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METALS
MachinE Tool ALliance for Skills

Deliverable D.2.2: EU machine tool industry skills panorama

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1. Introduction

The rise of new industrial technologies impacts considerably on competence requirements in the machine tool industry. The objective of this document is to offer an overview of the consortium's research on current and future (2025) skills' needs in the sector and on the related emerging occupational profiles in key areas. The analysis builds upon the two-layer methodological approach illustrated in D.2.1 on "Skills needs analysis, scope and methodology". It is the product of a survey investigating on emerging technologies in the machine tool industry, as well as of workshops and interviews on most relevant skills needs in the field. The data collected and later elaborated comes from machine tool industrialists, workers in the field and further manufacturing experts.
Section 2 of this deliverable details the results of the expert-worker-workshops (EWW) introduced in D.2.1. Section 3 provides a snapshot of the survey results on the most relevant industrial technologies in the machine tool industry between 2015 and 2025. In accordance with its high rating in the survey and the extensive attention it gathers from literature on industrial processes, Section 3 dedicates special focus to additive manufacturing (AM). A table on job forecasts, activities and skills constructed by partners around the different aspects of this technology is then presented. Finally, section 4 bundles up key information gathered with regards to skills for AM technical and soft skills, describing emerging needs and occupational profiles to unleash the capabilities of AM technologies.

2. Spheres of activity: machine tool industry

The 14 spheres of activity are the result of 4 Expert-worker-workshops (EWW) in 2016, where more than 20 expert-workers from over 10 companies from machine tool sector participated. Approximately two thirds of the participating workers learnt the vocation "removing machine mechanic", while the remaining one third learnt "industry mechanic". Spheres of activity are valid in the meaning that sketched work processes are part of actual daily work in the sector. However, summarising the findings could have happened in another manner or with a different amount of spheres. For instance, the distinction between CNC removal production (metal) and CNC removal production (synthetics) could be questioned, but it reflects the outcomes of EWW.
It is relevant to remind that findings do not claim completeness. It remains possible that companies in the sector work (also) in other spheres of activity. Yet, the most important spheres are nevertheless listed here. The amount of new spheres decreased, the amount of spheres named again increased from EWW to EWW. The findings here described reveal the state-of-the-art developments in 2016. In a sector like the machine tool, challenged by permanent technological developments, new spheres might emerge in the upcoming years. Surely, some of the spheres might also lose relevance or become even irrelevant. Although, the latter scenarios is likely not to happen if one looks at the findings from EWW. Even a classical sphere from industry 2.0, "conventional removing production", is still very relevant. It will remain important for products which do not need very precise dimensions.

2.1. Sphere of activity 1: Conventional removing production

Work tasks:
Products are machined based on technical drawings and work orders; drawings and work flow are partly sketched by performing skilled workers themselves. Dimensioning and cutting data reference values must be controlled and, if necessary, adapted. Tools and tensioning means must be chosen and equipped.
Production is controlled with reference to environmental and work security regulations.
Parts produced are controlled, if necessary refinished, cleaned and stored. Documentation of production process and potential peculiarities is an integral part of this sphere of activity.
Potential mechanical processes are turning, milling, drilling, reaming, and countersinking.

Future trends:
In the future, conventional removing production will lose quantitative relevance. Additionally, an intensification of environmental regulations, especially of appropriate disposal of waste materials and lubricants, is expected.

2.2. Sphere of activity 2: CNC- removing production (metal)

Work tasks:
In some cases, a time- and business-plan must be drawn together with foremen and engineers at the beginning of working within this sphere of activity. If the work order is given, products are machined based on technical drawings, CNC-programmes, and work orders. Drawings and work flow are partly sketched by performing skilled workers themselves. Dimensioning and cutting data reference values must be controlled and, if necessary, adapted. Tools and tensioning means must be chosen and equipped. CNC programmes must be imported with respect to speed of milling and turning tools.
Production is controlled with reference to environmental and work security regulations.
Parts produced are controlled, if necessary refinished, cleaned and stored. Documentation of production process and potential peculiarities is an integral part of this sphere of activity.
Both, 3-axis and 5-axis machine tools are used. The main mechanical processes are turning, milling, drilling, and wire eroding.

Future trends:
Future expectations for this sphere of activity include an increasing amount of cycles with turning and milling machines, that 3-D drawings might by read by machines, that bigger parts might be produced, that better options for tensioning will be developed, that inductively hardening with same machine will be possible, and that working with lightweight materials will increase.

2.3 Sphere of activity 3: CNC- non-removing production

Work tasks:
Products are machined based on technical drawings, CNC-programmes, and work orders. Drawings and work flow are partly sketched by performing skilled workers themselves. Dimensioning and cutting data reference values must be controlled and, if necessary, adapted. The machine must be adjusted and CNC programmes must be imported. Production is controlled with reference to environmental and work security regulations.
Parts produced are controlled, if necessary refinished, cleaned and stored. Documentation of production process and potential peculiarities is an integral part of this sphere of activity.
The main mechanical processes are flame-cutting and laser-cutting.

Future trends:
Future expectations for this sphere of activity include advanced software, the option of cutting additional materials (e. g. copper), linked production and an increase of quality and security measures.

2.4 Sphere of activity 4: CNC- removing production (synthetics)

Work tasks:
Products are machined based on technical drawings, CNC-programmes, and work orders. Drawings and work flow are partly sketched by performing skilled workers themselves. Dimensioning and cutting data reference values must be controlled and, if necessary, adapted. Tools, materials, and tensioning means must be chosen and equipped. CNC programmes must be imported with respect to speed of milling and turning tools – depending on the specific synthetics material - those react very differently. Production is controlled with reference to environmental and work security regulations. It might occur that synthetics has tensions, that cannot be balanced by varying speed or tensioning – in this case synthetics has to be send back to the producer for tempering. In general, removing production of synthetics is more challenging than removing production of metals.
Parts produced are controlled, if necessary refinished, cleaned and stored. Documentation of production process and potential peculiarities is an integral part of this sphere of activity.
Both, 3-axis and 5-axis machine tools are used. The main mechanical processes are turning and milling.

Future trends:
Future expectations for this sphere of activity include the option of producing bigger parts, an increasing variety of tensioning means, the development of synthetics without internal tensions, and faster and more secure production processes.

2.5 Sphere of activity 5: Adapted production

Work tasks:
Adapted production consists both of refinishing and producing new parts. Work depends on the ability to read complex technical drawings and is performed in close co-operation with the colleagues from the development department who built the new machinery. Joint ideas, for example where and how a device could be mounted (either tightening, boltening, or moulding) or which tolerances for diameter and distances are acceptable, have to be developed and discussed.

Involved colleagues discuss modification and solution proposals based on self-drawn sketches (digital or analogue). Clients are sometimes, depending on the order, already involved in the processes of planning and producing by communicating and respecting their ideas.

After finishing these preparatory works, a process sheet must be sketched and machinery, tools, and raw materials must be chosen. It happens that tools must be optimised, according to the specific needs of the production process. Afterwards products, for example parts for prototypes or modified parts due to constructive modifications have to be produced.

Parts produced are controlled, if necessary refinished, cleaned and prepared for delivery. Documentation of production process and potential peculiarities is an integral part of this sphere of activity. Main mechanical processes are turning, drilling, and milling.

Future trends:
Future expectations for this sphere of activity include paper-less working (touch-screen) and an ongoing acceleration of work-processes.

2.6 Sphere of activity 6: Programming

Work tasks:
Work in this sphere of activity starts with a programming order, often spontaneous and urgent, from operation scheduling department. Programming work is shared by the team in case of bigger orders; programming follows parameters of the parts to be produced. After finishing programming, next steps are simulating and testing of the programmes. New CNC milling and turning machines are delivered was advanced simulation software; so already testing reveals whether there is an error or not.

A copy of programme and technical documentation are archived; the programme is delivered to colleagues from production department.

Future trends:
Future expectations for this sphere of activity include easier and faster software, for example by user-friendly interfaces, an upgrade to faster and better 3-D graphics, the introduction of CAM-software, and that programming of CNC machines becomes part of daily work of all colleagues from production departments.

2.7 Sphere of activity 7: Welding

Work tasks:
This sphere of activity covers different methods of stainless steel welding, for example metal inert gas welding (MIG). After receiving the order tools and material have to be prepared, welding happens with electrodes under inert gas conditions. Some departments weld already with support by robots; than parameters (speed, gas mixture) must be controlled. When a welding seam is finished, quality has to be controlled. If the product is distorted, it has to be corrected by flame-straightening. Production process and potential deviations have to be documented.

Future trends:
Future expectations for this sphere of activity include the option of laser welding with respective security measures, the reduction of needs to corrections due to warping, and that support by robots will increase.

2.8 Sphere of activity 8: Arranging

Work tasks:
The client contacts, usually by phone, the sales department before working in this sphere of activity starts. An offer is developed jointly with colleagues from the sales department, if necessary including a consultancy of the client in his premises. If succeeded, the IT department develops programmes based on technical drawings. Tools and tensioning means have to be ordered or taken from the storage, tools have to be mounted, and the machine must be set up. Programmes have to be controlled, checked and adapted. Afterwards first test products have to be produced and measured, if necessary parameters have to be adapted. Client will be invited for pre-inspection when the machine runs according to specifications (quality, waste, and time). If accepted, the machine has to be deconstructed and transported to the clients' premises. Colleagues follow the machine (worldwide) for reconstruction and testing. After successful installation workers of the clients have to be instructed for operation. The whole process has to be documented. The client also receives a copy of the technical documentation. Arranged machines could be, for example, CNC-milling-spindle machines or CNC-milling/turning machines with 3 or 5 axes.

Future trends:
Expectations for this sphere of activity include that complexity of products and machineries increases (e. g. laser treatment on milling-turning machines or double milling heads), that programming will be based on 3-D-sketches, that time available for working on an order (actually some weeks) and physical stress decrease, and that variety of materials increases.

2.9 Sphere of activity 9: Maintenance

Work tasks:

This sphere of activity includes routine maintenance and control (e.g. cooling water, oil level) of machine tools, but also overhauling of small damages or the repair or exchange of parts of machinery by the colleagues of the production department. Small reconstruction works, due to varying production processes, are also included. After finishing maintenance or overhauling work processes machine has to be adjusted again and a trial run (functional test) has to be performed. Functional test is either performed by colleagues from the production department or from the maintenance department. The documentation of work processes and functional tests is an integral part of this sphere of activity.

Future trends:
Expectations include mainly that maintenance will be performed more often by the producers of machine tools.

2.10 Sphere of activity 10: Quality assurance

Work tasks:
Depending on the product, potentially not only self-test but also independent inspections might be necessary. This could refer to process planning (e.g. technical drawings), product-, and process quality. In case of complex or security-relevant products additionally to self-test by the producing expert-worker, a quality audit by a colleague takes place. Potential objects of quality testing (partly in the separate measuring room) are the completeness of parts, adherence of tolerances, or used measures and auxiliaries. It might happen that colleagues from the quality assurance department perform additional tests.

Working on (internal and external) reclamations and the training and internal auditing of colleagues are also part of this sphere of activity. Documentation of testing procedures and potential abnormal findings are also integral part of this sphere of activity.

Future trends:
Expectations include an increasing relevance of optics of products, increased requirements on communication and negotiation skills (both internal and with clients), and a unification of standards and inspection protocols.

2.11 Sphere of activity 11: Mounting

Work tasks:
Complex structural components or assemblies have to be produced from single elements. Basing on technical documentations, elements or simple assemblies, made from different materials, have to be chosen, adapted, and jointed or mounted. Means of production have to be chosen, also. Fitting and mounting have to follow present clearances. Connecting elements and work processes depend on material, material combination, and strains of the assembly. Connections, having been mounted within this sphere of activity, underlie a permanent control. In case of defective connections or malfunctions, an immediate repair or exchange has to be done. Quality control (self-test), and documentation of work orders and potential deviations are also an integral part of this sphere of activity. In some departments, an electronic justification of work processes is part of the documentation. Having finished mounting works, surface of assembly must be protected.

Future trends:
Expectations include an increasing complexity of assemblies, an increasing amount of different mounting techniques, stronger security regulations, and increased different orders by clients – that have to be performed under advanced time pressure.

2.12 Sphere of activity 12: Marketing (e.g. exhibitions)

Work tasks:
The event has to be organised before the main tasks of this sphere of activity start: region, contact persons, and logistics (transport) must be clarified. The choice of which machine tools takes place in close co-operation with the local organisers. Machines are reconstructed, equipped and tested at the premises of the organiser. During the event the production has to be supervised, machines have to be presented in co-operation with colleagues from the sales department, and questions by potential clients and other interested persons have to be answered. Explaining machine tools to groups of pupils or students and answering their questions is also part of this sphere of activity. In case of successful sale of a machine tool to a client, expert workers from his company have to be instructed.

Impressions and sales of the event have to be documented in co-operation with colleagues from sales department at the end of the activities.

Future trends:
For this sphere of activity increased communication and presentation skills (also in English) are the main expectations – also due to increased competition.

2.13 Sphere of activity 13: Production planning

Work tasks:

The client presents the product that he wants to produce, asks for time needed, the type of machine tool needed, as well as the expected expenses. All this happens at the beginning of working in this sphere of activity. The next step is analysing the product: which material is needed? Is there the need of special cooling liquids? A small project study for the product then has to be sketched, including a feasible study, analysis of time and machine tools needed, if possible with respect to other production sites or affiliated companies. After clarifying these principal decisions, an offer is to be prepared. In case of acceptance, the order has to be conducted and documented, including provision of production manuals, spare-parts lists, maintenance manuals, and quality certificates.

Future trends:
Expectations for this sphere of activity include new IT-programmes, the upcoming of man-machine systems, an electronic supervision of processes including relevant environmental protection regulations, an increased quality, going hand in hand with decreased costs and delivery times, and increased teamwork of colleagues from different cultures, including the need of appropriate knowledge of foreign languages.

2.14 Sphere of activity 14: Additive Manufacturing

Work tasks:
In this sphere of activity the work starts with designing a time and work plan and a CAD-sketch. Then materials needed have to be chosen and a file that is readable by the printer has to be produced. Next step is the equipping of the 3-D printer with respect to work security and environmental protection regulations. Literal printing process needs only monitoring. After the successful production, the printer has to be cleaned and the product has to be post-processed (e. g. removing bars). Finally, quality control (non-destructive measures), documentation of work-processes and delivery or storage are the last tasks of this sphere of activity.

Future trends:
Expectations include increasing speed and decreasing expenses of additive manufacturing, and that standardisation and complexity of products increases. Another consequence could be less waste of material and increasing relevance of materials science. A potential effect could be the option of designing 3-D graphics in an office and a loss of market shares by conventional producers. Additive manufacturing might become a separate branch of “removing machine mechanic” apprenticeship or even an own vocation.

3. Research focus on additive manufacturing

As said, the METALS consortium circulated a questionnaire to gather data for producing this report. Overall, 45 between tool industrialists and advanced manufacturing experts participated to it. In line with the survey rationale explained in D.2.1, results highlight the most prominent current and future technologies characterizing the machine tool sector between 2015 and 2025. A total of 41 technologies, split along four categories, was included in the survey. As D.2.1 planned, respondents rated them on a scale of relevance from 0 to 5. Here below in Figure 1 are presented average results for each technology by time-frame. While “Short” reflects the importance of the given technology in the short-time, i.e. between the moment of the survey dissemination to two years later, “long” refers to its relevant in 8 to 10 years from the survey dissemination. “Medium” concerns its impact on the medium-term, i.e. between 3 to 7 years. Full results country-by-country are represented in Annex III.

FIGURE 1: SURVEY RESULTS

		TOTAL METALS AVERAGE SHORT (2 years	TOTAL METALS AVERAGE MEDIUM (5 years)	TOTAL METALS AVERAGE LONG (10 years)
1 – ADVANCED MANUFACTURING MATERIALS AND PROCESSES				
1.1	Additive manufacturing (Design and Manufacturing)	2.42	3.41	3.83
1.2	Processes for the post-processing of parts manufactured by additive technologies	2.30	3.13	3.60
1.3	Checking the behaviour and characterization of new materials, both polymers and metals, for additive manufacturing.	2.58	3.05	3.48
1.4	Welding technologies, mechanical and adhesive union for hybrid components	2.23	2.81	3.08
1.5	Process simulation and integration in manufacturing	2.83	3.45	3.90
1.6	High efficiency, zero defects and high precision production	3.47	3.98	4.15
1.7	Advanced manufacturing technologies for composites	2.65	3.26	3.42
1.8	New methodologies: Design for Manufacturing & Assembly	2.42	2.96	3.35
1.9	Functionalization of surfaces (Surface Finish ....)	2.32	2.79	3.23
1.10	Láser technology and its applications	2.60	3.21	3.56
1.11	Hybrid manufacturing processeses – processes combination	2.79	3.32	3.72
2 – FLEXIBLE, SMART AND EFFICIENT MANUFACTURING SYSTEMS				
2.1	Collaborative Robotics (human-robots collaboration in friendly work environments)	2.40	3.25	3.65
2.2	Artificial vision	2.48	3.05	3.43
2.3	Hybrid and/or multitasking machinery/equipment	2.86	3.25	3.82
2.4	Flexible, intelligent and connected machinery/equipment, components and tooling	2.88	3.61	4.12
2.5	Agile human-machine interfaces (HM)	2.88	3.51	3.76
2.6	Inspection and measurement systems integrated in the production process and connected online	3.15	3.66	3.95
2.7	Intelligent systems to compensate vibration and deformations	2.59	3.25	3.70
2.8	Reliable and ergonomic equipment/machines	3.07	3.52	3.83
2.9	Equipment with self-learning systems and coach for the user	2.30	3.07	3.28
2.10	Sensorization and communication among components, equipment and environment	2.67	3.49	3.88
2.11	Data management-safe storage, treatment, analysis y modelisation	3.11	3.70	3.93
2.12	Process simulation	2.98	3.51	3.90
3 – DIGITAL, VIRTUAL AND CONNECTED FACTORY				
3.1	Big Data	2.52	3.51	4.03
3.2	Cloud Computing	2.42	3.36	3.83
3.3	Cyber-physical systems (IoT)	2.60	3.27	3.75
3.4	Augmented reality	2.17	2.81	3.14
3.5	Equipment and processes monitoring, and its implementation in the production processes	2.98	3.64	4.05
3.6	Communication systems among equipments for consecutive production processes (M2M)	2.74	3.33	3.78
3.7	ERP and MES System integration	2.80	3.44	3.76
3.8	Intelligent marking and traceability with embedded information for monitoring throughout the life cycle of the products	2.66	3.30	3.68
3.9	Virtual systems for simulation and control of processes and production plant(s)	2.72	3.33	3.76
3.10	Customization of products and processes	3.18	3.71	4.03
3.11	Introduction of intelligence in the product	2.78	3.57	3.80
3.12	Services related to the manufacture and use of data in real time and on-line: Predictive and proactive maintenance service	2.93	3.69	4.03
4 – SUSTAINABLE MANUFACTURING				
4.1	Manufacturing, reuse, assembly and dis-assembly oriented design	2.34	2.91	3.35
4.2	Platforms and advanced tools for energy management of production equipment and plants	2.53	3.26	3.64
4.3	Monitoring and control systems of energy consumption for each stage of the life cycle	2.79	3.29	3.71
4.4	Energy generation, recovery and conversion systems	2.75	3.22	3.49
4.5	Model-based resources management, modular, scalable and based on open source software	2.07	2.70	2.92
4.6	Modularity, reconfigurability of machines and processes	2.70	3.20	3.57

For its relatively high results and the amount of sectorial literature currently focusing on its potential impact on industrial production techniques, the METALS consortium selected AM as key technology to be further investigated. Accordingly, Figure 2 shows the work of project partners in creating a table that summarizes key stages of the additive manufacturing production process, job forecasts for interacting with this technology, activities it involves as well as related skills needs. A further visual explanation of the stages in the AM process is provided in Annex I by means of a flow chart. Annex II lists instead the entrepreneurial skills in the EU Eurydice report to which the right-end column of this table refers.

FIGURE 2: TABLE ON SKILLS NEEDS

Emergent technology: ADDITIVE MANUFACTURING

General Competence
The general competence is to plan, programme and control the manufacture by casting, powder metallurgy, transformation of plastics and composite materials, starting from the process documentation and specifications of the products to be manufactured, ensuring the quality of management and products, and the maintenance of risk prevention and environmental protection systems.

<table>
<tr><th rowspan="2">1 Segments</th><th rowspan="2">2 Jobs forecast
(Competence Units)</th><th rowspan="2">3 Activities
(Professional achievements)</th><th colspan="3">4 Performance Criteria</th></tr>
<tr><th>Knowledge</th><th>Technical Skills</th><th>Entrepreneurial Skills
(Select from Annex 2)</th></tr>
<tr><td rowspan="5">Design, planning</td><td rowspan="5">Design parts manufactured by Additive Manufacturing (AM)</td><td>Identify requests and functionalities of the part to be designed, analyzing the characteristics and use that you will give it. (understanding clients' needs)</td><td>Knowledge on AM materials & processes</td><td>Choosing the AM materials and processes, depending on the features and functionalities of the part to be designed</td><td>A2 Sense of initiative</td></tr>
<tr><td>Design the supports required for the manufacturing, considering the type of process of additive manufacturing (AM)</td><td>Specific CAD for AM

Effects of different AM technologies on the performance of the workpiece (quality, functionality, precision...)

Structural density depending on the requirements.</td><td>Designing the supports, according to workpiece and process specifications and limitations.</td><td>S1 Creativity</td></tr>
<tr><td>Select the type of 3D printing process or Additive Manufacturing function, considering the requirements of the piece to manufacture.</td><td>3D printing technologies (FDM, SLA, etc.)

Additive Manufacturing technologies (SLM, SLS, DLDM, laser cladding, etc.)

3D Printers

Additive Manufacturing machines

Positioning of the workpiece on the basis: Limitations of the manufacturing process (support material) and performance of the workpiece according to the directions of the layers of deposition or contribution.</td><td>Selecting the right process considering the requirements of the piece (material, etc.)

Building the piece.</td><td>S2 Planning

S3 Financial literacy</td></tr>
<tr><td>Select the workpiece material according to the characteristics of the part to be designed, to the requests and the Additive Manufacturing process or 3D Printing</td><td>Polymers and other non-metallic materials used in 3D printing: features, limitations, specifications of the 3D printing processes, business forms, and common uses.

Metal powders and filler wires used in Additive Manufacturing: characteristics, constraints, specifications for 3D printing processes, business forms, common uses.</td><td>Selecting the material depending on the requirements of the piece.</td><td>S4 Organising resources</td></tr>
<tr><td>Design the workpiece using a specific 3D CAD for Additive Manufacturing.

Design the required supports for the manufacturing, considering the type of process.</td><td>CAD for 3D Printing and Additive Manufacturing.

Considerations for designing parts manufactured by 3D printing and Additive Manufacturing.

Structural density depending on the requests.</td><td>Designing the parts manufactured by 3D printing: considerations and limitations of the printing process.

Designing the parts manufactured by Additive Manufacturing: considerations and limitations of the Additive Manufacturing process.</td><td></td></tr>
</table>

		Design pieces starting from physic models, using 3D scanners	Reverse engineering processes: Types of 3D scanners: functions and limitations. Use of 3D scanners for the generation of surfaces and solids. Software for edition of complex surfaces.	Selecting the proper scanner considering the physical model. Performing the scanning process. Using and managing specific software for reverse engineering.	
		Optimize the part design (shape, size, supports and positioning on the machine or printer) according to its specifications and requests and to the Additive Manufacturing process	Effects of the different printing technologies of Additive Manufacturing in the performance of the manufactured parts.	Optimizing the design of a part for its construction by Additive Manufacturing or 3D printing: resizing, depending on the requests and the functionality of the workpiece, the manufacturing process and the technology used.	
	Operate systems of topology optimization considering the type of additive manufacturing process	Identify, asses and develop the process of topology optimization, according to the requirements and the functionalities of the part to be designed	Software and processes related to topology optimization: edition of solids.	Using and managing specific software for topology optimization, fulfilling requirements and light weighting.	
	Elaborate the CNC program with an Additive Manufacturing CAM	Set the parameters of the Additive Manufacturing process and the processing strategies considering the material to process	Manufacturing and printing parameters for different materials and technologies	Selecting the parameters depending on the materials and technologies that are being used.	
	Prepare the CNC program with an Additive Manufacturing CAM	Enter data into the control program of the Additive Manufacturing system using a specific CAM	CAM for 3D Printing and Additive Manufacturing: CAM functions and process strategies. Post processing and obtaining the CNC or robot program.	Using and managing the parameters on specific CAM for AM technologies: Introducing the data, selecting the functions and production strategies and getting the CNC programme.	
		Simulate the manufacturing process using the specific software for the various types of Additive Manufacturing and 3D Printing	Knowledge of simulation processes for AM technologies.	Simulation of 3D Printing and Additive Manufacturing processes.	
		Transfer the post processing program to the Advanced Manufacturing system using the specific devices.	Devices and CAM-machine FA or I3D communications	Transferring and loading programs to the 3D Printer or Additive Manufacturing machine.	
	Consider the rules applicable to the selected method and material	Attending to the selected process and material, adapt the design of the piece and specify the parameters of the building process.	Knowledge of the selected process and material.	Designing parts adapted to the selected process and material.	
Assembly					
Operation: Programming, Materials	Prepare the 3D Printer, meeting the standards of	Load the material following the procedure established for the type of 3D Printer	Systems of wire contribution to 3D Printers	Preparing and loading the filament of raw material to the 3D printer.	S6 Teamwork

Preparation and Mechanization	Labour Risk Prevention and Environmental Protection	Level the bed of printing according to the procedure established for the type of 3D Printer.	Levelling systems in the 3D Printer bed	Levelling processes in the 3D Printer bed	
		Prepare the printhead cleaning the extruder	Extruders cleaning systems	Extruder cleaning process	
	Prepare the Additive Manufacturing machine, meeting the standards of Labour Risk Prevention and Environmental Protection	Load the CNC program using the specified devices and channels.	Types of devices and communication channels	Loading the CNC program	
		Take references of the workpiece position (zero point, plane and x, y, z axes)	Control devices of the Additive Manufacturing machine or 3D Printer	Reference procedure of the workpiece relative to the machine or 3D Printer Axis movements of the machine or 3D Printer by means of the control panel.	
		Adapt the metal powder feed system, cleaning and adjusting its pipes and devices	Feed the system of metal powder or wire to the Additive Manufacturing process Labour Risk Prevention on handling metal powders Existing Specific Regulations on handling dangerous powders	Cleaning and adjustment procedure of the input device	
		Prepare the metal powder feed system, loading it into the specified warehouse and regulating its dosage and the gas input.	Conservation of metal powders Labour Risk Prevention on handling metal powders.	Preparing the contribution of material: powder packaging, storage conditions, load in tanks, dosage, etc.	
		Assemble the support plate of the workpiece using the accessories or devices specified in the process.	Mooring or securing systems of the workpiece or support plate in Additive Manufacturing machines	Assembling and mooring the support plate and/or the workpiece on the AM machine.	
	Get the workpiece meeting the standards of Labour Risk Prevention and Environmental Protection	Monitor the manufacturing process, checking visually the dosage of the material and its fusion.	Controlling the manufacturing process Visual effects of the Additive Manufacturing and 3D Printing processes during the construction process	Cause-effect analysis of the Additive Manufacturing and 3D Printing processes	S5 Managing uncertainty/risk
		Adjust the flow of powder and gas acting on the sliders or program parameters, depending on the observed process deviations.	Effects on the process and the quality of the workpiece when varying the flow / pressure of powder and the gas supplied.	Selecting and adjusting the parameters: Adjusting the input rate of powder, adjusting the pressure and flow of the gas considering the deviations of the process.	
		Perform the final operations needed for the extraction of the piece (removal of supports, cutting of the support plate)	Operations and tools for: Removal of the support material and the support plate.	Using specific tools for extracting the workpiece.	
		Perform the finishing operations, machining the workpiece manufactured in order to fit the shapes and dimensions set out in the technical specifications.	Finishing operations with proper tools and machines to do it.	Using the proper tools and machines for finishing the processes.	
		Perform operations for the relief of stresses generated in the process	Mechanical methods to relieve stress Non-mechanical methods: Heat and vibration treatments	Using specific tools and machines for the relief of stresses.	

Checking the product (Post processing, checking for validation)	Check the part manufactured	Check the dimensions and geometry of the workpiece using the tools or technologies needed for each case (Coordinate Measuring Machine, caliber, ...)	Coordinate Measuring Machines used for the verification of parts manufactured by 3D Printing and Additive Manufacturing	Dimensional and geometric measurement Procedures. Adequacy of the piece	
		Check the structure of the piece using Non-Destructive and/or Destructive Testing (NDT) (DT)	NDT and DT	Procedures for NDT and DT	
		Check the additive manufacturing process using metallographic techniques	Method for detecting the defects of grain and the metallographic composition of the workpiece	Developing the metalography test.	
		Identify the defects of Additive Manufacturing and 3D Printing process	Defectology on additive manufacturing and 3D printing processes	Detecting and assessing defectology on each AM process	
Maintenance (At ordinary and extraordinary levels)	Perform the maintenance of the 3D Printers user	Clean the pipes of contribution of wire and the extruders	Knowledge of parts, assembly and operation of printing machine: particularly methods for cleaning and/or replacing the input pieces.	Managing the use and (dis)assembly of parts of the printing machine: doing the cleaning process and/or replacement of the parts.	S5 Managing uncertainty/risk
		Clean the print bed	Knowledge of the parts, assembly and operation of the printing machine: particularly methods for cleaning the printing bed.	Managing the use and (dis)assemble parts of the printing machine: Cleaning process of the printing bed.	
		Keep tidy and clean the working place	Methods for keeping the workplace tidy and clean.	Cleaning and arranging the workplace.	
	Perform the Maintenance of Additive Manufacturing machine and devices user	Clean the working place	Methods for keeping the workplace tidy and clean.	Cleaning and arranging the workplace.	
		Clean the laser focal lens and, if necessary, replace it according to process and machine specifications.	Maintenance of the Laser and its optics	Replacing the Laser focusing lens	
		Recharge and recover the metal powder.	Knowledge of the recovering and recharging process for each machine and technology.	Recovering and recharging the metal powder.	

4. Analytical Highlight: Focus on additive manufacturing

This section textually summarizes skills required to use additive manufacturing technologies. It shows how the AM workforce will be characterized by a hybrid skills pool comprising typical skills in subtractive manufacturing, new emerging skills specific to additive machines, as well as heightened soft skills in communication and presentation.

4.1 Overall trends

- After the economic hardship of the 2009 economic and financial crisis, the European machine tool sector recorded a strong recovery in 2016, mainly thanks to exports. As a result of focusing on advanced and sophisticated products, the combined output of a leading club of European countries[1] amounted to 24.2 billion euros in 2016. The figure for 2017 is forecast to be above this level. The machine tool sector has entered a new era, characterized by the emergence of new industrial technologies. One of the most important among these is additive manufacturing (AM), otherwise known as 3D Printing. Several reasons account for the rising attention of machine tool builders on AM. The opportunity to better customize final products, localize the manufacturing process, minimize waste in production and bring down inventory costs are just some of the main incentives behind the rise of AM technologies on the shop floor. And while they are not yet at the level of widespread industrialization, such technologies are part of a continuously expanding industry.
  The global value of the AM market is set to rise three-fold between 2004 and 2018, and hit 21 billion USD by 2021[2]. Indeed, this trend highlights the need to address possible implications in several aspects of production, including skills. This a particularly important variable for key application industries of AM systems such as aircraft, medical devices and automotive. A workforce of world-class standards represents one of the cornerstones of Europe's leading position in advanced manufacturing.
- The analysis conducted by the METALS project on skills requirements in AM technologies yielded a clear conclusion. As AM will move closer and closer to series production in the period leading to 2025, the relevance of workforce competent in additive production methods is predictably set to rise in the European machine tool sector. The skillset it will need to have will gradually evolve into a hybrid one, where conventional competences in subtractive manufacturing will be coupled with new skills specific to the manufacturing process with additive machines. These new competences will be in particular concentrated in stages such as design, STL[3] conversion and file manipulation, post-processing, testing and maintenance. Moreover, greater soft skills in communication and presentation will be part of this evolved skillset. They will become more acute as growing competition in manufacturing will put greater and greater emphasis on marketing opportunities.

4.2 Rise of new skills in specific segments of the additive manufacturing process

With AM technologies in Europe gradually industrializing, new skills demands will arise in the sector. **Design, STL conversion and file manipulation, post-processing**, **testing** as well as **maintenance** will be five areas urging new skills.

New competences needed to enable AM's design freedom

In design, the use of 3D modeling software kick starts the AM production process. It allows for the creation of a Computer-Aided Design (CAD) file, which is then read by the machine that begins to add layer upon layer of material in order to create the final part needed. Software application represents one of the main advantages of producing with additive machines, as it allows for the reduction of geometry restrictions that conventional, subtractive machines face in design. To this extent, despite software technology is still under development, demand for unleashing its benefits is nonetheless set to rise. **Knowledge of AM materials and processes**, together with competences in **free surface modelling**, **structural calculus, topography optimization** and **computational thermal fluid dynamics** will be increasingly in demand. They will be employed to conduct activities such as understanding the needs of the client by identifying requests of the part to be designed, as well as choosing the appropriate AM material for production. Expectedly, these will emerge along skills in proper **design**, today a two-stage process where the use of topological software is followed by the application of conventional CAD tools. Given the set of competences needed, the relevance of the **AM specialized designer** will surge in the AM workforce.

STL conversion and file manipulation becomes a new phase of the manufacturing process, and demands new skills in accordance

The occupation of the AM specialized designer will rise together with that of the **worker in application engineering**, with whom it will coordinate closely. The latter's chief activities will focus on the stage of STL conversion and file manipulation. They will entail part positioning and addition of support structures on the build plate, parameters' setting and slicing of CAD models into a specific code listing commands for the machine to read and follow. The worker in application engineering will also be an occupation requiring knowledge of **AM materials and understanding of features of Computer-aided manufacturing (CAM) software**. This occupational profile will be characterized by individuals with extensive **soft skills in decision-making and problem-solving** and, crucially, with sufficient practical experience to **oversee the whole production process**.

Changes in the skillset for post-processing are concentrated mostly on a specific dimension

[1] Figure take from CECIMO. The countries included are: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Italy, the Netherlands, Portugal, Spain, Sweden Switzerland, Turkey and United Kingdom
[2] Accounting for products & services (all materials). Source: Wohlers Report 2015
[3] Acronym for Stereolithography

Post-processing, which takes place once operation is completed, is another area of the manufacturing process where skills will evolve until 2025 as a result of more and more machine tool builders tapping into the opportunities of additive techniques. To this extent, workers in AM will need new vocational skills for removing and recycling redundant metal powder around the part fabricated, a task peculiar of the AM process. Metal cutting, surface finishing and heat treatment, other activities to which the part produced is subjected in post-processing, are activities relatively common also to conventional machines.

Competences in testing are also affected in the shift from subtractive to additive

Also the identification of defects of the fabrication process in the stage of testing product and production cycle will become more important in the period analyzed by METALS. This activity requires expertise specific to additive machines, and is conducted by using computed tomography**. Knowledge of AM materials and processes is essential in this respect**. Controls of the fabricated part, instead, follow in general the path delineated in subtractive manufacturing. As a consequence, the occupation of the **metrologist,** in charge of these tasks, will remain equally important between now and 2025**.**

Maintenance skills are distributed along two core areas

Furthermore, a note must be made of the **maintenance stage**. The duration of the time frame analyzed by this project, spanning from now until 2025, will be long enough to show how maintenance practices will evolve to adapt to new needs deriving from the gradual deployment of AM at industrial level. For the additive machine to be used on the shop floor, it must be routinely cleaned up and upkept. It is also subjected, approximatively every six months, to extraordinary diagnostic work in order to solve any potential non-functioning or failure. All these tasks require knowledge and competences specific to the AM space. There are risks linked to use of metal powders, and they characterize the peculiarity of maintenance of additive machines. They are to account, too, for an increased focus on safety standards in the workplace. **Keeping high safety levels** is especially relevant in maintenance tasks such as changing filters used during production to capture gases potentially harmful for human health, and detrimental to the process efficiency. In a similar fashion, safety is the main driver for carefully handling and storing feed materials, and guaranteeing a safe and clean work environment. Thus, as materials in the additive process will induce greater and greater attention on safety, needs of specific maintenance competences will intensify in the time frame observed. In the case of extraordinary maintenance, the end-user of the machine will need to rely on **specialized AM maintenance personnel** sent by the supplier to the manufacturing facility where the machine is located. About ordinary maintenance, tasks will instead be conducted directly by the **specialized technicians** of the end-user company. The role of the additive system supplier, and particularly the vocational skillset of its shop-floor level workforce in maintenance, will therefore be crucial. Needed training and specific instruction on ordinary maintenance of the machine will need to come from the supplier.

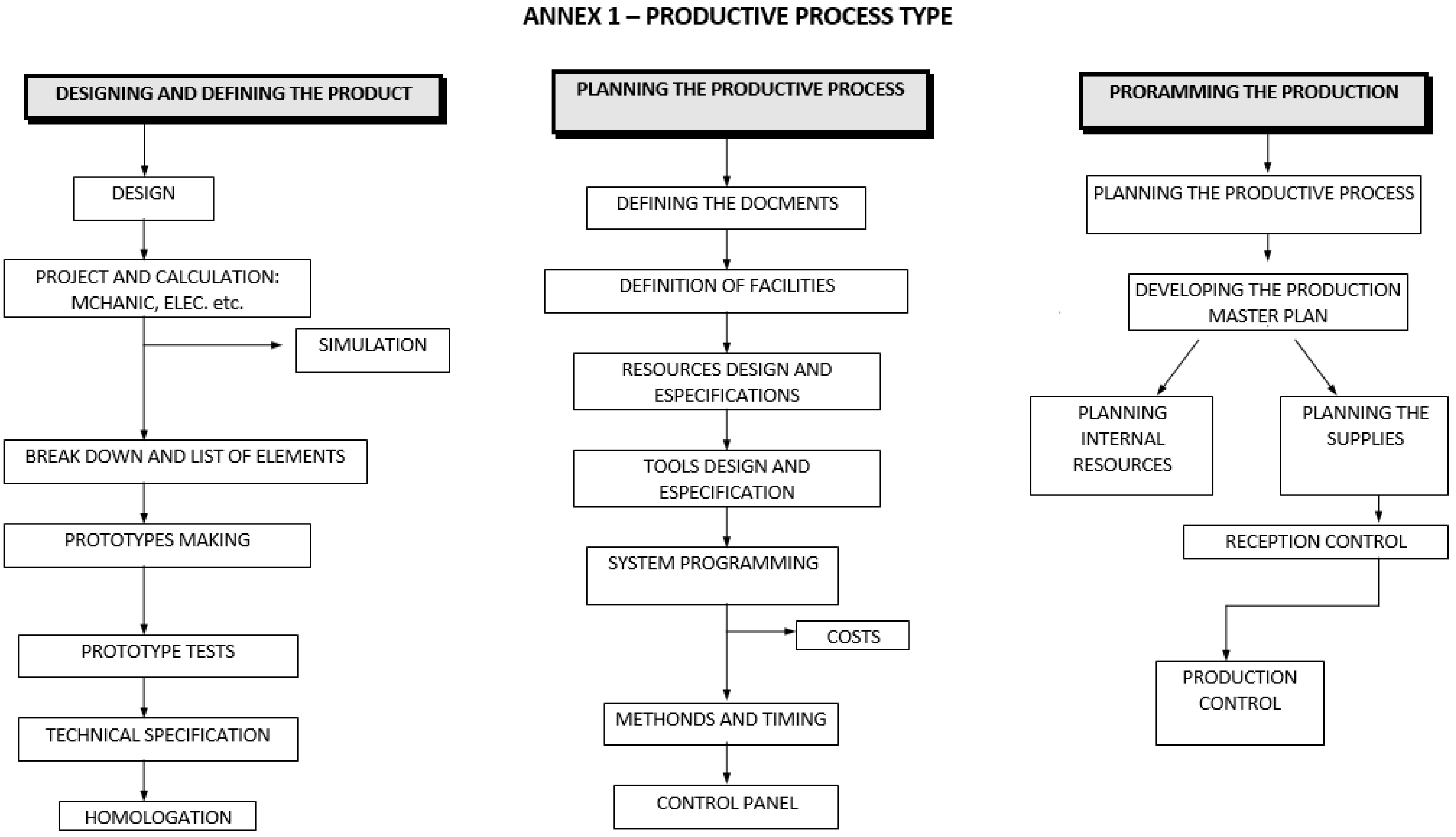
Safety will be at the forefront of vocational operation skills, the majority of which can be retained in the transition from subtractive to additive

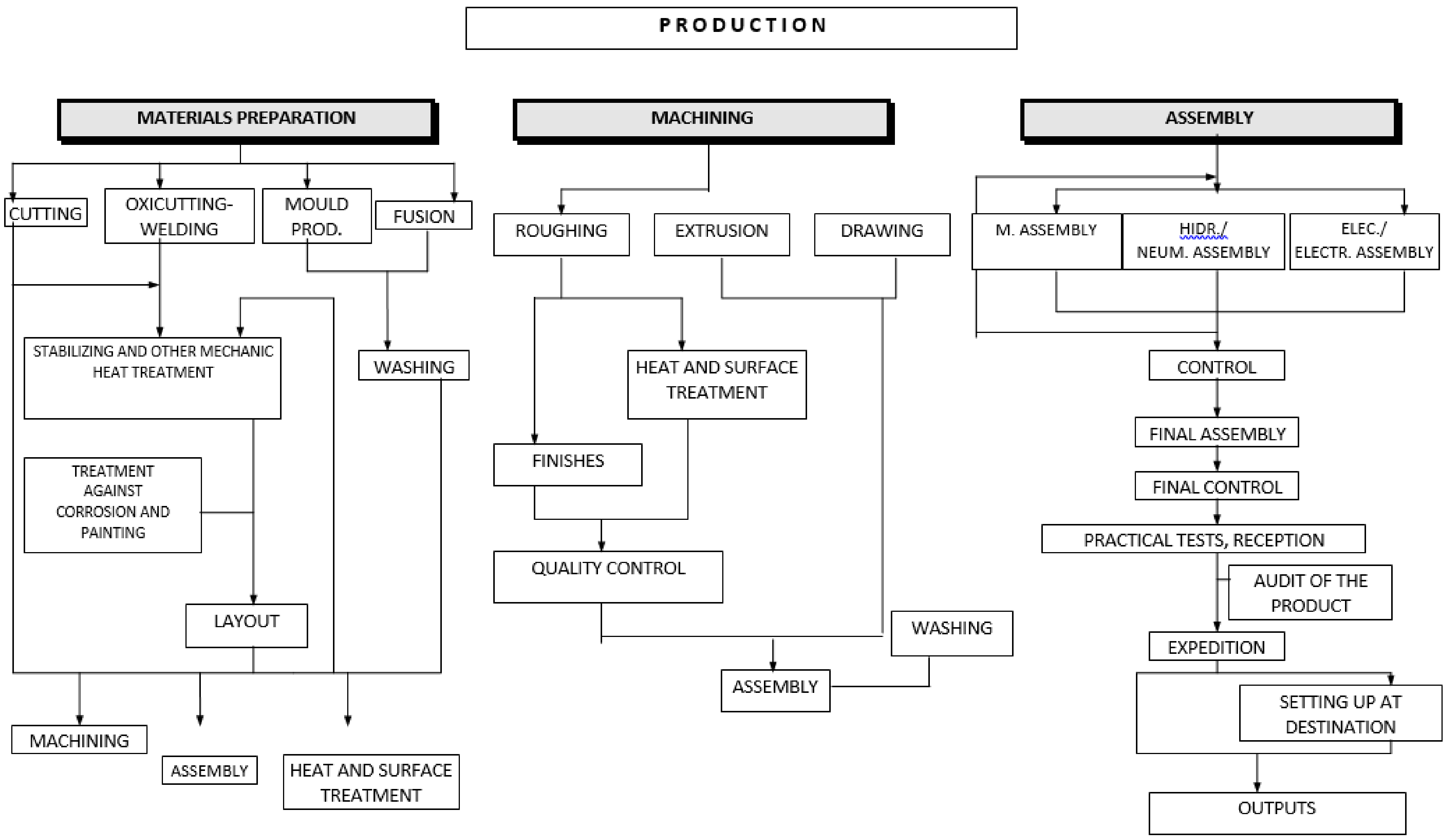
The occupation of the **AM operator** , will be characterized by **enhanced safety standards.** It will be centered on the activities of software and hardware set-up, monitoring of process parameters and extraction of the workpiece. These will be implemented by **safety-minded specialized workers with basic knowledge of materials,** and **competent in emergency management and handling minor deviations of the process parameters.** Operation is also one stage where AM-driven automation is set to make redundant certain competences. The fact that today software is well-developed at this stage of AM technological developed, being wired into the machine and managed remotely, will make knowledge of software a less central need for operators. In production, the additive machine functions independently with little need of manufacturing process monitoring.

The emergence of new skills is not only confined to the production process: certain soft skills gain in importance

Between now and 2025, predictions of growing market competition are expected to trigger a greater emphasis on the marketing dimension of the business. Opportunities for showcasing and demonstrating the manufacturer’s latest own products will be increasingly pursued. To foster the use of AM technologies, machine demonstrations in trade fairs will multiply. Workforce in AM will therefore improve abilities in showcasing the machine in the exhibition’s premises, interacting with potential users interested in it, and coordinating when answering questions from potential customers. Competences in this domain will also be essential when reporting customer inputs at the end of exhibiting activities. Greater **soft skills in communication and presentation** will thus be needed by the AM workforce to sustain properly more developed and exhibition-oriented marketing strategies.

Annex I – Productive Process Type





Annex II: Eurydice Report Entrepreneurship Education at School in Europe

Entrepreneurial attitudes:

A1 Self-confidence

A2 Sense of initiative

Entrepreneurial skills:

S1 Creativity

S2 Planning

S3 Financial literacy

S4 Organising resources

S5 Managing uncertainty/risk

S6 Teamwork

Entrepreneurial knowledge:

K1 Assessing opportunities

K2 Role of entrepreneurs in society

K3 Entrepreneurial career options

Annex III: Country-by-country results of METALS survey

WP02 - Questionnaire for detecting Emerging Technologies - Metals Project

METALS
MachinE Tool ALliance for Skills

		SPAIN			GERMANY			EUROPE			ITALY			TOTAL METALS		
		IMPACT			IMPACT			IMPACT			IMPACT			AVERAGE		
		SHORT (2 years	MEDIUM (5 years)	LONG (10 years)	SHORT (2 years	MEDIUM (5 years)	LONG (10 years)	SHORT (2 years	MEDIUM (5 years)	LONG (10 years)	SHORT (2 years	MEDIUM (5 years)	LONG (10 years)	SHORT (2 years	MEDIUM (5 years)	LONG (10 years)
1 – ADVANCED MANUFACTURING MATERIALS AND PROCESSES																
1.1	Additive manufacturing (Design and Manufacturing)	40	55	57	23	28	28	28	46	47	18	21	21	2.42	3.41	3.83
1.2	Processes for the post-processing of parts manufactured by additive technologies	40	52	55	20	24	25	27	41	41	14	24	23	2.30	3.13	3.60
1.3	Checking the behaviour and characterization of new materials, both polymers and metals, for additive manufacturing.	34	44	49	19	21	21	34	45	47	24	24	22	2.58	3.05	3.48
1.4	Welding technologies, mechanical and adhesive union for hybrid components	31	37	40	10	24	19	29	36	40	26	24	21	2.23	2.81	3.08
1.5	Process simulation and integration in manufacturing	46	51	56	19	26	30	38	47	47	27	28	23	2.83	3.45	3.90
1.6	High efficiency, zero defects and high precision production	56	63	64	40	35	35	40	43	45	27	26	22	3.47	3.98	4.15
1.7	Advanced manufacturing technologies for composites	36	42	44	22	32	24	33	40	39	23	26	23	2.65	3.26	3.42
1.8	New methodologies: Design for Manufacturing & Assembly	38	47	53	16	24	20	32	39	40	23	23	21	2.42	2.96	3.35
1.9	Functionalization of surfaces (Surface Finish ....)	29	38	45	15	23	21	32	38	42	19	21	21	2.32	2.79	3.23
1.10	Láser technology and its applications	41	46	52	12	24	28	36	42	44	20	23	22	2.60	3.21	3.56
1.11	Hybrid manufacturing processeses – processes combination	43	52	58	14	27	18	37	42	44	23	25	25	2.79	3.32	3.72
2 – FLEXIBLE, SMART AND EFFICIENT MANUFACTURING SYSTEMS																
2.1	Collaborative Robotics (human-robots collaboration in friendly work environments)	33	49	50	14	33	30	34	37	42	20	24	24	2.40	3.25	3.65
2.2	Artificial vision	37	45	52	18	29	23	30	36	40	24	24	22	2.48	3.05	3.43
2.3	Hybrid and/or multitasking machinery/equipment	46	55	59	16	21	17	38	43	48	20	24	25	2.86	3.25	3.82
2.4	Flexible, intelligent and connected machinery/equipment, components and tooling	46	61	63	16	31	24	37	48	52	22	26	30	2.88	3.61	4.12
2.5	Agile human-machine interfaces (HM)	46	58	58	18	25	19	36	45	47	18	23	19	2.88	3.51	3.76
2.6	Inspection and measurement systems integrated in the production process and connected online	51	54	60	29	34	30	41	45	47	24	28	25	3.15	3.66	3.95
2.7	Intelligent systems to compensate vibration and deformations	47	57	61	10	21	19	38	41	45	19	24	23	2.59	3.25	3.70
2.8	Reliable and ergonomic equipment/machines	55	58	59	24	22	24	43	46	48	19	22	22	3.07	3.52	3.83
2.9	Equipment with self-learning systems and coach for the user	36	45	53	14	24	22	27	40	43	24	26	23	2.30	3.07	3.28
2.10	Sensorization and communication among components, equipment and environment	47	60	62	10	25	19	35	45	49	23	27	25	2.67	3.49	3.88
2.11	Data management-safe storage, treatment, analysis y modelisation	49	55	60	29	34	29	40	46	50	25	28	22	3.11	3.70	3.93
2.12	Process simulation	47	50	59	17	32	28	39	43	44	25	26	21	2.98	3.51	3.90
3 – DIGITAL, VIRTUAL AND CONNECTED FACTORY																
3.1	Big Data	36	51	58	25	34	33	28	41	45	17	25	25	2.52	3.51	4.03
3.2	Cloud Computing	33	48	56	20	33	35	33	42	45	18	25	25	2.42	3.36	3.83
3.3	Cyber-physical systems (IoT)	47	55	63	8	21	17	36	41	44	18	27	26	2.60	3.27	3.75
3.4	Augmented reality	31	43	55	13	18	19	28	35	38	19	22	20	2.17	2.81	3.14
3.5	Equipment and processes monitoring, and its implementation in the production processes	53	60	65	14	28	29	38	43	44	20	29	24	2.98	3.64	4.05
3.6	Communication systems among equipments for consecutive production processes (M2M)	44	50	55	13	26	26	39	44	48	22	23	22	2.74	3.33	3.78
3.7	ERP and MES System integration	43	50	59	26	34	32	34	39	40	23	25	23	2.80	3.44	3.76
3.8	Intelligent marking and traceability with embedded information for monitoring throughout the life cycle of the products	35	49	52	27	31	30	33	40	43	22	25	26	2.66	3.30	3.68
3.9	Virtual systems for simulation and control of processes and production plant(s)	38	52	55	17	29	30	39	46	48	23	23	21	2.72	3.33	3.76
3.10	Customization of products and processes	53	58	63	27	24	27	42	47	49	21	23	22	3.18	3.71	4.03
3.11	Introduction of intelligence in the product	45	58	58	18	30	31	31	39	39	20	23	24	2.78	3.57	3.80
3.12	Services related to the manufacture and use of data in real time and on-line: Predictive and proactive maintenance service	46	62	62	13	21	23	41	46	45	23	26	27	2.93	3.69	4.03
4 – SUSTAINABLE MANUFACTURING																
4.1	Manufacturing, reuse, assembly and dis-assembly oriented design	38	44	54	17	27	29	29	36	41	19	21	20	2.34	2.91	3.35
4.2	Platforms and advanced tools for energy management of production equipment and plants	40	53	54	17	34	34	35	43	45	17	20	20	2.53	3.26	3.64
4.3	Monitoring and control systems of energy consumption for each stage of the life cycle	38	49	51	22	34	34	38	43	46	19	22	21	2.79	3.29	3.71
4.4	Energy generation, recovery and conversion systems	40	44	48	25	42	30	32	37	40	24	25	25	2.75	3.22	3.49
4.5	Model-based resources management, modular, scalable and based on open source software	25	32	35	19	33	24	28	36	38	15	18	17	2.07	2.70	2.92
4.6	Modularity, reconfigurability of machines and processes	40	48	58	19	31	23	36	42	45	24	23	24	2.70	3.20	3.57