the Cyber Physical Production System approach to be used in parallel with the real physical system.

R&D Area Description: New technologies with multitude of data/information types visualized according to user needs give new opportunities for decisions based on use of virtual tools during early phases in product development and manufacturing engineering processes. There is also a need to transfer data and information between different tools for a complete digital chain of virtual manufacturing engineering. This will result in major increase of accurate data available for decision-making. It will in addition require new work methods and procedures as well as new software architectures and tools. The area is unique according to its cross disciplinary requirements included in all area initiatives described in other paragraphs. Examples within each cluster which utilizes virtual tools for manufacturing development in specific fields are plentiful. In this effort the aim is to focus on multidisciplinary approaches using data, tools and information from many of the other clusters to enable overall decision support when interacting parameters/technologies are of importance. There are also opportunities to make better use of data from the production system and feedback as an input to the simulations and fine tune the virtual model of the system and/or processes.

Identified R&D Topics:
- Tools for Product Process Resource modelling and simulation, including advanced process simulations and optimization.
- Modelling techniques, methods and formats that enable transparent data transformation and communication in the virtual environment (tools, virtual representation of resources, controllers etc.).
- Complete planning of control systems and Virtual Commissioning.
- Layout Configuration Assessment and Evaluation (also related to BIM)
- Immersive tools using Augmented Reality, Mixed Reality etc. in a real 3D representation of factories.
- Visualisation of information in overlays on other informative models/pictures/3D environments.
- Motion capture use in daily design of products and processes.
- Human velocity pattern calculations and ergonomics evaluation.

Wanted Effects:
- More accurate virtual models.
- Convey better mental models for engineers, which increase understanding and awareness of the development at hand.
- Increase decision basis materials with more and accurate information.
- Decreased time on model building.
- An organization working with virtual tools as a natural part of their work.
- Possibility to simulate an increased number of parameters.

- Increased data transfer in between simulations in series.
- Increased resource efficiency by using virtual tools throughout the whole life cycle.
- Increased education experience through utilizing the new developments for teaching/conveying ideas, describe concepts etc.

3.6.5 Management of production related life-cycle data

Aim and Vision: The capability to efficiently handling data and data streams in industrial processes is critical for digitalization and renewal of the manufacturing industry. Understanding how to represent and process industrial data using database and data stream management systems will be central. The vision is that digital information is easy to access and manage, is relevant and usable for the activities in a sustainable manufacturing system. Various analyses from factory design, process planning, simulations and follow-up can be coordinated through a common information framework. This will reduce the need for physical prototyping and improve the efficiency, sustainability and adaptability of manufacturing systems. Each stake holder (OEM or SME) can use whichever tool is available and relevant to their specific task, and still communicate and coordinate models and results. The overall vision is to enable analysis and decisions which are based on up-to-date, coordinated and usable digital information from various sources, data bases, stake holders and IT-tools.

R&D Area Description: A central problem within this area is to provide and handle scalable capabilities to collect, model, process, analyze, and visualize data and information streams found in industrial applications. Information related to materials flow and capacity analysis, process planning, factory installations, off-line programming, quality control, preparation of work instructions for operation, resetting and maintenance needs an enormous amount of data which need to be created, shared, updated and managed.

To be able to maximize use of Virtual Engineering in production, it’s necessary to create realistic validated digital models of the production system with its various types of resources and processes, etc. These models should be used during the whole lifecycle of the system and be interoperable with models of the components with their functions, physical dimensions and tolerances, kinematics and dynamics. Since manufacturing is characterized by the involvement of many stake holders from various fields and organisations (product design, manufacturing, and production equipment suppliers) it is key to facilitate the sharing of models and data independent of application and system vendor. The use of engineering (simulated) data and actual operational data will also be more integrated and less disparate, used e.g. in Digital Twin applications.

The data safety and security is also of great concern and needs special attention, e.g. use of Block Chain technology for industrial applications. The development of techniques and ever extensive implementation of connectivity based on Internet of Things, Edge and Cloud solutions, Big Data analysis etc. will the base for further research and development. Many of the applications found in industrial processes, simulation activities, and scientific experimental work deal with data that have a streaming nature such as continuous data streams or data sets that are so big that streamed-based processing is required for performance reasons.

Identified R&D Topics:

- Efficient data collection and processing methods to enable continuously updated data models.
- Communication and utilization of models, data and information from different sources and vendors, to make this available for different consumers of data.
- Safe and secure data communication and storage (Block Chain etc.)
- Adaptation of work processes and methods to fully benefit from using large amount of available data and techniques for management and analysis etc.- Big Data, Data Lakes, Artificial Intelligence, Machine Learning.
- User intuitive man-model interfaces, input for processing and analysis, and visualization of results.

- Life-cycle management of data related to products, in production and through service and take-back (including remanufacturing and recycling), as well as manufacturing systems from the design phase to operations and maintenance.

Wanted Effects:
- Data acquisition, storage, processing and reuse of information through a continuous data flow for multi-purpose use.
- Access to the right version of models and up-dated data, thus avoiding making decisions based on invalid information.
- Ability to connect and synchronize available models (from various databases) within organisation to combine different analyses and decrease response time, e.g. for analyses of the impact of changes or validate new production concepts.
- Standardized information system for the digital factory, which can evolve over time and easily be changed to suit new demands in the manufacturing system.
- User intuitive interaction with digital models.
- Efficient collection, storage and representation of data parameters required for analysis of sustainability performance of manufacturing systems.

3.6.6 Simulation, analysis and optimization of manufacturing systems

Aim and Vision: To be at the competitive edge, the Swedish manufacturing industry need to develop, adopt and use the latest advanced modeling, simulation, analysis and optimisation technologies. This can enable simultaneously profitability and sustainability, by increasing energy efficiency, reducing losses/wastes and shorten lead times, etc.
With the advent of low-cost high-performance computing technologies, it is envisaged that extremely cost-effective simulation optimisation techniques can be developed to provide further real benefits to the industry.

R&D Area Description: Due to the inherent complexity and variability of manufacturing systems, decision makers, such as production managers, technicians and engineers, at various levels of any manufacturing operations need advanced tools to facilitate their day-to-day work. These tools need to provide quick and accurate answers for the decision makers to make the optimal, robust and timely decisions. The user friendliness, availability and how the information is presented and visualized are also of importance for how well as an organisation can benefit and be committed to use these tools.

In all phases of system design, operations and improvement etc. there is a need of being able to test and verify different concepts or ideas, e.g. material flow strategy and process simulations, that can lead to cost reduction and more efficient production There is also a continuous need for optimizing the production system due to changes in product mixes, volumes and sequences. To address this type of problem in an advanced way, the use of Digital Twin and Cyber Physical Systems has a large potential. To utilize such methods and tools, there is a need for efficient input from data collection and management, correctly abstracted and detailed models, and intelligent and interactive optimisation systems. For these purposes Industrial Internet of Things, Artificial Intelligence, Machine Learning and Big Data techniques can be used to support traditional methods and physically based modeling and simulations.

Identified R&D Topics:
- How simulation and optimisation technologies can be used effectively to support the decision-making process across multi-levels of the organisation (e.g. strategic/tactical/operational; from complete supply chain, down to production process)?
- How simulation-based multi-objective optimisation can be effectively integrated in the process development lifecycle and production management methods to maximize the impact (e.g. to support complex optimisation tasks in the design of factory layouts, adaptive balancing of production lines in a real-time dynamic environment, etc.)?

- How can the performance of machine learning, simulation and optimisation be boosted, e.g. by using the state-of-the-art High Performance Computing (HPC) technologies.
- How can data from data lakes, information backbones and legacy systems efficiently be used to decrease the time to build better (relevant and correct) models for machine learning simulation and optimization?
- How to use Industrial Internet of Things and Big Data for discrete and/or continuous data flows to feed the simulation, optimization and Machine Learning models.
- How can the simulation tools and associated work procedures be improved to enable continuous and cross-functional use of simulation for analysis and optimisation of manufacturing systems?
- How does this technology change the way we are organized, and how to adopt and implement this technologies and tools efficiently?

Wanted Effects:

- Optimized and robust manufacturing systems and processes, taking into account the optimal settings across various levels of the manufacturing organisation.
- Fast ramp up to a production rate corresponding to current market demand at product changes both in existing and new manufacturing systems.
- Fast adaptation to varying demands and customization by optimal use of flexibility in the system, or plan for necessary change overs.
- Decision making based on the best trade-offs between optimal economic outcomes and minimum impact on environment and climate when designing/operating production systems.
- Frontloading the simulation and optimisation analyses to support the entire process development lifecycle.
- Reliable support for continuous improvement work to reach high production efficiency and productivity.
- 5-15% productivity increase; 5-10% reduction in energy consumption; 10-20% lead-time reduction.
- To create a common view of optimal design principles for production systems to facilitate the sharing of knowledge among different companies.
- Increase the simulation and/or optimisation speed by 200-500% using HPC.
- Extend the application area of manufacturing simulation to include sustainability aspects.

3.6.7 Re-use of data and simulations for efficient service, maintenance and end of life activities

Aim and Vision: To achieve increased resource efficiency during the product life-cycle, data and information can be re-used in later stages. This include the phases of product and production development, production, usage, maintenance, service, take-back, and production phase out.

R&D Area Description: Enabling resource efficient usage of virtual tools and 3D-Models developed early in the product life-cycle. This means that these models and tools also will be used during the latter stages of the product life-cycle e.g. when performing maintenance, service and take-back operations e.g. remanufacturing. The aim and vision will also be achieved by using product data (information) management efficiently during the product life-cycle.

Identified R&D Topics:

- What kind of product data is needed at the product life-cycle phases in order to achieve a resource efficient business?
- How can current access of product data, 3D-models and virtual tools be implemented efficiently throughout the product life-cycle?

- How can aspects of service and take-back operations be included in product 3D-models?
- How can environmental and ergonomic evaluations be made by combining virtual assembly and disassembly tools with life-cycle assessment tools?
- How can virtual service and disassembly instructions be developed from existing 3D-models?

Wanted Effects:

- More sustainable product development including service and take-back
- Shorter and simplified assembly, maintenance, disassembly and reassembly of products
- Reduced life-cycle costs (LCC) and environmental impact
- Increased control of and support to the aftermarket and downstream supply chain – e.g. easier to predict and perform service and maintenence activities.
- A generic information model that describes what kind of information is needed when.
- Developed demonstrators to illustrate use of information models as support for PLM system implementation at remanufacturing companies, and in coherence with existing systems.
- More efficient remanufacturing and recycling processes leading to shorter lead times, less work-in-progress and higher accuracy in product delivery.

3.7 Logistics

Logistics which is the focus area in this document, is one part of the total Supply Chain. Logistics is an integrated part of the production system but has also a relation to product development and inbound as well as outbound transport and distribution. The supply chain is of great importance to the environment.

The mass customized production concept, demanding a huge number and variety of components being supplied and exposed in production without violating, for example, cost efficiency, component availability, quality, and space, underpins the importance of the area. Manufacturing planning and control is a part of logistics and rules much of the prerequisites for both customer orientation (service level and flexibility) and the internal efficiency of the production operations.

The main areas for R&D needs within Logistics & Materials handling are:

- Efficient and sustainable material flows
- Materials handling and packaging systems
- Manufacturing planning and control

Table 1 Schematic of how logistics covers or has important relations to other areas, i.e., is dependent on other thechnology areas, in addition to the relation beween the sub-areas themselves.

	Efficient and sustainable material flows	**Materials handling and packaging systems**	**Manufacturing planning and control**
Product design and design for logistics, e.g. variants	X	X	
Manufacturing strategy and Business models	X	X	X
Supplier structure, production location and production network	X		X
Procurement	X		X
Transportation solutions in the supply chain	X	X	X
Production Management, work organization, competence and learning	X	X	X
Facilities and space management	X	X	
Layout and workstation design		X	
Ergonomics and human factors		X	
Performance management			X
MES and ERP systems			X

The following programmatic needs and proposals for these areas are identified:

3.7.1 R&D Area: Efficient and sustainable material flows

Aim and Vision: The vision is sustainable and efficient material flows, enabling increased productivity, responsiveness and flexibility in supply chains. The R&D area aims to support performance in the order-to-delivery process and the supply chain as a whole, contributing to reduced cost, improved service and reliability, as well as sustainability in terms of economy, human factors and environmental impact.

R&D Area description: The supply chain includes aspects of the information flow, the monetary flow (e.g. invoicing), and the materials flow, throughout the entire order-to-delivery process, i.e. from the moment the end customer (vehicle buyer) places an order for a new vehicle, through materials ordering, transportation, production and distribution, up until the moment the end customer receives the vehicle, focusing on the efficient and effective processing of materials and related information. In addition, return flows of empty packaging and recycling of components are becoming increasingly important. Distribution of spare parts is another area that needs to be managed, so that spare parts are available with a high service level, without penalties of high distribution cost or large amounts of tied-up capital.

Supply chains of today are faced with a comprehensive set of challenges as well as with considerable opportunities. Competition is strong and global, bringing constant pressure for the supply chains to deliver high service to end customers, while at the same time operating at a low cost to ensure profit margins. Additionally, the number of product platforms assembled on the same assembly line has increased and large variations in demand and frequent engineering changes have become normal, requiring high flexibility. There are also increasing requirements for environmental sustainability and regulations demanding that a larger share of the vehicle is re-circulated. At the same time, the supply networks become ever more globalized, posing challenges in terms of lead-times and supply chain risks. Beside all these challenges, technological development is changing the conditions for supply chains, e.g. through digitalization and through the imminent introduction of autonomous driving. All in all, the situation justifies research in the area of supply chain management, where it is important to adapt and develop new and innovative methods and to increase the knowledge of options available.

The design of the supply chain is an integrated part of the production system design, for two obvious reasons. First, the production system places important requirements on the supply chain and the supply chain design permits possibilities in the design of the production system. Second, the location of a certain production or materials handling activity is not fixed, but can be performed in the own production plant, at logistics centres, at component suppliers or at third parties. New conditions and business opportunities place new demands on the supply chain design, including organisational set-ups and work processes for cooperation between the supply chain actors: suppliers (logistics service providers as well as material suppliers), OEM production facilities, dealers and distributors, and vehicle buyers. For example, increased use of automation of production, material handling, and transportation, can change the cost structure of a supply chain and can result in the need to revise the supply chain configuration.

Further development of performance measurement and management systems in relation to supply chains is required, including assessment methodologies based on chosen manufacturing strategy and production philosophy, and including decision support tools. Landed cost models constitute one example of tools that can facilitate accurate assessment of performance, and that can support decision making. Sourcing decisions constitute one area in need of further supporting tools. Sourcing often includes both nearby and long-distance suppliers. Sourcing decisions also include choices between single-sourcing, dual sourcing, and multi-sourcing. With long-distance transportation, risk and uncertainties tend to increase (e.g. risk of delays) and environmental sustainability is challenged. Today, these aspects are often not given sufficient attention in decisions regarding the supply chain configuration.

Another aspect related to the use of long-distance suppliers is that SILS (Supply In Line Sequence) deliveries of components to the assembly plants are difficult to achieve, which could negatively affect the logistics and potentially the assembly operations in the receiving plant. To achieve long-range SILS, information of the final assembly sequence needs to be made available to the suppliers before shipping, and potentially before production at the supplier site. This could in turn require the final assembly sequence to be frozen further in advance than with current practice. Improved information sharing between assembly pland and supplier may be a further enabler. Overall, different measures may be taken to achieve long-distance SILS, but current knowledge is not sufficient.

A general key issue is access to high quality information, which is increasingly regarded as a competitive advantage. The need for information sharing is becoming more and more important in order to maintain reliable and robust supply chains, improving decision and support system functionality. Here, new technology and the use of digitalization can improve supply chain alignment and enhance flexibility and responsiveness. However, sharing information across the supply chain can lead to fear of decreased information security and discussions on conflict of interests, which calls for new ideas and models for managing and sharing information.

Overall, more knowledge is required to understand the fit between the design of the supply chain and the production system, i.e., being highly efficient and conforming to the requirements and principles of the production system.

Identified R&D topics are:

Research will focus the challenges and needs identified above. By this, the research will contribute to the ability of effective design of supply chains, by focusing both the design process and the normative system characteristics. The supply chains have to support the core value-adding activities of production – being effective – as well as themselves being highly efficient. Research effort will be devoted to better integration of environmental performance measurement and management in both the design and the operational phase of the supply chains. Furthermore, the performance characteristics of the different options of supply chain structures, and their applicability for different manufacturing strategies, will be researched to better understand how to manage changing requirements in terms of markets, products and production methods.

- Improved conceptual and applied supply chain design processes
- Understanding of the effective application of new technology in supply chains
- Efficient integration of external materials nodes and warehouses and the location of activities in the supply chain
- Flexibility and Managing of supply chain disturbances, especially for distant suppliers
- Adaption of the supply chain to the mass customized concept
- Recycled material streams for regular production purposes
- Supply chain cost analyses
- Information management and sharing throughout the supply chain

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 supply chain
- 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
- Understanding of the challenges posed by circular material streams
- Faster and higher quality of relevant information exchanged between actors of the supply chain, with greater benefits for all parties
- A collection of well performing material supply system cases to show their benefits and incorporate it into educational material

3.7.2 R&D Area: Materials handling and packaging systems

Aim and Vision: The vision of the materials handling and packaging systems area is to achieve sustainable and high performing materials handling systems fulfilling manufacturing processes requirements. There is a close relation to production workstation operations and their requirements on materials handling. The aim is to develop materials handling systems appropriate for different contexts where the design of operations, equipment and packaging result in efficiency, quality, flexibility, robustness and good ergonomics. The (materials handling and packaging) systems should sustain efficient material flows interrelating with external transports and manufacturing, not just optimising separate processes. Thus the aimed progress within the materials handling and packaging systems area should be interrelated to the development in the material flow (3.7.1) and planning and control (3.7.3) areas.

R&D Area description:

The materials handling and packaging systems area include handling and transport of materials in plants, such as factories, warehouses, depots. The area include packaging and load carriers needed. The processes studied comprise different forms of materials preparation required in supply of, or distribution from manufacturing. Also management, administration and organisation of these processes is covered by the research area.

The research area is affected by the fast development in information technology. Important topic is use of technology, especially digital tools. In what situations and for what processes is automation appropriate to use? Applications concern a wide area 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 in order to form internal logistics strategies that allow stepwise development and basis for continuous improvements.

Performance in this area has traditionally referred to measures such as cost efficiency, product quality and human factors, which still are very important, also environmental sustainability should be highly considered.

The packaging serves several purposes and functions of great importance for efficiency, flexibility and environmental performance of the production system. Choice of packaging is central in material handling. The packaging effects on picking of material to and from a package as well as transportation and handling of complete packages is important. Strive for automation, especially in transportation, handling and picking, now enforce develop–edenment of packaging. The digital progress develop the packaging possibility of displaying and carry information. New packaging standards need to be formed, as existing are inadequate and also constraints development in the area. Naturally packaging systems is a vital and integrated part of the supply chain and do influence the material flow (3.7.1) and planning and control (3.7.3) areas. Globalization and supply network performance make the decision between one-way and returnable packaging important. Also 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 are:

Based on the aim and area description, a number of research topics has 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 (3.7.2) which concern material flow supply chains connecting and synchronising factories, warehouses and logistic centres.

The basis for material handling operations has foremost been influenced by production systems becoming more of mixed model type and by the manufacturing processes' requirements on the material handling operations. This has resulted in increased demands on materials preparation and on synchronisation of materials handling operations and packaging systems to manufacturing processes. Central research topics relate to contextual effects on materials feeding methods and material preparation processes performance. The problems include specific design of and combinations of methods and processes concerning engineering, information technology, organisation and management.

Research in packaging systems has to address the production workstation and plant efficiency, concerning both customer and supplier, given the settings of a dispersed supplier structure and low volumes of individual parts, characterizing the Swedish automotive sector, aiming at developing next generation smart packaging systems.

3.7.3 R&D Area: Manufacturing planning and control

Aim and Vision: Research in this area focuses on planning methods, planning process and organization, planning information, information system support for manufacturing planning and control, and the interplay between these issues, at all levels of the planning hierarchy, i.e. from long-term strategic and tactical planning down to the execution level at the shop-floor. The aim and vision is to achieve high-performing and user-friendly planning systems that contribute to proactive and real time balancing of demand and supply in manufacturing sites, manufacturing networks and supply chains. Thereby, uncertainty is managed, flexibility requirements are reduced, and resource utilization and delivery services optimized.

R&D Area description: Manufacturing planning and control is concerned with planning and controlling 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 both the ERP and the MES systems.

The planning environmental (situation) impact on planning and control strategies is of great importance, e.g. different demand, product and material flow characteristics, in order to design a planning and control system that matches the production situation. 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-organisational 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 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.

Identified R&D topics are:

Lack of proper planning information is a serious problem in the automotive supply chain today, resulting in higher freight costs, stock outs, long lead-times, tied up capital, and high administrative costs. This involves information from actors in production, in other functions of the company, and from external parts. It takes too long for demand information to be properly spread upstream in the supply chain. Increased visibility and involvement in 2nd and 3rd tier suppliers improves these conditions. The 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. This implies that the companies in the supply chain need to exchange high quality information automatically, synchronize demand and stock level information in the chain, and that the SCM solution should create alerts for critical situations. Research on the use and applicability of modern information technology, e.g. real-time information sensoring and big data analyses, is needed in this area.

Related to the above area is the topic of planning information quality, e.g. short- and long-term variation in forecast and order information. Even if the information is visual, it can be of poor quality. Research is consequently needed about explaining the impact of information quality, but also about explaining the causes to and flexibility requirements and management of information quality deficiencies in planning processes. Also, information produced by the planning system has to be easily understood and utilized for pro-active actions in the materials flow and materials handling systems.

Planning and control in production networks and supply chains have to 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, in order to be proactive and better adapt to flexibility demands. Planning and control systems for mass customized products at mixed-model assembly lines require, on one hand, order schedule stability in terms of e.g. long order time fences. On the other hand, one would like high flexibility to accommodate disturbances in supply and production, and the ability to respond to customer demands. This calls for a planning system not only being able to produce long term stable plans, but also being able to re-plan at shorter notice by means of 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 has to take the actual circumstances into consideration, e.g. referring to choice of packaging, routes and safety stocks. This is problematic when there are many active number of parts in the operation. Methods and techniques should be developed for a dynamic optimization, approaching planning of every-part-ervery-day.

Most aspects above is not only true for inbound flows produced from virgin material, but also for circular material flows. Especially the supply network of component suppliers require known and manageable uncertainties regarding supply of recycled raw material. This is important to increase competitiveness of recycled materials.

Advancements in the direction of additive manufacturing technologies, and similar technologies, possibly driving more decentralized production and changing planning conditions, are important developments to have under observation. Probably, there will be no great impact in the near future, but readiness to benefit from the technologies once introduced is important.

Research is needed about designing new planning approaches, but also about implementing and using them, as feasibility has proven to be both problematic and important, especialy 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.

Wanted effects:

- Reduced risks and increased pro-activeness through scenario-based and inter-organisational planning.
- Improved responsiveness and flexibility through information visibility and event-based planning and control.
- Reduced tied-up capital through collaborative planning approaches and pull control.
- Reduced lead time
- Increased service-level
- Higher information quality throughout the supply chain (relevance, timeliness, etc)
- Understanding of the opportunities driven by technology, e.g. sensors and big data analysis.

3.8 Production Management

In order to obtain competitive advantages over time and secure competitive factories in Sweden, production systems in Sweden have to be innovative, slim, readily adjustable, and must meet the sustainability requirements. Sustainability here refers to economic/business issues as well as ecological and social/human issues.
The rapid development of digitalization, automation and electrification creates new business opportunities as well as new possibilities for production process, hence also new challenges. The ability of minimizing the environmental footprint also in production is also trending towards strengthened business opportunities in Swedish organizations.

Sustainability requirements in combination with increased globalization thus increase challenges and makes optimization of production increasingly advanced. A holistic perspective including macro-, micro, and meso levels in production systems are therefore needed to strengthen and develop competitiveness over time in Swedish industry. The production system prioritized R&D areas includes a strategic innovative focus (Planning what to do), focus on design and industrialization (How to do it), and focus on an operational and continuous improvement level (How to manage, control, and improve).

Production Management is connected to the following technology areas:

- Production strategies
- Innovation processes
- Globalization, changes, restructuring within companies
- Product-, production development
- Maintenance Management
- Economic, ecological and social/human sustainability
- Sociotechnical Systems
- Production Ergonomics and human factors
- Operations Management
- Organizational Learning

The main areas for R&D needs within Production Management are:

- Production strategies
- Production System Design & Industrialization
- Management and control

3.8.1 R&D Area: Production Strategies

Aim and Vision: Innovation processes and dynamic strategies to meet increased speed of changing demands on a global market, e.g considering increased complexity in global manufacturing networks

R&D Area Description: The vehicle manufacturing companies, and suppliers, in Sweden are players on a global market. The products are sold and produced worldwide. To stay competitive it is important to manoeuvre intelligent and innovative in this global puzzle. When it comes to the production strategies there are many crucial decisions to make, that requires appropriate analyses.
These challenges have an impact on companies´ ways of organizing work, individuals new work conditions, as well as conditions in specific workplaces. Hence, further research is needed on business development, global and restructuring effects on both companies and individuals in a life long work perspective.

Identified R&D Topics:

- Innovation processes
- Change capability, including volume and variant flexibility
- Holistic evaluations of purchasing strategies, including environmental impact of products and production processes
- Cooperation with external actors world wide

- Combination of daily operations, continuous improvements and innovative development steps
- Restructuring impacts and opportunities on work, workplaces, and working conditions

Wanted Effects:
Roadmaps, methods and guidelines to support strategic decision processes, innovations, and sustainability.

3.8.2 R&D Area: Production System Design & Industrialisation

Aim and Vision: Fully integrated development of products and processes for economic, ecological and social/human sustainability

R&D Area Description: Vehicles are complex products with a highly complex product realization process, including various processes and rapid changes. Development of the production system requires a constant interaction between the product design process and the manufacturing system design process. New types of products and short product life cycles require flexibility and new approaches which have effects on the design of the production system and work processes.

Identified R&D Topics:
- Support of factory design processes
- Integration of green and social/human aspects in production system design
- Working methods and tools to support cross functional collaboration
- Opportunities and challenges regarding AI, digitalization etc
- How to work with overall plant efficiency
- How to increase organizational capability to efficient production ramp-up
- Human-centered design

Wanted Effects:
- Design of optimal products and production systems characterized by high performance, environmental care, continuous learning and healthy working life.
- Methods and tools to support factory design process.

3.8.3 R&D Area: Management and Control
Aim and Vision: Competitive performance through empowered, motivated, healthy and skilled workforce at all levels

R&D Area Description: Challenges addressed concern performance in daily operations and continuous improvements based on innovation awareness and ability. 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 organizations to join forces, efficiently and effectively. This in turn put high demands on different type of skills like management, technical, sociotechnical as well as operational skills. Based on Lean philosophy, methods and tools adopted in various business processes increase considerations of a holistic sustainability perspective. However, due to the increased speed of changing demands, management support at all levels need to be developed to maintain current status and create drivers for controlled development.
To enable sustainable advantages on a global market it is necessary to increase the ability to utilize specific local strengths and to take local conditions into consideration. Considerations also needed to be addressed are changed organizational structures, increased mobility i.e employers movements between workplaces and employees, development of operator work in increased global manufacturing structures, impacts on the labour market, support for leadership to create empowerment, motivation as well as required skills and competences.

Identified R&D Topics:

- Support of leadership and employee development in vehicle production
- Predictive maintenance
- Utilization of big data, real-time data, AI etc as management tools
- Inclusive and human centred leadership to maintain and improve performance
- Competence management, blended learning models
- Management of production complexity
- Integration of green and social/human perspectives in production system development, Social and environmental KPI:s
- Production system transparency and communication models
- Production ergonomics
- Workplace innovation
- Work life balance
- Diversity and inclusiveness
- Cultural efficiency, empowerment, individual- and team development

Wanted Effects:

- Efficient production systems and work places characterized by continuous improvements and innovation. Skilled, healthy and motivated people. Sustainable improvement and innovative employee-driven development work. Systems in place for competence management to identify, measure and validate competence. Employee empowerment, involvement and ownership. Efficient cross-organizational and cross-functional collaboration. Coaching leadership. Work balance and improved quality of working life. Attractive work, work places and company.

3.9 Knowledge & technology transfer

It is vital that the R&D-projects not only contain technical results but also provides education and training materials to be used in Companies and in education at different levels from Gymnasium to PhD student- and life-long learning education.

Aim and Vision: The aim is to spread and make available research results by supplying routines to the R&D projects resulting in distributed knowledge and access to state-of-the-art research useful for the creation of educational materials.

The vision is to improve the Knowledge & technology transfer to production engineers of state-of-the-art knowledge demanded by the industry and at the same time increase the status of production in society in general to motivate more students to choose a Production engineering education.

Area description: The Knowledge & technology transfer Cluster (K&TS cluster) will provide structures and routines for the transferring of production engineering competence. The Knowledge & technology transfer cluster shall have regular contacts with the other clusters to identify needs and availability and make proposals and priorities for new education-, knowledge transfer materials and services.

Wanted effects:

- *Easy access to research results and material* to be used in research, product development and education by the implementation of routines for the R&D clusters how to provide material for knowledge transfer and education. Example:
    - Education WEB portal – make it easy to access education material
    - Easy accessable R&D results "produktionsresultet" – For transfer of knowledge and technology reports and other media "Research Tube"
    - Create and market training and education in co-operaration with stakeholders all over the country.

4 Continuity and change – requirements for global competitiveness

The public funding made possible by research programs such as FFI, production 2030, H2020 and MERA has been of vital importance in building up the project portfolio that the manufacturing clusters have been, and are, involved in. By the collaboration between companies, public agencies, research institutes and academic partners many high quality projects with a wide range of partners have been executed and lessons learned on how to run and organise an R&D program to secure the competitiveness of the Swedish Automotive industry. The Swedish Manufacturing R&D clusters aim at building a continuity in manufacturing R&D, regardless the sources of funding.

In this chapter experiences from past and proposals for future programs are described. Some important aspects 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. It is of great significance that their Swedish R&D partners are also capable of acting on the same market. In the past the R&D structure has been fragmented. Sweden's R&D resources are relatively limited. It is therefore imperative that these resources are used efficiently in the future.

Collaboration: Sweden is a very small country and it is both necessary and also important that competing companies and universities will be able to co-operate in a constructive and pre-competitive way. The cluster cooperation which was started during the MERA-program has resulted in projects with increased quality as well as projects with many collaborating partners. The clusters have defined R&D programs and project roadmaps, which are of most importance to be able to build an R&D infrastructure of word class for a sustainable industry in Sweden. To share roadmaps and visions between several R&D programs will increase the possibility for Sweden to achive common missions.

Not only Automotive Companies: Today it is desirable to include more companies from manufacturing industry in Sweden in the cluster organization. By doing so an even stronger platform for demand driven, industrially applied, science could be formed. As industry input often is asked for in the forming of different funding programs the cluster organization, broadened with more manufacturing industry input, could provide a good base for such discussions.
The Swedish R&D programs described above have engaged several hundred companies. Many SME companies have in this way been able to take part of advanced R&D-programs. The automotive companies have also for a long time performed R&D together with other large companies such as Sandvik, SKF, Siemens etc.

Continuity and long term strategy: It takes many years to build R&D groups of world class (approximately 10-15 years). It also take several years to establish and operate new research programs. This means that it is important with continuation in the organisation and conditions for public funding.

R&D infrastructure: To ensure an efficient use of resources the automotive companies have an ongoing dialogue with the universities, institutes, relevant networks and organisations, such as the Swedish Production Academy, competence centres etc. Demand driven industrial applied science can very often be combined with basic research, PhD studies as well as education. The purpose with this dialogue is to decide how we should proceed jointly to build up a critical mass, avoid duplication, and strengthen and further develop the existing competencies to increase the global competitiveness of the universities and institutes.

5 References

a) FFI Sustainable Production: https://www.vinnova.se/en/e/ffi-hallbar-produktion/
b) EUCAR: http://www.eucar.be/
c) Manufuture: http://extra.ivf.se/manufuture/template.asp
d) EFFRA: www.effra.eu/
e) Statistiska centralbyrån: https://www.scb.se/Statistik/_Publikationer/UF0521_2013A01_BR_A40BR1301.pdf

6 Acknowledgement

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Link to the Clusters homepage where also an updated list of cluster members are available:

www.produktionskluster.se