FORESIGHTING REPORT 2022

OF ADVANCED MANUFACTURING SKILLS AND TRAINING

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of Advanced Manufacturing Skills and Training

By AMTA Programme Office, 18 Nov 2022

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EXECUTIVE SUMMARY

The manufacturing sector is a key pillar of Singapore's economy, representing 22 percent of its GDP and having 450,400 jobs created in 2021 (Source: Ministry of Trade and Industry and Ministry of Manpower). The Manufacturing 2030 (M2030) launched in January 2021 set a national goal to grow the sector by 50% over the next 10 years. The adoption of Industry 4.0 technologies presents an opportunity for Singapore to grow its manufacturing industries in a globally competitive and sustainable manner. As new technologies transform the workplace, there is an urgent need to identify the emerging advanced manufacturing technologies and skills and future-proof our workforce with relevant training programmes so as to achieve holistic advanced manufacturing transformation and stay relevant and competitive.

As a national programme supported by multiple government agencies, the Advanced Manufacturing Training Academy (AMTA) was tasked to lead the foresighting of emerging skills in advanced manufacturing, evaluate the existing training eco-system, chart and plan training offerings, facilitate the development of new training courses to address skills gaps in I4.0 transformation, and holistically upgrade the manufacturing workforce of Singapore for the future.

This paper summarizes AMTA's analysis of the global advanced manufacturing technology and skills trend and the interpretation of in-demand technologies and skills topics in the context of Singapore's manufacturing sectors, where emerging skills and topics are identified for workforce upskilling and transformation. Concurrently, AMTA has also studied the landscape of advanced manufacturing workforce training and upskilling through evaluation of the existing training offerings in the ecosystem, identified the training gaps for new courses development in partnership with leading training providers identified for respective topics. Below are the approaches of this effort.

- Study and review of 24 industry intelligence reports and review articles in the field of advanced manufacturing (references provided in the end of this report)
- Engagement with about 84 companies across 7 industry sectors
- Engagement with 18 key training providers involved in workforce training in advanced manufacturing, including 4 universities, 5 polytechnics, ITE, A*STAR SIMTech and ARTC, and 6 other training providers (IHCI/McKinsey, Tuv Sud, NTUC LearningHub, Bosch Rexroth, OMRON, and RACE)

- Engagement with consulting firms and companies (McKinsey, Jobkred) for skills profiling and skills and training need analysis
- Partnering with SSG Job Skills Insights Group in job-skills insights search and analysis and mapping the advanced manufacturing technology and skills to the SkillsFuture Series emerging skills and training topics, Technical Skills and Competencies (TSCs), Critical Core Skills (CCS) and training courses.

The outcomes of this joint effort with SSG are summarized below, serving as a recommendation of focused areas for the team's follow up actions in the next phase.

1) **Eight megatrends** in technology adoption (Figure 1) identified, which are driving global advanced manufacturing transformation towards integrated intelligent automation, manufacturing platform and IIoT-enabled horizontal and vertical integration, smart digital solutions enabled by artificial intelligence and digital twin, and sustainable manufacturing operations.

2) **Advanced Manufacturing Tech/Skills Taxonomy** developed, with structured domains of advanced manufacturing technology and their affiliated skills as a reference guide for planning of workforce upskilling and talent development.

3) **AM skills and training topics database** established, which aims to correlate the AM Tech/Skills Taxonomy with emerging skills and training topics from the SkillsFuture Series and relevant Technical Skills and Competency (TSC) and Critical Core Skills (CCS) established in SSG's Jobs-Skills Repository. Through this effort, we aim to establish an Advanced Manufacturing Skills Framework to identify the gaps of emerging skills and guide the skills and competencies development.

4) **Training database framework** established with the existing training courses in the ecosystem mapped to the AM Tech/Skills Taxonomy as a reference to recommend AM training courses for workforce upskilling. Through this effort, gap training topics are also identified to guide the development of new courses emphasizing enterprise-oriented training for adoption through partnership with training providers.

5) **Curation of a list of emerging AM skills** in a Singapore context to support the transformation of manufacturing industry

1.0 Overview of Advanced Manufacturing Technology and Skills

This section summarizes the global trend of advanced manufacturing technologies and skills through review of the industry intelligence reports and review articles in the field of advanced manufacturing. The Skills Future Series (SFS) Emerging Areas and Skills Domains developed by SSG is described in Section 1.2. The aim and outline of this report is illustrated through an activity flow chart in Section 1.3.

1.1 Global Trend of Advanced Manufacturing (AM) Technologies and Skills

Along with the tide of the fourth industrial revolution, manufacturing is rapidly evolving from a labour-intensive industry to one that incorporates cutting-edge technologies to transform production and drive innovation. Thanks to technologies such as 3D printing, advanced robotics, artificial intelligence, industrial internet of things, and virtual and augmented reality, the shift to advanced manufacturing is gathering pace and expected to reach a market size of US$156 billion by 2024. Eight megatrends in technology adoption (Figure 1) have emerged in this transformation process aimed at enabling tighter integration of R&D and production, mass product customization, intelligent automation, and more sustainable manufacturing operations.

Emerging Advanced Manufacturing Technologies	Key Examples
1 Lights out manufacturing enabled by advanced robotics and intelligent automation	• Micron (Singapore) • Makino (Singapore) • Koei Tools (Singapore)
2 Smart horizontal and vertical integration enabled by manufacturing platform, IIoT and connected technologies	• Real-time supply chain visibility for production planning • Mass customization enabled by seamless digital integration from design to production
3 Predictive maintenance applying in more manufacturing industries, enabled by machine learning and advanced analytics	• Skywise platform for preventive maintenance by Airbus • Predictive maintenance as a service by Rockwell Automation
4 Digital twins (digital design, simulation and integration) at the core of product and process development	• Large-scale adoption observed in automotive, aerospace, consumer goods, and MedTech industries • Siemens, Tesla, Boeing, BMW
5 Additive manufacturing making product innovation and production more effective and efficient	• Manufacturing of customized medical implants • Complex tooling for automotive, aerospace and electronics manufacturing
6 Immersive collaboration and training enabled by extended reality and metaverse technologies	• Nvidia omniverse • Smart glasses/ googles widely used for remote assistance and training
7 Increasing use of advanced materials developed using computational methods	• Computational drug and vaccine design • Light-weight materials and surface property modification for aerospace applications
8 Increasing focus on sustainability in product design and manufacturing operations	• Overwhelming demand for the Green Compass tools for sustainability transformation • Net-zero manufacturing: Tesla Gigafactory, Rolls Royce, Ingka (IKEA)

Figure 1 Megatrends in Advanced Manufacturing Technology Adoption

Lights-out manufacturing enabled by advanced robotics and intelligent automation

Dark factories are a reality today thanks to the rise of advanced robotics and automation technologies, machines can carry out more tasks previously reserved for humans. This not only liberates humans from laborious and repetitive operations to perform high-value tasks but also delivers higher productivity, greater accuracy, and lower cost. As automation becomes increasingly intelligent and sophisticated, a rise in the adoption of lights-out manufacturing where manufacturing activities happen without direct human intervention has been observed among leading manufacturing enterprises.

Smart horizontal and vertical integration enabled by manufacturing platform, IIoT and connected technologies

Smart manufacturing platform, IIoT and connected technologies, such as sensors, fieldbuses and industrial gateways enable the collection and sharing of data across

equipment and software both within the shopfloor and throughout an enterprise operating in multiple locations. This ultimately provides manufacturers, their customers, and suppliers with valuable insights into the manufacturing process status, helps manufacturers make informed, strategic decisions using real-time data and achieve a wide variety of goals, including cost reduction, enhanced efficiency, improved safety, and more. According to a study of US manufacturers, nearly a third (31%) of their production processes now incorporate smart IIoT devices and embedded intelligence. In addition, 34% of US manufacturers have plans to incorporate IoT technology into their processes, while 32% of them plan to embed IoT technology into their products.

Predictive maintenance applying in more manufacturing industries, enabled by machine learning and advanced analytics

A breakdown of critical equipment can be extremely costly in terms of repairs, downtime, and production disruption. Therefore, it is vitally important for manufacturers to predict the likely failure of equipment and perform preventive actions before failure occurs. The advancement in machine learning and data analytics technologies have made it possible to detect failure patterns in equipment and component, and therefore enabled predictive maintenance tools applying in more manufacturing sectors to analyse real-time data from machine sensors to identify irregularities and trigger maintenance actions to keep the equipment in optimal condition.

Digital twins (digital design, simulation, and integration) at the core of product and process development

Digital twins are digital constructions of objects or processes achieved through computer modelling and simulation. It can be used to create a virtual replica of a product, equipment, production processes, and even the entire shopfloor to evaluate how the product or factory functions under different conditions to achieve improvements in product quality and production efficiency. According to Deloitte’s Tech Trend 2020 report, as many as 70% of US manufacturers could have adopted digital twins to conduct simulations and evaluations by 2022.

Additive manufacturing making product innovation and production more effective and efficient

Over the past decades, additive manufacturing has transformed from a costly process with few materials options mainly reserved for prototyping to a revolutionary technology that is cost-effective, efficient, and scalable. It uses fewer materials, creates less waste, and is more accommodating to complex geometries than traditional manufacturing methods, making it an effective and efficient process method for product design and innovation and production in medical, aerospace, automotive and precision engineering applications.

Immersive collaboration and training enabled by extended reality and metaverse technologies

Extended reality technologies such as augmented and virtual reality will play an increasingly important part in manufacturing as more of the world extends into the metaverse. New opportunities and capabilities will be enabled, such as enhanced product design, better production planning, closer multi-site collaborations, augmenting human abilities on assembly lines, providing real-time remote assistance, and more immersive training.

Increasing use of advanced materials developed using computational methods

The combination of nano-manufacturing – the fabrication and manipulation of features at a nano-meter scale and computational modelling of functional materials at atomic levels has created the possibility of creating new materials to tackle technological challenges, such as the design and manufacturing of new drugs, semiconductor devices, and surface nanostructures with special wetting, adhesive, optical and friction properties.

Increasing focus on sustainability in product design and manufacturing operations

Sustainable manufacturing processes and operations that are non-polluting and conserve energy and natural resources are increasingly favoured as both consumers and policymakers become more environmentally conscious. With the rapid increase in energy prices, worldwide adoption of carbon reduction initiatives, and increasing concerns about the depletion of non-renewable resources, the integration of sustainable manufacturing philosophy and techniques is no longer an option but a necessity for manufacturers to reduce costs, decrease supply-chain risks, and enhance brand appeal to both consumers and regulators.

1.2 SSG Skills Future Series (SFS) Emerging Areas and Skills Domains

SkillsFuture Singapore (SSG) launched a SkillsFuture Series (SFS) of training programmes in eight priority and emerging skills areas in 2017 to equip working adults with the skills required across different economic sectors. In December 2021, SSG published its inaugural Skills Demand for the Future Economy (SDFE) Report. This report highlights in-demand skills and jobs in three priority economic areas, namely the Digital Economy, the Green Economy and the Care Economy and provides Singaporean the resources to embark on their skills development journey, such as career planning guides and corresponding training courses in the ecosystem. The latest version of SDFE Report 2022 was launched in November 2022 with updated emerging skills domains and priority skills and the inclusion of Jobs and Skills in I4.0 implementation which are linked with a new priority economic area named Industry 4.0 Economy. Figure 2 summarizes the four SFS economic areas and skills groups, with skills and training topics in each economic area provided in Annex A. These SFS skills topics together with their established Technical Skills Competency (TSC) framework and Critical Core Skills (CCS) provide a national level Jobs-Skills Repository to guide training course development and delivery for working adult learning and workforce upskilling and development.

Notes: Identification of Emerging Domains and Priority Skills for the Four Economies

Emerging domains were identified using a 3-step approach:

- Qualitative framing of potential emerging domains based on research on each economy and taking referencing to the four strategic economic growth pillars under the Research, Innovation and Enterprise (RIE), 2025
- Quantitative analysis by performing hierarchical clustering of the skills under each economy to identify common themes, which were then used to refine the emerging domains
- Expert validation with industry and academia on the emerging domains

Priority skills were identified as skills for citizens to gain access and thrive in the emerging domains. These skills were derived from SSG's Jobs-Skills Repository with expert input and validation by industry and academia.

Source: SSG Skills Demand for the Future Economy Report 2022 (SDFE 2022)

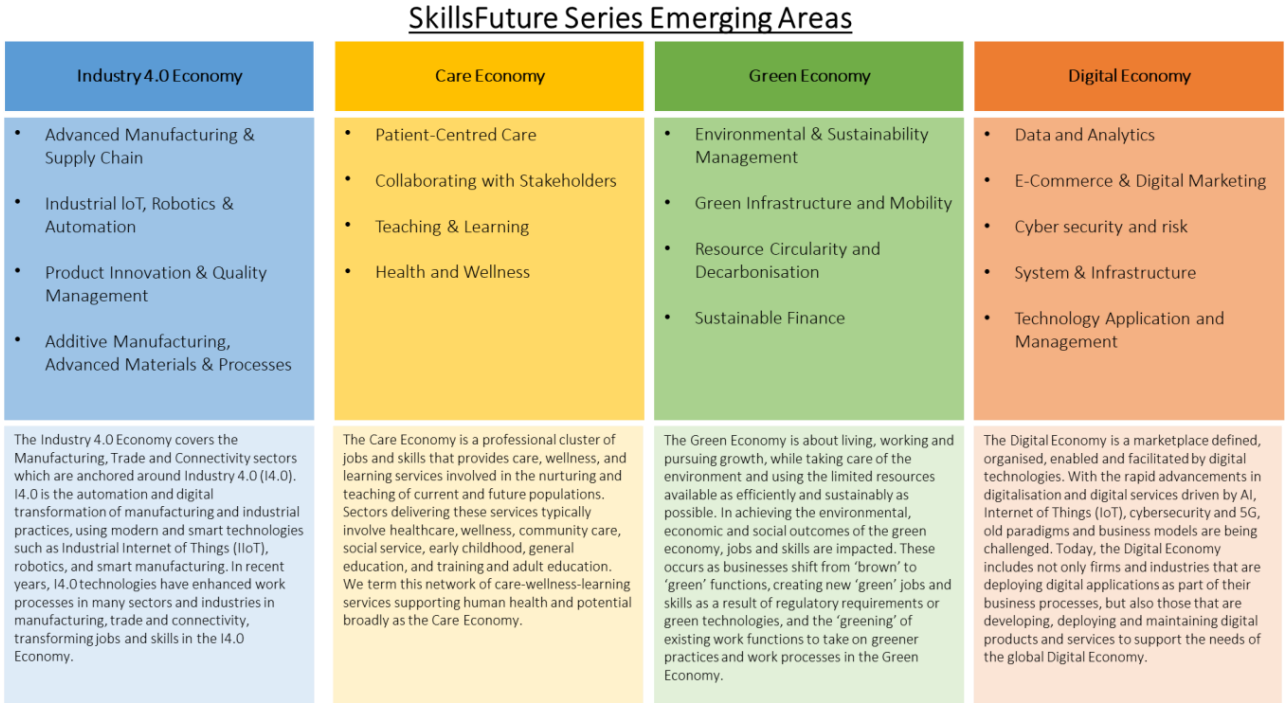

Figure 2 SkillsFuture Series Emerging Economy Areas and Grouping Skills Domains

1.3 Aim of This Foresighting Report

This AM skills and training foresighting report aims to provide a holistic picture of advanced manufacturing technology and skills domains and how their affiliated skills and training topics are mapped to the updated SkillsFuture Series emerging skills and training topics, the relevant Technical Skills Competency (TSC) and Critical Core Skills (CCS) established in SSG's Jobs-Skills Repository. The AM training topics and course offerings in the ecosystem are then mapped to their corresponding technology and skills domains and topics to provide guidance for adult learning and workforce upskilling, with emphasis on enterprise-oriented training for AM or I4.0 adoption. Gaps of AM skills and training topics are identified to guide and facilitate the development of new TSCs/CCSs and new training course through partnership with the training providers in the ecosystem. Figure 3 illustrates the effort of this development.

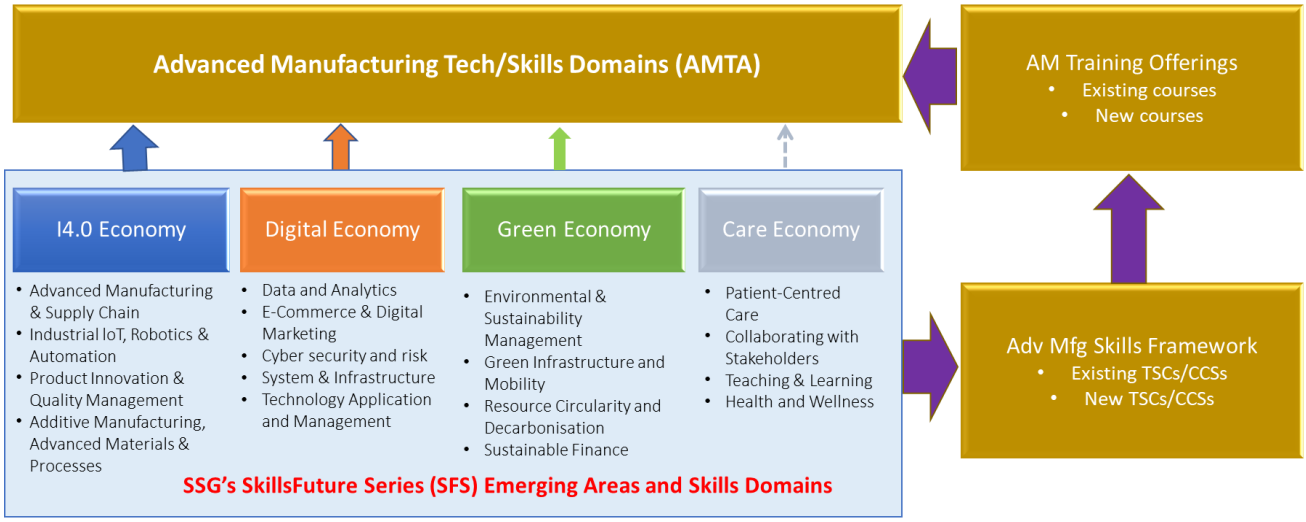

Figure 3 Mapping of the AM Tech/skills taxonomy with SSG's SFS emerging skills domains and Jobs-Skills Repository (TSCs/CCSs) and Training Courses

Section 2 presents the AM Technology and Skills Taxonomy developed by AMTA, the mapping of the technology and skill topics to the SFS emerging skills and training topics, and the list of emerging skills AMTA curated to support the transformation of Singapore manufacturing industry.

Section 3 presents Singapore's AM training provision landscape, the mapping of the AMTA-recommended training courses to AM Tech/Skills Taxonomy and the gaps identified in the training ecosystem in advanced manufacturing workforce upskilling.

2.0 Foresighting of Advanced Manufacturing Technology and Skills

This section describes the Advanced Manufacturing Technology and Skills Taxonomy (AM Tech/Skills Taxonomy) developed by AMTA which is mapped to SSG's updated SkillsFuture Series (SFS) economy areas and emerging skills and training topics. The AM Tech/Skills Taxonomy aims to cover the current and emerging technologies and skills topics that cut across all manufacturing industries. A list of emerging AM skills is curated in a Singapore context to support the transformation of manufacturing industry.

2.1 Advanced Manufacturing Technology and Skills Taxonomy

The Advanced Manufacturing Technology and Skills Taxonomy is structured into ten Tech/Skills domains to provide a comprehensive coverage of advanced manufacturing functional technologies and their affiliated skills, including digital/smart manufacturing platforms and tools, emerging digital technologies for manufacturing, advanced manufacturing processes and materials and product innovation and quality management. The 10 Tech/Skills domains are demonstrated in Figure 4.

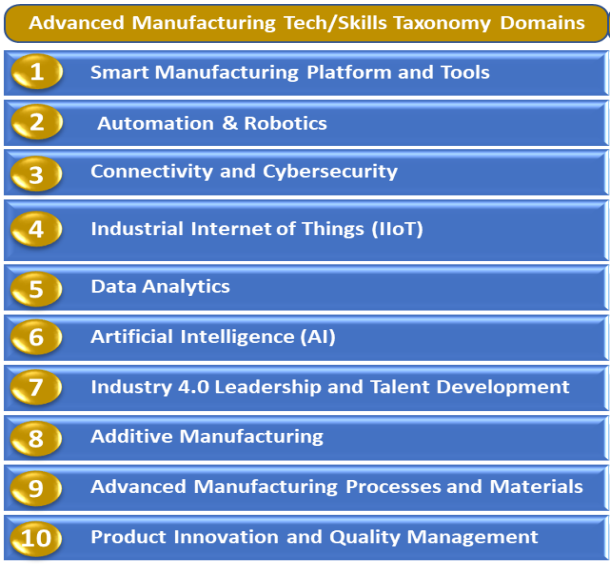

Figure 4 AM Tech/Skills Taxonomy Domains

Total 145 Tech/Skills topics are curated, which covers both current and emerging technologies and skills cutting across all manufacturing sectors. Table 1 summarizes the detailed technology and skills topics in each domain.

Table 1 Advanced Manufacturing Tech/Skills Taxonomy

Tech/skills Taxonomy Domain	Technology and Skills Topics
1. Smart Manufacturing Platform and Tools	**Digital Manufacturing IT-OT Platforms:** ERP, MES, Cloud Platforms [SAP, Oracle, Microsoft Azure, Amazon Cloud], **Smart Manufacturing Systems:** Cyber Physical Production Systems (CPPS), Manufacturing Process Simulation; Virtual Reality (VR); Augmented Reality (AR), Real-Time Operating System (RTOS); Real Time Production Flow Simulation; Supervisory Control and Data Acquisition (SCADA) **Smart Manufacturing Tools:** Overall Equipment Effectiveness (OEE); Production Planning and Scheduling; Smart Inventory Planning; Workflow Digitalization, Dynamic Scheduling; Microservices for Smart Manufacturing, DevOps, and Containerization in Industry 4.0 application **Supply Chain Management (SCM):** Machine Learning for Supply Chain, Supply Chain Analytics, Digital Supply Chains, Horizontal and vertical integration
2. Automation & Robotics	**Automation:** Sensors, Actuators, Motion Controls, Positioning Systems, Instrumentation Measurement and Control, Programmable Logic Controller, Human Machine Interface, Firmware Configuration and Programming, Embedded Systems Design and Programming; **Robotics:** Industry Robotic Systems, Robotic System Integration, Robot Operation Systems, Robotics Safety, Maintenance and Troubleshoot, Autonomous Mobile Robot (AMR), Automated Guided/Intelligent Vehicle (AGV/AIV), Collaborative Robots, Digital Twin and Simulation of Robots **Shopfloor Automation System:** Robotic/Intelligent Process Automation, Automated Inspections; Manufacturing Process Automation; Automated Process Control; Asset Condition Monitoring & Fault Detection, Automated Materials Handling System; Enterprise Automation System, Facility Automation System.
3. Connectivity and Cybersecurity	**Shopfloor Connectivity:** OT Connectivity, IT Connectivity, Fieldbus [Ethernet IP, EtherCAT, TwinCAT, Modbus], MQTT, OPC UA, SS IEC 62541 **Enterprise Connectivity:** PC Clusters, Servers], Edge Computing connectivity, Cloud Computing connectivity, Facility Connectivity, IT-OT Connectivity Network; Cyber Risk Management, IT-OT Network Security; Cybersecurity Standard-SS IEC 62443
4. Industrial Internet of Things (IIoT)	IIoT for Manufacturing, IoT Systems, IIoT Sensor Network, Security Architecture Design, Smart Sensor Solutions, Video Analytics, IIoT Application Development, IIoT Systems Network Design, Sensorization
5. Data Analytics	Data Analytics, Data Collection and Management, Data Design and Engineering, Data Mining and modelling; Data Sharing, Data Visualization and Control, Big Data Analytics, Data Management

6. Artificial Intelligence (AI)	AI in Manufacturing; Machine Learning (ML); Deep Learning (DL); Artificial Neural Networks, Computer Vision, Self-Learning Systems, Artificial Intelligence Application, AI for Robotics, Intelligent Robots, Predictive maintenance, AI-Enabled Quality Control and Assurance, AI-enabled Predictive Intelligence, AI-enabled Autonomous Control, Facility Intelligence [Facility Diagnostics & Prognostics, Facility Management System (FMS), Predictive Maintenance], Intelligent Systems
7. Industry 4.0 Leadership and Talent Development	Industry 4.0; SIRI Framework; Digital Transformation Methods; Training Planning and Development; Industry 4.0 Implementation, Industry 4.0 Standards for Manufacturing; Lean Manufacturing; Coding Skills [C, C#, C++, Python, Spark, Hadoop, etc], Critical Core Skills [Change Management, Creative Thinking, Problem Solving, Communication, Collaboration, Supplier Relations Management (SRM), Customer Relations Management (CRM), Digital Fluency, Learning agility]
8. Additive Manufacturing	Additive Manufacturing Processes and Systems; Additive Manufacturing for Metallic Components; Additive Manufacturing for Polymer-Based Components, Additive Manufacturing and 3D Printing Methods [Ceramics, Composites, Cement]; Hybrid Manufacturing (Subtractive and Additive); Design for Additive Manufacturing (DfAdM), Additive Manufacturing Standard, Qualification and Certification, AM Inspection Methods, AM Safety, AM Surface Finishing.
9. Advanced Manufacturing Processes and Materials	Advanced Materials, Functional Materials, Advanced Composite, Advanced Manufacturing Processes [Forming/Forging/ Welding/Machining/Coating methods] ; Advanced Material Treatment Processes [Heat Treatment, Surface Finishing and Modification methods]; Advanced Metrology, Advanced Inspection for Manufacturing; Flexible/Hybrid Materials Engineering and Processes, Smart Mold Design and Fabrication, Integrated Engineering for MRO, Materials Characterization, Green Manufacturing Design and Implementation, Green / Sustainable Manufacturing, Sustainable Manufacturing Assessment, Remanufacturing.
10. Product Innovation and Quality Management	Product Design and Modelling; Design Thinking for Product Innovation, Process Innovation, Operation Management and Innovation, Plant Simulation and Manufacturing Process Analysis, Manufacturing Product Lifecycle Management (PLM); Product Quality Assurance, Failure Analysis, Testing, Inspection, and Certification, Quality Control & Assurance, Product Qualification and Standards

A description for each of the ten Tech/Skills Taxonomy domains is provided below.

Smart Manufacturing Platforms and Tools

Smart Manufacturing Platforms drive a smart factory operation enabling vertical integration of all levels of manufacturing operations from shopfloor, enterprise to facilities levels through Enterprise Resource Planning (ERP) and Manufacturing Execution Systems (MES). These systems will be connected to the horizontal integration platforms for Supply Chain Management (SCM) and Product Lifecycle Management (PLM) tools for efficient integration of suppliers and customers enterprise systems for seamless integrated business operations. Smart Manufacturing Tools include Manufacturing Process Simulation and Digital Twin tools, Augmented Reality/Virtual Reality (AR/VR)

tools and other listed tools. Supervisory Control and Data Acquisition (SCADA) systems are in use for both asset facilities and manufacturing operations. Emerging AM Skills are increasingly moving smart manufacturing platforms and tools to operate in Cloud Platforms where Cyber-Physical Production Systems (CPPS) provide real-time operating systems, real-time production flow simulations, dynamic scheduling, and augmented reality in manufacturing controls. These Smart Manufacturing Platforms and Tools are highly automated, connected and enabled with intelligence such that they are controlling the smart factory operations and technology IT-OT systems.

Automation and Robotics

The Automation and Robotics Skills-Domain covers Job-Skills that are in demand for automation, including foundational skills such as Sensors and Actuators; Motion Control and Position System, Programmable Logic Controller and Human-Machine Interface etc, System or specialised application skills such as Automation System Integration and Assessment; Robotics; Collaborative Robots; Robotics Programming & Robot Operating System; Industrial Robotic system; Autonomous Guided Vehicle (AGV) and Autonomous Mobile Robot (AMR), Robotic Process Automation (RPA). Specific emerging skills for Shopfloor Automation and control includes Automated inspections, Computer vision for automation, Automated Materials Handling. For Enterprise Automation, emerging skills include Intelligent Process Automation (IPA), Facility Automation Systems, Asset condition monitoring and Asset Fault Detection etc.

Connectivity and Cybersecurity

The Connectivity and Cybersecurity Skills-Domain covers Job-Skills in Connectivity; Cybersecurity; IT/OT connectivity; and 5G Platform Connectivity. Emerging skills needed for Shopfloor Connectivity includes Operation Technology (OT) connectivity such as MQTT, OPC UA, and SS IEC 62541 Standard for OPC UA. For Enterprise connectivity emerging skills in Information Technology (IT) connectivity skills for PC Clusters, Servers, Edge Computing and Cloud Computing are required. Facility Connectivity emerging skills include IT-OT connectivity network job-skills and in-depth knowledge on different network connection protocols and methods. Cybersecurity job-skills is of critical importance for connected IT-OT systems at the shopfloor, enterprise and facility levels. Emerging job-skills include Cyber Risk Management, IT-OT Network Security and Cybersecurity Standard SS IEC 62443.

Industrial Internet of Things (IIoT)

The Industrial Internet of Things (IIoT) Skills-Domain requires Job-Skills and knowledge in IIoT for Manufacturing, IIoT Sensor Network and Embedded Systems and Integration. Emerging skills and knowledge are required for IIoT Systems Network Design, Connectivity and Integration, Edge and IoT solutions. Sensorization of legacy assets, Sensors and Actuators, Smart Sensors, Machine Analytics.

Data Analytics

The Data Analytics Skills-Domain covers fundamental skills in Data Analytics, including Data Analysis, Data Mining and Modelling, Data Processing, Data Visualization and Control. Emerging job-skills include Big Data Analytics which covers Data Management; Computational Modelling, and Data analytics for manufacturing applications.

Artificial Intelligence (AI)

The Artificial Intelligence (AI) Skills-Domain covers fundamental Skills in Artificial Intelligence, including Machine Learning (ML); Deep Learning (DL); Computer Vision, Artificial Neural Network and Self-Learning Systems. Emerging skills are in the area of Artificial Intelligent Applications in Manufacturing, including AI for shopfloor machines, AI for Robotics, AI-enabled Vision and Video Analytics, AI-enabled Predictive Maintenance, Predictive Intelligence, AI-enabled Autonomous Control, Facility Diagnostics & Prognostics, Facility Management System (FMS), and Intelligent Systems.

Industry 4.0 Leadership & Talent Development

The Industry 4.0 Leadership and Talent Development Domain covers the knowledge and skills required to drive I4.0 adoption and implementation. These skills include Industry 4.0; SIRI Framework; Digital Transformation Methods; Lean Manufacturing and Training Planning and Development; Critical Core Skills are essential for the I4.0 leaders and champions, especially the skills for Change Management; Creative Thinking, Problem Solving, Communication and Collaboration. Other people skills such as Supplier Relations Management (SRM) and Customer Relations Management (CRM), and emerging knowledge and skills such as Industry 4.0 Standards for Manufacturing and Coding skills in C, C#, C++, Python, Spark, Hadoop and others relevant to manufacturing environments are highly needed.

Additive Manufacturing

Additive manufacturing and 3D printing skills and capabilities provides a new paradigm shift for the precision engineering and manufacturing industry to develop a new digital product manufacturing value chain with an Industry 4.0 capability for customized manufacturing sectors. Job-Skills required includes Additive Manufacturing Processes and Systems, Additive Manufacturing for Metallic Components, Additive Manufacturing for Polymer-Based Components, 3D Printing Methods for Ceramics, Composites, Cement. Emerging skills include Hybrid Manufacturing (Subtractive and Additive), Design for Additive Manufacturing (DfAdM), Additive Manufacturing Standard, Qualification and Certification.

Advanced Manufacturing Processes and Materials

The Advanced Manufacturing Processes and Materials Domain includes Job-Skill in design and fabrication of advanced and functional materials, Advanced Manufacturing Processes like Forming, Forging, Welding, Machining; and Surface Engineering methods; Advanced Material Treatment Processes for Heat Treatment, Cladding, Surface Finishing and Modification methods; Metrology and Inspection, Quality Assurance and Failure Analysis. Emerging job-skills are required for Flexible/Hybrid Materials Engineering and Processes, Smart Mold Design and Fabrication, Integrated Engineering for MRO and Remanufacturing, and Sustainable Manufacturing Assessment and Green Manufacturing Design and Implementation.

Product Innovation and Quality Management

The Product Innovation and Quality Management Skills-Domain covers Job-Skills in Product Design and Innovation, Manufacturing Product Lifecycle Management (PLM), Operation Management and Innovation and product quality inspection and management. Emerging job-skills include AI enabled product design and innovation for product mass customisation, advanced and high-speed non-destructive inspection, and AI-enabled product quality control and assurance.

2.2 Mapping SFS Emerging Skills to AM Technology and Skills Taxonomy

One of the major efforts in this report is to map the updated SFS economy areas, skills domains and emerging skills topics and their affiliated Technical Skills Competencies (TSCs) and Critical Core Skills (CCSs) to the AM Technology and Skills Taxonomy. Table 2 provides a summary of mapping of SFS skills domains and number of topics to the AM Tech/Skills Taxonomy with more details of mapping provided in **Annex B**.

Table 2 Summary of mapped number of SFS skills domains and topics to the AM Tech/Skills Taxonomy

AMTA AM Tech/Skills Taxonomy			SFS Economy Areas and Skills Domains			
Tech/Skills Domain		No. of Tech/ Skills Topics	Economy Area	SFS Skills Domains	No of Skills Topics	No of Gap Topics
1	**Smart Manufacturing Platform and Tools**	23	I4.0	Advanced Manufacturing and Supply Chain	18	4
			Digital	System and Infrastructure	1	
2	**Automation and Robotics**	27	I4.0	Industrial IoT, Robotics & Automation	20	8
3	**Cconnectivity and Cybersecurity**	15	I4.0	Advanced Manufacturing and Supply Chain	2	8
			Digital	Cyber security and risk	12	
4	**Industrial IOT (IIOT)**	9	I4.0	Industrial IoT, Robotics & Automation	9	3
5	**Data Analytics**	7	I4.0	Advanced Manufacturing and Supply Chain	2	3
			Digital	Data and Analytics	7	
6	**Artificial Intelligence (AI)**	13	I4.0	Advanced Manufacturing and Supply Chain	9	3
				Industrial IoT, Robotics & Automation	3	
			Digital	Technology Application and Management	2	
7	**Industry 4.0 Leadership and Talent Development**	17		I4.0 Leadership and skills		5
				Productivity and Innovation	2	
				Critical Core Skills (CCS)	10	
8	**Additive Manufacturing**	9	I4.0	Additive Manufacturing, Advanced Materials & Processes	7	6
9	**Advanced Manufacturing Processes and Materials**	15	I4.0	Additive Manufacturing, Advanced Materials & Processes	10	6
			Green	Green Infrastructure & Mobility	3	
				Resource Circularity & Decarbonization		
10	**Product Innovation and Quality Management**	10	I4.0	Product Innovation & Quality Management	9	1

47 gap topics of skills are identified through this initial mapping exercise, which will be further calibrated and validated through engagement with industry leaders and domain subject experts.

Table 3 provides a sample mapping of SFS skills domains and topics and the relevant Technical Skills Competencies (TSCs) to the AM Tech/Skills Taxonomy for Domain 1 on Smart Manufacturing Platform and Tools, while the detailed mapping of all ten Tech/Skills domains are provided in **Annex C**. The outcome of this mapping is based on the skills titles and descriptions in SSG's Jobs-Skills Repository which contains more than 10,000 TSCs and CCSs. Further study is required to analyze the TSC Skills Proficiency Levels and align the skills mapping and the corresponding training courses.

Table 3: Sample mapping SFS skills domain and topics and the Technical Skills & Competencies (TSCs) to the AM Tech/Skills Taxonomy - Domain 1: Smart Manufacturing Platform and Tools

AMTA AM Tech/Skills Taxonomy				SSG SkillsFuture Series (SFS) Emerging Skills Areas and Topics			Mapped Technical Skills Competency (TSC)	
S/No.	Tech/Skills Domains	AM Tech/Skills Taxonomy Topics		Economy Area	SFS Skills Domain	SFS Skills Topics	S/No.	Skills Title (TSC)
1	Smart Manufacturing Platform and Tools	1.1	Enterprise Resource Planning (ERP)	I4.0	Advanced Manufacturing & Supply Chain	Enterprise Resource Planning (ERP) system	1.1.1	Production Resource Management (PE)
							1.1.2	Production Resource Management (Electronics)
							1.1.3	Production Resource Management (FM)
							1.1.4	Organisational Resource Management
		1.2	Manufacturing Execution System (MES)			Manufacturing Execution System (MES)	1.2.1	Production Planning
							1.2.2	Manufacturing Process Management (Electronics)
							1.2.3	Manufacturing Process Management

2.3 Emerging Advanced Manufacturing Skills

According to a BCG study, emerging skills are always associated with the latest trends in technology development. As the eight megatrends described in Section 1.1 are set to revolutionize the manufacturing industry in the next decade, the emerging technologies and concepts in manufacturing are also shifting the job skills to make it happen. This has created one of the biggest challenges in manufacturing: the skills gaps between the workforce today and the future. In the US alone, more than 2 million vacancies in manufacturing will remain unfilled in the next decade unless effective actions are taken to bridge the manufacturing skills gaps, according to a joint study by Deloitte and the Manufacturing Institute. Foresighting the emerging skills is required to develop systematic workforce upskilling initiatives to close these skills gaps.

Reviewing the megatrends in technology development, the comprehensive skills framework and job skills insights developed by SkillsFuture Singapore, as well as inputs from AMTA's industry engagement, AMTA has curated a list of emerging skills in a Singapore context to support the transformation of our manufacturing industry.

Data Analytics

Today's manufacturers are generating more data than ever before from their manufacturing processes, business operations, product life cycles, supply chains, product quality and even customer engagements. These massive data sets have the power to enhance productivity and perforation, unlock new business opportunities and optimize decision-making, but only if they are properly and systematically analysed. To harness the full potential of manufacturing data sets, data analytics covering the entire spectrum of data collection, management, sharing, analysis, modelling, and visualization has become a critical skill for the manufacturing workforce across at all levels and across all the sub-sectors.

Cloud computing

Cloud computing breaks the limitation of backend server rooms and enables the manufacturers' access to virtually infinitely scalable computing resources, infrastructures and services over the internets. As the global cloud computing market is forecasted to grow at a compound annual growth rate of 16.3% and expected to reach USD 947.3 billion by 2026, it is in the process of transforming every aspect of modern manufacturing. Cloud computing augments the capabilities of other manufacturing technologies, such as additive manufacturing, high-performance computing, the industrial internet of things (IIoT), and

industrial robots, and by 2023, almost half of the software used by the manufacturers would be cloud based. Therefore, the workforce of future should be equipped with the knowledge and skills of cloud computing, such the deployment and migration across multiple cloud platforms, development of application programming interfaces (API), DevOps, and database management.

Automation assessment and design

According to Frost and Sullivan, more than 80% of the manufacturers have embraced automation to address the challenges in manpower constraints, productivity enhancement, and rising competition. The adoption of automation is especially critical to Singapore, as the national envisions to achieve 50% growth in manufacturing by 2030 without any significant increase in the manufacturing workforce. To facilitate the implementation of industrial automation, manufacturing companies, especially the SMEs see an urgent demand in skills associated with automation assessment and design to identify bottleneck processes, evaluate suitable automation technologies, and develop effective and suitable automation solutions.

Advanced robotics

The integration of advanced robotic systems in manufacturing workflows such as process operations, maintenance, logistics, and plant surveillance is a core component of manufacturing automation that enables productivity and performance enhancement. As the costs of robots continue to decline because of the evolving economies of scale, the adoption of advanced robotics will become a common sight in the manufacturing floor. Therefore, it is necessary for workforce across the manufacturing sectors to be equipped with emerging skills associated with the industrial robots, including the design and application of industrial robots, robot operating system and robotic programming, safety and maintenance of robots, human-robot collaboration, autonomous mobile robots, and robot navigation and fleet management.

Computer vision

Computer vision in manufacturing refers to intelligent systems that can capture, process, and interpret visual inputs from the physical manufacturing environments, processes, or products to provide proper reactions and assist humans in a wide range of production-related task, such as guiding robots for navigation or object manipulation, performing inspection and quality control, detecting equipment/operation anomalies, and conducting

site surveillance. Emerging skills in computer vision include image/video acquisition and processing, development of vision analytics algorithms, pattern recognition systems, and spatial sensing and reason systems.

Modelling and simulation

Modelling and simulation is the essential driving forces behind all the megatrends summarized in Section 1.1. With the virtual assets created through modelling and simulation, the manufacturers are empowered to design, experiment, predict and optimize the outcomes of manufacturing activities and products at virtually any spatial and temporal dimensions before making any strategic decision. Leveraging the advancement in cloud computing, modelling and has also become critical skill for metaverse and extended reality applications that make remote assistance and multi-site collaboration possible.

Additive manufacturing

Unlike traditional manufacturing methods that cut away materials to achieve the desired geometry, additive manufacturing achieves the same result through adding layers in succession. This new manufacturing concept not only produces less waste but is also agile enough to create complex and highly customized products. The global additive manufacturing market is forecasted to grow at an annual growth rate of 15%, with aerospace, MedTech, automobile, consumer products, and their associated supply chains as the main adopters. As the concept of additive manufacturing permeates across all the sub-sectors, manufacturers should take swift actions to equip the workforce with relevant additive manufacturing expertise to stay competitive. These emerging additive manufacturing skills include different types of additive manufacturing processes and systems, materials for additive manufacturing, hybrid additive methods, design for additive manufacturing, and additive manufacturing standards, qualification and certification.

Programming and coding

In a report on skills shift by McKinsey, programming has been identified a fastest growing skill in manufacturing. This makes sense, as the rise of digital technologies has created a new paradigm of increased human-machine interaction on the manufacturing shopfloor, and along with it, there's a growing demand for the workforce to speak in programs and codes, the language of the machines. More and more manufacturers are starting to require programming and coding skills associated with their roles from the programming of manufacturing-specific machines and devices like CNCs, PLCs, and MES to sophisticated applications in machine learning, data analytics, and computer visions.

Cybersecurity

The integration of I4.0 technologies to manufacturing operations has brought a new level of cyber complexity to the modern factories. A Deloitte and MAPI Cybersecurity for Smart Factory study reported that 4 in 10 manufacturers surveyed had their operations affected by cyber incidents in the past 12 months, with unauthorized access, operational disruption and intellectual property thefts topping the list of risks. There is also growing trend of incidents associated with operational technologies (OT) such as programmable logic controllers, embedded systems and IIoT devices, likely due to the lack of awareness, focus, and expertise in the cybersecurity of OT environments. To achieve holistic cyber preparedness across the OT and IT landscapes and effectively respond to and recover from cyberattacks, the manufacturing workforce needs to equip themselves with emerging cybersecurity skills, including cybersecurity assessment and mitigation, cyber risks management, cybersecurity standards, IT-OT cybersecurity governance, and cyber incident response and management.

IIoT management

The Industrial Internet of Things (IIoT) is a system of a multitude of industrial devices connected by communications technologies that can monitor, collect, exchange, analyse, and deliver valuable insights in real-time and help drive smarter, faster, and data-driven decision-making. Combining machine-to-machine communication with industrial data analytics, IIoT is driving unprecedented levels of efficiency, productivity, and performance for the manufacturing companies. Therefore, it is vital for the manufacturing workforce to equip with emerging IIoT management skills, such as IIoT concepts and technical knowledge of IIoT implementation, connectivity in manufacturing, IOT system interface, smart sensors and equipment sensorization, and technologies for data transmission and manufacturing control, to harness IIoT's full potential.

Artificial intelligence

With the comprehensive automation of manufacturing processes, machines are set to perform more than 95% of the production tasks that are repetitive in nature with extreme accuracy, efficiency, and reliability. However, when the production flow is subject to frequent changes, shifts in priorities or disruptions, the capability of the current automated production concepts is pushed to the limited. This calls for autonomous systems enabled by artificial intelligence that can immediately assess the situations, respond to changes, and recommend improvement options. As artificial intelligence evolves into a key enabler for

other technologies such as computer vision, advanced robotics, and cognitive automation, it has also become a priority topic for the manufacturing workforce and covers a wide spectrum of emerging skillsets such as machining learning, evolutionary computing, intelligent process automation, self-learning systems, and artificial neural networks.

Sustainability management

As more government regulations are expected to set a path to net zero manufacturing operations by 2050 and with growing public emphasis on corporate environmental sustainability, manufacturers across the world are scrambling to develop strategic actions plans to embark and accelerate their sustainability transformation journey, only to find themselves hindered by the lack of talent with the right knowledge and expertise. To streamline the sustainability transformation, forward looking manufacturers are calling for a workforce well equipped with sustainability management skills, such as sustainability assessment and road-mapping tools, product life-cycle assessment, environmental and resource management, energy efficiency monitoring and analysis, and lean manufacturing techniques and waste reduction.

3.0 Singapore's AM Training Provision Landscape and Training Gaps

This section describes Singapore's AM training provision landscape, which is charted based on the ten AM Tech/Skills Taxonomy domains and training providers in the eco-system. A list of available training courses recommended for company workforce upskilling are mapped to the AM Tech/Skills Taxonomy and SFS skills topics. The gaps in the training ecosystem for AM workforce upskilling and talent development are identified and discussed as a reference guide for new course development and training offerings.

3.1 Singapore's AM Training Provision Landscape

The advanced manufacturing (AM) training for workforce upskilling in Singapore are offered primarily by IHLs and A*STAR SIMTech and ARTC as the SSG certified Continuing Educating and Training centres (CETs), complemented by other training programmes offered by leading private training providers, for examples, the Queen-bee programmes offered by Bosch Rexroth, Omron, Siemens and HP in partnership with respective IHLs, the IHCI enabler programme offered by McKinsey partnering EY through SBF and the I4.0/SIRI relevant programmes by Tuv Sud. There are about 400 AM-relevant training courses in the ecosystem supported by SSG. AMTA made the effort to chart these AM courses through course evaluation and mapped them to ten AM technology and skills domains and topics as described in Section 2. Gaps of training topics are identified based on the existing training courses in the eco-system.

Figure 5 and Figure 6 present a snapshot of the AM courses offered by the training providers in the local ecosystem. Hands-on practical and experiential training and workplace learning/on-job training (OJT) are advocated and encouraged to complement classroom learning or online learning, in particular for enterprise-oriented I4.0 transformation and workforce upskilling. More details of the AM training offerings and evaluation have been documented in the Advanced Manufacturing Training Evaluation Report 2022, reported in the fourth training council meeting (July 2022).

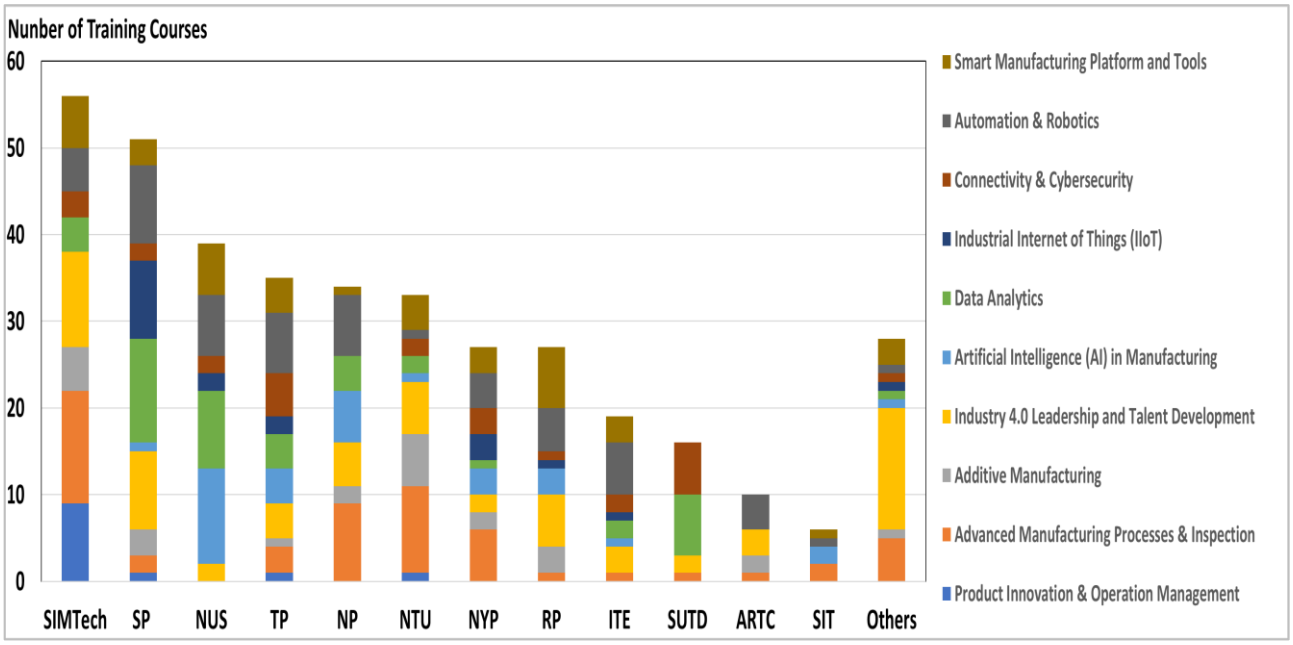

Figure 5 Number of AM training courses offered by the training providers in the ecosystem

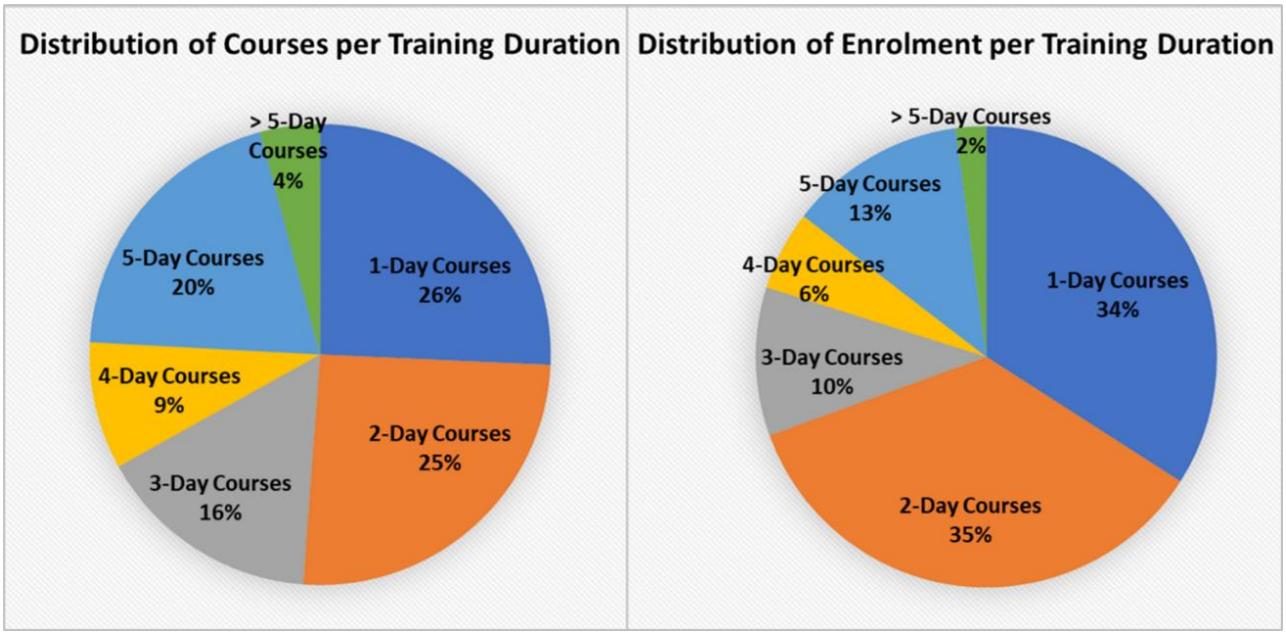

Figure 6 Distribution of AM courses and enrolment by training duration

3.2 Mapping Training Offerings to AM Tech/Skills Taxonomy

As a continuous effort to provide guidance for companies to select relevant training courses for workforce upskilling, AMTA selected 133 training courses as AMTA-recommended courses through evaluation of all AM-relevant courses in the ecosystem including the newly launched courses up to Oct 2022. These courses were mapped to the respective AM Tech/Skills Taxonomy domains and topics. Table 4 summarises the outcome of the course mapping. Out of the total 145 topics from the ten AM Tech/Skills domains, 80 topics have been covered by the 133 AMTA-recommended courses at a varied level of depth, and 65 topics are identified to be the gap training topics for new courses development through this initial mapping exercise.

Table 4 Summary of recommended training courses mapped to AM skills and training topics

	Tech/Skills Domain	No. of AM Taxonomy Topics	No of Courses Identified	No of Mapped Skills Topics	No of Gap Topics
1	**Smart Manufacturing Platform and Tools**	23	16	15	8
2	**Automation and Robotics**	27	30	19	8
3	**Cconnectivity and Cybersecurity**	15	6	4	11
4	**Industrial IOT (IIOT)**	9	7	3	6
5	**Data Analytics**	7	12	5	2
6	**Artificial Intelligence (AI)**	13	9	3	10
7	**Industry 4.0 Leadership and Talent Development**	17	13	7	10
8	**Additive Manufacturing**	9	13	7	2
9	**Advanced Manufacturing Processes and Materials**	15	17	10	5
10	**Product Innovation and Quality Management**	10	10	7	3
	Total	**145**	**133**	**80**	**65**

Notes: Courses Evaluation Guidelines for Recommendation of Advanced Manufacturing Workforce Training

Aligned Level of the Skills	Curriculum Design & Delivery Mode	Quality Attributes
○ Basic level targeting at the beginners for skills introduction of the topic, ○ Intermediate level targeting at the experienced working adults for upgrading, ○ Advanced level targeting at the proficient professionals or practitioners in the field.	○ Interactive classroom teaching and/or blended learning for fundamentals, ○ Hands-on practice training for skills utilisation and ○ Project-based training for skills implementation.	○ Relevance to advanced manufacturing, ○ Relevant case studies in manufacturing applications, ○ Trainer's industrial knowledge and experience in the topic of training, ○ Course feedback from companies and course participants.

Source: AMTA Advanced Manufacturing Training Evaluation Report 2022

Table 5 provides a sample mapping of the training courses to **Domain 1 – Smart Manufacturing Platform and Tools**, and the full list of course mapping to the AM Tech/Skills Taxonomy domains and topics is provided in **Annex D**. For each mapped course, the course title, training provider, training duration and a link to the course brochure are provided. Gap topics (e.g. 1.5 and 1.6) are highlighted in red text for new course development. As a follow up effort for the next phase, these AMTA-recommended courses will be mapped to the updated SFS skills domains and emerging skills topics and their relevant Technical Skills Competencies (TSCs) or Critical Core Skills (CCSs) Proficiency Levels to provide the workforce with more informed and guided training and upskilling options.

Table 5 Sample Mapping of the Training Courses to AM Tech/Skills Taxonomy

Domain 1: Smart Manufacturing Platform and Tools

AMTA Tech/Skills Taxonomy Topics		Course Title	Training Institute	Training Duration (hours)	Link to Course
1.1	Enterprise Resource Planning (ERP)	SAP ERP Production Planning & Manufacturing	TP	142	Link
		Production Planning and Scheduling for Smart Manufacturing	SIMTech	24	Link
1.2	Manufacturing Execution System (MES)	Manufacturing Execution System 4.0: Applications, Technologies, and Benefit	TUV SUD	8	Link
1.3	Cloud Platforms	Amazon Web Services Cloud Computing Architecture	SP	56	Link
1.4	5G	Envisioning 5G IoT Solutions	ISS	20	Link
		Introduction to 5G Technology and Applications	SP	16	Link
1.5	Cyber Physical production System				
1.6	Real-Time Operating Systems (RTOS)				
1.7	Digital Twin for Manufacturing System	Virtual Manufacturing and Digital Twin	TP	40	Link
		Manufacturing Process Simulation	NYP	28	Link
1.8	Augmented Reality	Augmented Reality for Enhancing Work Productivity	TP	24	Link
		Virtual & Augmented Reality in Manufacturing	NTU	14	Link
1.9	Virtual Reality	Go-VR Basic: VR Learning Content Creation Using 360 Cameras	RP	16	Link

3.3 Gaps in the Training Ecosystem in AM Workforce Upskilling

Training gaps in advanced manufacturing are associated with the gaps of talent expertise and skills required to drive industry transformation through I4.0 adoption and implementation. We observed two categories of training gaps based on the inputs through AMTA's industry engagement and course evaluation.

1) Lack of training courses to address the emerging new AM skills in demand

Depending on the momentum of technology advancement and I4.0 adoption, there's a rising demand for new training courses to address the skills needs for emerging technology and solution adoption. Through mapping the training courses to the AM Tech/Skills Taxonomy, we identified 65 gap topics for new course development. Table 6 lists the gap topics in each of the AM Tech/Skills domain.

Checking and comparing with the existing training courses among the ten Tech/Skills domains, we observed that four Tech/Skills domains (D3, D4, D6, D7) have more gap topics than the number of topics with available training courses. They are Connectivity and Cybersecurity, Industrial IOT, Artificial Intelligence (AI) and Industry 4.0 Leadership and Talent Development. This is well aligned with the SIRI data provided by the World Economic Forum (WEF) white paper on *"Global Smart Industry Readiness Index Initiative: Manufacturing Transformation Insights Report 2022"* which provides manufacturing insights (I4.0 maturity status and gaps) from around 600 manufacturers across 30 countries including Singapore. It is also well aligned with the findings from our company engagement, suggesting an urgent need to encourage new course development for these gap topics via partnership with selected training providers.

Table 6 Gap Topics of AM Training for Course Development

S/N	Tech/Skills Domain	No of Gap Topics	Gap Topics for Course Development
1	**Smart Manufacturing Platform and Tools**	8	Cyber Physical Production Systems (CPPS) Real-Time Operating System (RTOS Smart solution architecture Microservices for Manufacturing DevOps and Containerization in I4.0 application Dynamic scheduling Digital Supply Chains Horizontal Integration
2	**Automation & Robotics**	8	Instrumentation measurement and Controls Firmware Programming Robotic Safety Automated Materials Handling System Manufacturing Process Automation Shopfloor Automation and Control Enterprise Automation System Facility Automation System
3	**Connectivity and Cybersecurity**	11	Fieldbus [Ethernet IP, EtherCAT, TwinCAT, Modbus] Message Queuing Telemetry Transport (MQTT) IEC 62541 Shopfloor Connectivity Edge Computing Connectivity Enterprise Connectivity [IT Connectivity, PC Clusters, Servers, Edge Computing, Cloud Computing] Facility Connectivity [IT-OT Connectivity Network [Ethernet IP, EtherCAT, TwinCAT, Modbus, Fieldbus, etc] Cloud Computing Connectivity IT-OT Connectivity Network IT-OT Network Security Cybersecurity Standard-SS IEC 62443
4	**Industrial Internet of Things (IIoT)**	6	IIoT Systems Security Architecture Design Smart Sensor Solutions Video Analytics IIoT Systems Network Design Sensorization
5	**Data Analytics**	2	Data Collection and Management Data Management
6	**Artificial Intelligence (AI)**	10	Deep Learning (DL) Artificial Neural Networks Self-Learning Systems Artificial Intelligence Application AI for Robotics AI-enabled Facility Management System [FMS] AI-enabled Autonomous Control AI-enabled Quality Control and Assurance AI-enabled Predictive Intelligence Intelligent Systems

7	**Industry 4.0 Leadership and Talent Development**	10	Training Planning and Development Industry 4.0 Standards for Manufacturing Creative Thinking Problem Solving Communication Collaboration Supplier Relations Management (SRM), Customer Relations Management (CRM) Digital Fluency Learning agility
8	**Additive Manufacturing**	5	Hybrid Manufacturing (Subtractive and Additive) Design for Additive Manufacturing
9	**Advanced Manufacturing Processes and Inspection**	5	Functional Materials Flexible/Hybrid Materials Engineering and Processes Smart Mold Design and Fabrication Integrated Engineering for MRO and Remanufacturing Remanufacturing
10	**Product Innovation and Operation Management**	3	Process innovation Plant Simulation and Manufacturing Process Analysis Product Qualification and Standards

2) Gaps of the existing training courses to address the needs for AM skills implementation

Regardless of being an MNC, LLE, or SME, all companies we engaged consider continuous reskilling and upskilling essential to stay competitive as digital transformation and technological evolution in manufacturing start to gather pace. However, the subscription from companies for advanced manufacturing courses does not match the scale of the workforce across different sectors. The subscription from SMEs for workforce upskilling is particularly low compared with MNCs and LLEs. Below are the observations from our company engagement.

(i) Lack of implementation-oriented training curriculum design and offering

MNCs/LLEs and SMEs vastly differ in i4.0 adoption and status of maturity mainly due to difference of their management's buy-in for I4.0, the ability to identify technology gaps and solutions, and the manpower and expertise available to drive I4.0 transformation. MNCs/LLEs and SMEs also have intrinsically different needs of support for I4.0 adoption or continuous improvement of implementation. This requires the training courses to be designed with differentiated curriculum contents and delivery modality to address the skills needs of different architypes of companies based on their I4.0 maturity status, manpower skills readiness and business transformation strategy and implementation planning. Hands-

on practical and experiential training and workplace learning/on-job training (OJT) are critical, particularly for SMEs to support their capability upgrading and workforce upskilling for I4.0 transformation.

(ii) Lack of coordination in training offerings to address the market demand

The training courses are offered, by and large, through a "free market" mode driven by individual training providers or trainers involved in the ecosystem. There exists an unbalanced training supply and demand. For certain AM Tech/Skills domains, such as Additive Manufacturing and Robotics and Automation, there is an oversupply of training courses on the same skill topics with similar curriculum, e. g. basic level awareness training, and no clear differentiation in training outcome in terms of depth of skills and applications. This dilutes the subscription on the topic, making many courses not economically justifiable for continuation, let alone further improvement on course contents and delivery quality to address the needs from the perspective of companies' interest and applications. On the other hand, there are limited training courses in emerging Tech/Skills domains such as IIoT and Connectivity, machine learning and artificial intelligence in terms of topics coverage, relevant use cases and practical training for applications**.**

(iii) Lack of collaboration in formulating integrated training programme to holistically address companies' multi-faceted training needs

Industry 4.0 adoption and transformation requires companies to have adequate exposure to relevant I4.0 transformation success cases and solutions and get upskilled in many facets of expertise and skills, from gaining confidence and trust for transformation to developing expertise to identify technology and skills gaps & plan transformation, and from plotting training roadmaps for adoption to applying knowledge and skills for implementation. For I4.0 transformation champions at all levels, being multi-skilled across functional job roles is a most prominent feature, for example, manufacturing engineers cross-trained with digital skills for data analytics and programming/coding and cyber security and well equipped the Critical Core Skills such as creative thinking, sense-making, problem solving and communication are becoming a critical asset in optimising human-machine interaction and effectively managing the multi-faceted requirements in digital manufacturing.

A single training provider is unable to address these multi-facet training needs. Currently, training providers are disparate or of competitors in some cases, causing issues of overlapped or mismatched training contents affiliated to a specific training provider. There

is also a lack of mechanism in the ecosystem to encourage collaboration among the training providers to develop more integrated training programmes to holistically address companies' training needs. The market calls for collaboration among government agencies, Institutes of Higher Learning (IHLs), Research institutions (RIs), and solution providers to leverage on the strength/capabilities and resources of the stakeholders to deliver an integrated set of training courses to guide/support companies' transformation needs.

(iv) Lack of sectoral skills and training playbooks to guide talent and workforce development

There is a lack of talents and in-house I4.0 expertise for majority of SMEs to identify the skills gaps and prioritise the needs of AM skills & training at both individual and enterprise level. Leading MNCs have developed their own Skills and Training Need Analysis (STNA) framework and tools based on SSG's Skills Framework (Micron, TechnipFMC). SMEs need support to interpret and contextualize the Skills Framework and make it practical for their adoption. There are offerings of Training Need Analysis programmes in the ecosystem through the National Centre of Excellence for Workplace Learning (NACE) and consulting companies, aiming at establishing skills profiling, skills benchmarks and prioritized training topics for companies' workforce upskilling. More efforts should be made to help manufacturing SMEs to develop systematic enterprise training roadmaps to guide the implementation of workforce upskilling based on companies' status, circumstances, strategy, and plans for I4.0 adoption. Further effort is also needed to expand the scope to work with TACs and other key stakeholders to develop sectoral skills and training playbook to guide the talent and workforce development of the companies in the similar business or operation environments.

To bridge these gaps, AMTA will focus its effort on below two areas.

- Development of new training courses to address the emerging AM skills in demand, in alignment with the megatrend of global advanced manufacturing as described in Section 1.1 and 2.3.
- Improvement of the existing AM training courses and ecosystem to address the skills and training needs base on companies' I4.0 transformation strategy and implementation planning.

ENDING REMARKS

As AMTA's first foresighting report of advanced manufacturing skills and training, this work provides a review of the global trends of advanced manufacturing technology and skills and the technologies and skills topics in demand from local manufacturing sectors. Emerging skills and gap topics are suggested from the perspective of needs and preparation for workforce upskilling and transformation. An Advanced Manufacturing Tech/Skills Taxonomy was developed and mapped with the updated SkillsFuture Series emerging skills and training topics, the relevant Technical Skills Competency (TSC) and Critical Core Skills (CCS) established in SSG's Jobs-Skills Repository, aiming to establish an advanced manufacturing skills framework as a reference guide for AM workforce upskilling and talent development. A training provision database was established which mapped AMTA-recommended AM training courses from the ecosystem to the AM Tech/Skills Taxonomy for workforce upskilling, with emphasis on enterprise-oriented training for adoption. Gaps of training topics are identified to guide new course development through partnership with training providers. Areas for improvement of the existing AM training courses and

ecosystem are discussed from the perspective of better addressing the skills and training needs for companies' I4.0 adoption and implementation.

Further efforts are needed to update and validate the AM Tech/Skills Taxonomy by engaging manufacturing leaders and other key stakeholders to achieve a holistic and in-depth understanding of the global trend of advanced manufacturing and the emerging technologies and skills in context of Singapore's manufacturing industry. Continuous efforts are also needed to identify and prioritise the gaps in AM skills and training offerings for the development of new training programmes and innovative curriculum and delivery modality to address the emerging industry training needs for I4.0 transformation.

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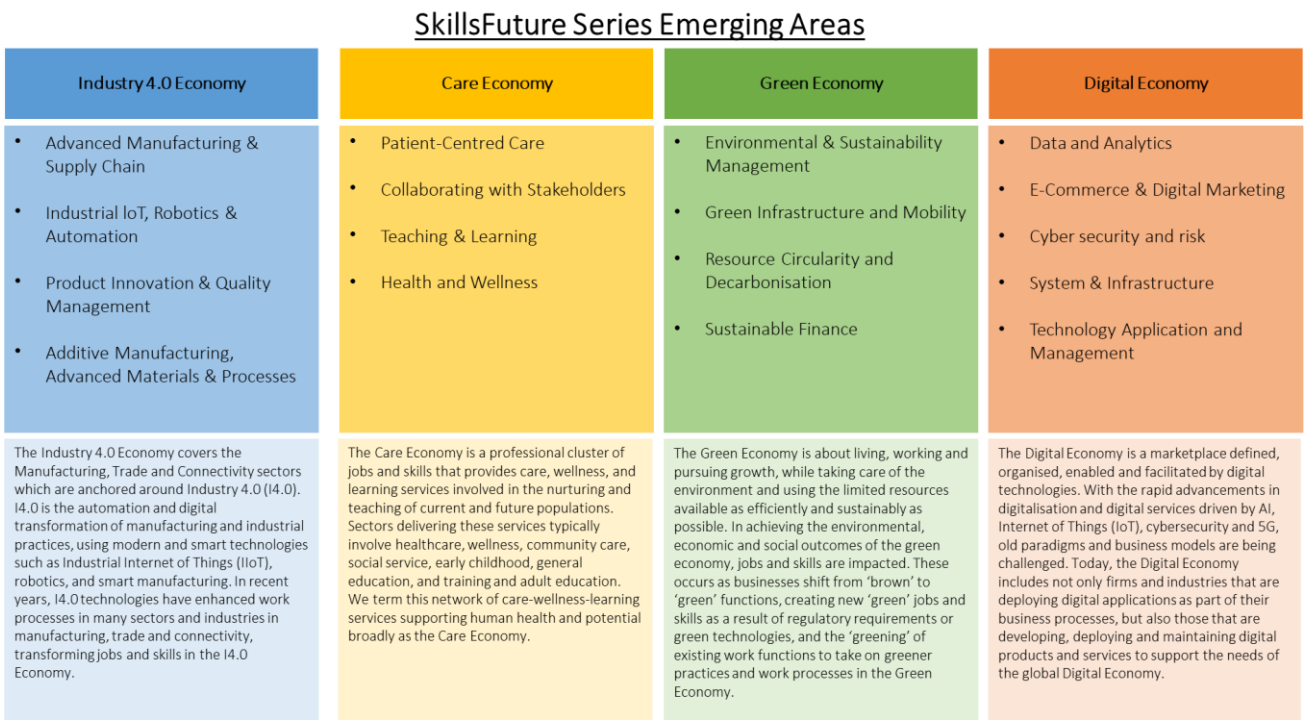
Annex A: SkillsFuture Series Economy Areas and Skills Domains



Green: Emerging Areas, Skills and Training topics

Economy	Emerging Areas	Skills & Training Topics (non-exhaustive)
Green	Environmental & Sustainability Management	Environment & Social Governance, Non-financial reporting, Sustainable Management, Environmental Sustainability Management, Design Sustainability and Ethics Management, Health, Safety and Environment Procedures Implementation, Environmental Management System Framework Development and Implementation, Environmental Management System Policies, Standards, Procedures and Practices Management, Sustainability strategy, corporate sustainability, Non-Financial Industry Sustainability Developments, Sustainability/Environmental Risk Management, Sustainability/Environmental Reporting, Sustainability Stewardship, Climate Change, Green Taxonomies/Standards
	Green Infrastructure & Mobility	**Green Mobility** Green Ship Design, Ammonia Bunkering, Maritime decarbonization, harbour craft electrification, Sustainable Aviation fuel, biofuel, Electrical, Electronic and Control Engineering, Electrical Testing, Electrical Termination, Connection and Measurement, Electrical Wiring Interconnection Systems Maintenance, Electric Vehicle/bus motor/engine/components maintenance & repair (Troubleshooting, diagnostic, Commissioning, Preventive/corrective Maintenance), Electric transmission, regenerative braking technology, EV Fleet Management, Product Development, EV Battery management, EV Charging, Smart Charging, Fuel Cell, telematics, V2X/V2V, In-vehicle applications/programming and system integration **Green Infrastructure** Green Manufacturing Design and Implementation, Design for Maintainability, Green Building Strategy Implementation, Green Facilities Management, Sustainable Engineering, Biophilic Design in Built Environment, Biophilic Design, Life-cycle costing analysis, Value Engineering, Indoor Environmental Quality Improvement, Indoor Air quality, Design for Disassembly, Climate-mitigating features, near/net zero energy building, Building Energy Audit
	Resource Circularity & Decarbonisation	**Resource Circularity** Sustainable Food Production Design, Ecology in Landscapes, Environment Management in Landscape Operations, Microclimate in Landscape Design, Sustainable Landscape Design, Waste Collection Management, Environmental Protection Management, Agri-technology, Aqua-technology, urban farming, vertical farming, sustainable farming/agriculture precision farming, alternative proteins, Resource Sustainability, Sustainable Feedstock, Reforestation, Rehabilitation, Waste Remanufacturing/Refurbishing, Phase change material
		Clean Energy Solar Photovoltaic Systems Design, Solar Photovoltaic Energy Assessment, Energy Storage, Smart Grid, Micro-grid, Renewable energy, Green Hydrogen, Grey Hydrogen,, Chemical Engineering, Energy Security, biofuel
		Decarbonisation Carbon Footprint Management, Carbon Offsets, Carbon Aggregates, Low Carbon Cement, Emission Capture, Carbon Capture/Storage/Transport, Bioremediation, Decarbonization Technology
	Sustainable Finance	Solar Photovoltaic Project Financing and Risk Analysis, Carbon Accounting, Carbon trading, Carbon Credits, Sustainable Finance, Non-Financial Industry Sustainability , Developments, Impact Indicators, Measurement and Reporting, Sustainability/Green Investment Sustainability/Green Lending Instruments Structuring, Sustainability/Green Re/Insurance, Carbon Markets and Decarbonisation, Natural Capital, Carbon Tax

Industry 4.0: Emerging Areas, Skills and Training topics

Economy	Emerging Areas	Skills & Training Topics (non-exhaustive)
Industry 4.0	Advanced Manufacturing & Supply Chain	Smart Manufacturing Systems [Cyber Physical System, Digital Twin and Augmented Reality/Virtual Reality (AR/VR), Smart Solution Architecture, Connectivity and Cybersecurity, Manufacturing Data Analytics, OOE Analytics]. Digital Manufacturing IT-OT Platforms [Enterprise Resource Planning (ERP) System, Manufacturing Execution System (MES), Cloud platforms, 5G], Microservices for Smart Manufacturing, DevOps and Containerization in Industry 4.0 application, Real-Time Operating Systems (RTOS), AI for Manufacturing Operations [Deep Learning, Artificial Neural Networks, Intelligent Systems, Video Analytics], Production Supply Chain, Machine Learning for Supply Chain, Analytics, Digital Supply Chains, Horizontal and vertical integration
	Industrial IoT, Robotics & Automation	Industrial IoT for Manufacturing [IoT Systems, Security Architecture Design, Smart Sensor Solutions, Video Analytics, IIoT Application Development]. Embedded Systems [Design, Connectivity, Sensors, Data Analytics, Embedded Systems Design and Programming, Sensorisation of Legacy Machines] Robotics Systems [Digital Twin for Robotics, AI for Robotics, Robot Operating Systems (ROS), Intelligent Robots, Cobots, Computer Vision, Robot safety] Automation Systems [Sensors,Actuators,Programmable LogicController (PLC), Computer Vision for Automation, Automated Inspections Systems] Robotic Process Automation (RPA, UiPath), Human Machine Interface (HMI programming, Firmware Programming)
	Product Innovation & Quality Management	Product design and modeling, Design Thinking, Process innovation, Operations Innovation, Plant Simulation and Manufacturing Process Analysis, Product Lifecycle Management, Product Quality Assurance, Product Qualification and Standards, Quality Control & Assurance, Testing, Inspection, and Certification.
	Additive Manufacturing, Advanced Materials & Processes	Additive Manufacturing and 3D Printing [Metals, Ceramic, Polymers, Composites, Concrete], Hybrid Manufacturing, Design for Additive Manufacturing, Metallurgy for Additive Manufacturing, Product Qualification for Additive Manufacturing, AM Inspection Methods, AM Surface Finishing, AM Safety. Advanced Materials [Novel Materials and Processes, Advanced Composites, Powder Metallurgy, Materials Characterization, Functional Materials] Advanced Processes [Forming methods, Forging methods, Advanced Welding methods, Surface Modification methods, Heat Treatment methods] Advanced Metrology, Advanced Inspections for Manufacturing,

Care: Emerging Areas, Skills and Training topics

Economy	Emerging Areas	Skills & Training Topics (non-exhaustive)
Care	Patient-Centred Care	Individual and cultural diversity, Change management, Effective client communication, Continuous improvement management, Excellence in service, Service quality management, Diversity awareness and management, Social service programme development, Service excellence, Customer relationship management operations, Business innovation, Business opportunities development, Group therapy planning and implementation, Intervention implementation in therapy support, Therapy discharge planning, Development on intervention plan for physiotherapy, Intervention planning (in occupational therapy, speech therapy), Clinical services development, Nursing productivity and innovation, Care transition in nursing, Data and information management, Data collection and management, Research data collection and management, Data governance, Data management, Analysis of research data, Data analytics, Data and statistical analytics, Pharmacy information technology management, Automated distribution management, Emerging technology synthesis, User interface design, Diversity and inclusion, Child screening and assessment, Learning support session planning and implementation, Mentoring for youths, Youth development, Youth outreach
	Collaborating with Stakeholders	Situation management with families and community, Collaborative practices with stakeholders across disciplines and sectors, Conflict management, Inter-professional collaboration, Professional consultation, Family and caregiver engagement, Volunteer recruitment, Volunteer retention and engagement
	Teaching & Learning	Business environment analysis, Research data analysis, Practitioner inquiry, Practice supervision, Group dynamics facilitation, Trends evaluation and application, Research design, Research into professional practice translation, Staff continuous learning, Learner assessments, Staff training management, Staff communication and engagement, Learning and development, Learning programme delivery, Learning programme design, Learning programme evaluation, Talent management, Coaching and mentoring, Learning experience delivery, Technology-enabled learning delivery, Learning mode design, Learning solution design, Learning technology design, Organisational impact analysis, Workplace learning delivery, Early intervention curriculum design, Reflective practice for educators, Workplace performance diagnosis
	Health and Wellness	Patient empowerment on self-care, Client education (in rehabilitation therapy, therapy support), Patient education on use of prescribed drugs, Health education programme development and implementation, Health promotion, Patient education and engagement, Resilience and self-care

Digital: Emerging Areas, Skills and Training topics		
Economy	**Emerging Areas**	**Skills & Training Topics (non-exhaustive)**
Digital	Data and Analytics	Analysis of Research Data, Analytical Method Validation, Analytics and Computational Modelling, Big Data Analysis, Business Data Analysis, Business Intelligence, Computational Modelling, Data Analytics System Design, Data and Statistical Analysis, Data Collection and Management, Data Design, Data Engineering, Data Management, Data Migration, Data Mining and Modelling, Data Sharing, Forensic Data Analytics, Intelligent Reasoning, Learner Profile Analysis, Pattern Recognition Systems, Plant Economic Modelling, Qualitative Research, Quantitative Research, Research Data Analysis, Research Data Collection and Management, Text Analytics and Processing, Data Storytelling and Visualization, Financial Analysis, Financial Modelling, Financial Planning and Analysis, Price Verification and Profit Analysis, Risk Analytics
	E-Commerce & Digital Marketing	Trend Forecasting, Market Demand and Feedstock Management, Market Research and Analysis, Market Specialisation, Revenue Optimisation, Market Trend Analysis, Market intelligence, Service information and Results, Behavioural Economics in Design, Customer Behaviour Analysis, Customer Experience Management, Consumer intelligence Analysis, Sentiment Analysis, Category Management, Delivery Optimisation,, Demand and Supply Analysis, Market Evaluation, Merchandise Performance Analysis, Pricing Strategy, Product Development, Sales Trends and Opportunities Analysis, Business Environment Analysis, Scenario Planning and Analysis, Affiliate Marketing, Digital Marketing and Communication, E-Commerce Management, inbound Marketing, integrated Marketing, Mobile Apps Marketing, Sales Channel Management, Marketing Campaign Management, Blog and Vlog Deployment, Content Management, Content Marketing Strategy, Paid Search Engine Marketing (Sem), Search Engine Optimisation (SEO), Website Performance Management, Social Media Content Creation and Management, Social Media Marketing
	Cyber security and risk	Data Ethics, Data Governance, Data Migration, Data Protection Management, Data Strategy, Data Wrangling, Database Administration, Digital Asset and File Management, IT Governance, Cyber Risk Management, Cybersecurity, Cybersecurity Framework Application, Detection and Monitoring Application, Infocomm Security and Data Privacy, information Technology and Network Security, Operational Technology Security Audit Management, Security Architecture, Security Assessment and Testing, Security Education and Awareness, Security Governance, Security Programme Management, Security Strategy, Threat and Vulnerability Management, Access Control Management, Cyber and Data Breach incident Management, Cyber Forensics, ICT Disaster Recovery Management, Security Administration
	System & Infrastructure	Cloud Computing, Computer Vision Technology, Data Centre Facilities Management, Enterprise Database System Administration, Infrastructure Support, Integrated System Design and Application, Network Administration and Maintenance, Network Configuration, Self-Learning Systems, System Configuration Management, Business Continuity, Business Requirements Mapping, Enterprise Architecture, Infrastructure Strategy, IT Asset Management, Technology Road Mapping, Workflow Digitalization, Systems Thinking, Infrastructure Deployment, Infrastructure Design, System Integration, Systems Design, Technology Infrastructure Management and Integration
	Technology Application and Management	Agile Software Development, Application Development, Applications Integration, Computational Design, Continuous Integration and Continuous Deployment, Design Creation and Development, Game User Interface Development, Interaction Design Practice, Learning Technology Design, Programming and Coding, Software Configuration, Software Design, Tools Development, User Interface and User Experience (UI/UX) Optimisation, User Interface Design, User Testing and Usability Testing, Digital Technology Adoption and Innovation, Digital Technology Environment Scanning, Emerging Technology Synthesis, Technology Application and Implementation, Technology Infrastructure Management and Integration, Technology Integration, Technology-Enabled Learning Delivery, Artificial Intelligence Application, Automation Design, Autonomous Logistics Design and Application, Autonomous Systems Technology Application, Digital Techniques Application, Augmented Reality Application, Content Delivery Network Operations, Integrated Digital Delivery Application, Internet of Things Management, E-Logistics IT Solutioning, Order Fulfilment and Returns Processing

Annex B: Mapping the SFS economy areas and skills domains and topics to the AM Tech/Skills Taxonomy

AMTA Tech/skills Taxonomy Domain	AM Technology and Skills Taxonomy Topics	Mapped to SSG's SFS Four Economies Areas and Skills and Training Topics (TSC/CCS)
Smart Manufacturing Platform and Tools	**Digital Manufacturing IT-OT Platforms,** ERP, MES, Cloud Platforms [SAP, Oracle, Microsoft Azure, Amazon Cloud], 5G **Smart Manufacturing Systems**, Cyber Physical Production Systems (CPPS), Manufacturing Process Simulation; Virtual Reality (VR); Augmented Reality (AR), Real-Time Operating System (RTOS); Real Time Production Flow Simulation; Supervisory Control and Data Acquisition (SCADA) **Smart Manufacturing Tools,** Overall Equipment Effectiveness (OEE); Production Planning and Scheduling; Smart Inventory Planning; Workflow Digitalization, Dynamic Scheduling; Microservices for Smart Manufacturing, DevOps and Containerization in Industry 4.0 application **Supply Chain Management (SCM),** Machine Learning for Supply Chain, Supply Chain Analytics, Digital Supply Chains, Horizontal and vertical integration	**Industry 4.0 Economy - Advanced Manufacturing and Supply Chain** Smart Manufacturing Systems, Cyber Physical System, Digital Twin and Augmented Reality /Virtual Reality (AR/VR), Smart Solution Architecture, OEE Analytics. Digital Manufacturing IT-OT Platforms, Enterprise Resource Planning (ERP) System, Manufacturing Execution System (MES), Cloud platforms, 5G, Microservices for Smart Manufacturing, DevOps and Containerization in Industry 4.0 application, Real-Time Operating Systems (RTOS), Production Supply Chain, Machine Learning for Supply Chain, Analytics, Digital Supply Chains, Horizontal and vertical integration **Digital Economy –System & Infrastructure** Cloud computing, Workflow Digitalization
2. Automation & Robotics	**Automation:** Sensors, Actuators, Motion Controls, Positioning Systems, Instrumentation Measurement and Control, Programmable Logic Controller, Human Machine Interface, Firmware Configuration and Programming, Embedded Systems Design and Programming; **Robotics:** Industry Robotic Systems, Robotic System Integration, Robot Operation Systems, Robotics Safety, Maintenance and Troubleshoot, Autonomous Mobile Robot (AMR), Automated Guided/Intelligent Vehicle (AGV/AIV), Collaborative Robots, Digital Twin and Simulation of Robots, Robotic Process Automation, Intelligent Process Automation, Automated Inspections; Manufacturing Process Automation; Automated Process Control; Asset Condition Monitoring & Fault Detection, Automated Materials Handling System; Enterprise Automation System, Facility Automation System; Shopfloor Automation System; Automation Diagnostics & Assessment, Automation System Integration	**Industry 4.0 Economy - Industrial IoT, Robotics & Automation** Automation Systems, Sensors, Actuators, Programmable Logic Control (PLC), Smart Sensor Solutions, Video Analytics, Human Machine Interface, Firmware Programming, Embedded Systems Design, Embedded Systems Programming Robotics Systems, AI for Robotics, Robot Operating Systems (ROS), Intelligent Robots, Cobots, Digital Twin for Robotics, Robot safety, Robotic Process Automation (RPA,), Automated Inspections Systems

3. Connectivity and Cybersecurity	OT Connectivity, IT Connectivity, Fieldbus [Ethernet IP, EtherCAT, TwinCAT, Modbus], MQTT, OPC UA, SS IEC 62541 Shopfloor Connectivity Enterprise Connectivity [PC Clusters, Servers], Edge Computing connectivity, Cloud Computing connectivity, Facility Connectivity, IT-OT Connectivity Network; Cyber Risk Management, IT-OT Network Security; Cybersecurity Standard-SS IEC 62443	**Digital Economy - Cyber security and risk** Cyber Risk Management, Cybersecurity, Cybersecurity Framework Application, Infocomm Security and Data Privacy, information Technology and Network Security, Security Architecture, Security Assessment and Testing, Security Strategy, Security Administration **Industry 4.0 Economy - Advanced Manufacturing and Supply Chain** Connectivity and Cybersecurity
4. Industrial Internet of Things (IIoT)	IIoT for Manufacturing, IoT Systems, IIoT Sensor Network, Security Architecture Design, Smart Sensor Solutions, Video Analytics, IIoT Application Development, IIoT Systems Network Design, Sensorization	**Industry 4.0 Economy - Industrial IoT, Robotics & Automation** Industrial IoT for Manufacturing, IoT Systems, Security Architecture Design, Smart Sensor Solutions, Video Analytics, IIoT Application Development, Sensorization of Legacy Machines
5. Data Analytics	Data Analytics, Data Collection and Management, Data Design and Engineering, Data Mining and Modelling; Data Sharing, Data Visualization and Control. Big Data Analytics, Data Management	**Industry 4.0 Economy- Advanced Manufacturing and Supply Chain** Manufacturing Data Analytics, Supply Chain Analytics **Digital Economy - Data and Analytics** Analytics and Computational Modelling, Big Data Analysis, Data Collection and Management, Data Design, Data Engineering, Data Management, Data Mining and Modelling, Data Sharing, Data Storytelling and Visualization
6. Artificial Intelligence (AI)	AI in Manufacturing; Machine Learning (ML); Deep Learning (DL); Artificial Neural Networks, Computer Vision; Self-Learning Systems, Artificial Intelligence Application, AI for Robotics, Intelligent Robots, Predictive maintenance, AI-enabled Predictive Intelligence, AI-enabled Autonomous Control, Facility Intelligence [Facility Diagnostics & Prognostics, Facility Management System (FMS), Predictive Maintenance], Intelligent Systems	**Industry 4.0 Economy - Advanced Manufacturing and Supply Chain** AI for Manufacturing Operations, Deep Learning, Artificial Neural Networks, Computer Vision; Intelligent Systems, Video Analytics, Machine Learning for Supply Chain **Digital Economy - Technology Application and Management** Artificial Intelligence Application, Self-learning system
7. Industry 4.0 Leadership and Talent Development	Industry 4.0; SIRI Framework; Digital Transformation Methods; Industry 4.0 Implementation, Industry 4.0 Standards for Manufacturing; Lean Manufacturing; Training Planning and Development; Coding Skills [C, C#, C++, Python, Spark, Hadoop, etc] Critical Core Skills [Change Management, Creative Thinking, Problem Solving, Communication, Collaboration, Supplier Relations Management (SRM), Customer	**Critical Core Skills (CCS)** Creative Thinking, Decision Making, Problem Solving, Sense Making, Collaboration, Communication, Customer Orientation, Adaptability, Digital Fluency, Learning Agility, **Digital Economy - Technology Application and Management** Agile Software Development, Programming and Coding, Digital Technology Adoption and Innovation,

	Relations Management (CRM), Digital Fluency, Learning agility]	Technology Application and Implementation
8. Additive Manufacturing	Additive Manufacturing Processes and Systems; Additive Manufacturing for Metallic Components; Additive Manufacturing for Polymer-Based Components, Additive Manufacturing and 3D Printing Methods [Ceramics, Composites, Cement]; Hybrid Manufacturing (Subtractive and Additive); Design for Additive Manufacturing (DfAdM), AM Inspection Methods, Additive Manufacturing Standard, Qualification and Certification. Additive Manufacturing Safety, AM Surface Finish	**Industry 4.0 Economy - Additive Manufacturing, Advanced Materials & Processes** Additive Manufacturing and 3D Printing [Metals, Ceramic, Polymers, Composites, Concrete], Hybrid Manufacturing, Design for Additive Manufacturing, Product Qualification for Additive Manufacturing, Advanced Inspection Methods, AM Surface Finishing, AM Safety.
9. Advanced Manufacturing Processes and Materials	Advanced Materials, Functional Materials, Advanced Composite, Advanced Manufacturing Processes [Forming/Forging/ Welding/Machining/Coating methods] ; Advanced Material Treatment Processes [Heat Treatment, Surface Finishing and Modification methods]; Advanced Metrology, Advanced Inspection for Manufacturing; Flexible/Hybrid Materials Engineering and Processes, Smart Mold Design and Fabrication, Integrated Engineering for MRO, Materials Characterisation, Green Manufacturing Design and Implementation, Green / Sustainable Manufacturing, Sustainable Manufacturing Assessment, Remanufacturing.	**Industry 4.0 Economy - Additive Manufacturing, Advanced Materials & Processes** Advanced Materials, Novel Processes, Advanced Composites, Materials Characterization, Functional Materials; Advanced Processes [Forming methods, Forging methods, Advanced Welding methods, Surface Modification methods, Heat Treatment methods], Advanced Metrology, Advanced Inspections for Manufacturing, **Green Economy - Green Infrastructure & Mobility** Green Manufacturing Design and Implementation, Sustainable Engineering, **Green Economy - Resource Circularity & Decarbonization** Environmental Protection Management, Resource Sustainability, Waste Remanufacturing/Refurbishing,
10. Product Innovation and Quality Management	Product Design and Modelling; Design Thinking for Product Innovation, Process Innovation, Operation Management and Innovation, Plant Simulation and Manufacturing Process Analysis, Manufacturing Product Lifecycle Management (PLM); Product Quality Assurance, Failure Analysis, Testing, Inspection, and Certification, Quality Control & Assurance, Product Qualification and Standards	**Industry 4.0 Economy - Product Innovation & Quality Management** Product design and modeling, Design Thinking, Process innovation, Operations Innovation, Plant Simulation and Manufacturing Process Analysis, Product Lifecycle Management, Product Quality Assurance, Product Qualification and Standards, Quality Control & Assurance, Testing, Inspection, and Certification

Annex C: Mapping SFS Skills Domains and Skills Topics to the AM Tech/Skills Taxonomy

By AMTA Programme Office, 18 Nov 2022

AM Tech/Skills Taxonomy Domain 1: Smart Manufacturing Platform and Tools

AMTA Tech/Skill Taxonomy		SSF Economy	SFS Skills Domain	SFS Skills Topics	S/No.	Skills Title (TSC)
1.1	Enterprise Resource Planning (ERP)	I4.0	Advanced Manufacturing & Supply Chain	Enterprise Resource Planning (ERP) system	1.1.1	Production Resource Management (PE)
					1.1.2	Production Resource Management (Electronic)
					1.1.3	Production Resource Management (FM)
					1.1.4	Organisational Resource Management
1.2	Manufacturing Execution System (MES)			Manufacturing Execution System (MES)	1.2.1	Production Planning
					1.2.2	Manufacturing Process Management (Elect)
					1.2.3	Manufacturing Process Management (Aero/PE/FM)
1.3	Cloud Platforms			Cloud Platform	1.3.1	Organisational Resource Management (1.1.4)
1.4	5G			5G	1.4.1	Nil
1.5	Cyber Physical production System			Cyber Physical System	1.5.1	Organisational Resource Management (1.1.4)
1.6	Real-Time Operating Systems (RTOS)			Real-Time Operating Systems (RTOS)	1.6.1	Manufacturing Process Management (1.2.3)
1.7	Digital Twin for Manufacturing System			Digital Twin	1.7.1	Digital Techniques Application
1.8	Augmented Reality			Augmented Reality	1.8.1	Augmented Reality Application
1.9	Virtual Reality			Virtual Reality	1.9.1	Virtual Reality Application
1.10	Smart solution architecture			Smart solution architecture	1.10.1	Nil
1.11	Overall Equipment Effectiveness			OEE	1.11.1	Preventive Maintenance Management
1.12	Production planning and scheduling				1.12.1	Production Planning (1.2.1, 1.2.2, 1.2.3)
1.13	Smart Inventory Planning				1.13.1	Production Planning (1.2.1, 1.2.2, 1.2.3)
1.14	Workflow Digitalization	Digital			1.14.1	Manufacturing Workflow Management
1.15	Microservices for Manufacturing	I4.0		Microservices for Manufacturing	1.15.1	Nil
1.16	DevOps and Containerization in Industry 4.0 application			DevOps and Containerization in Industry 4.0 application	1.16.1	Nil
1.17	Dynamic scheduling				1.17.1	Production Planning (1.2.1)
1.18	Supervisory Control and Data Acquisition				1.18.1	Supervisory Control and Data Acquisition Maintenance Management
1.19	Production Supply Chain			Production Supply Chain	1.19.1	Supply Chain Solutioning
1.20	Machine Learning for Supply Chain			Machine Learning for Supply Chain	1.20.1	Supply Chain Solutioning
1.21	Supply Chain Analytics			Supply Chain Analytics	1.21.1	Big Data Analytics (5.1.1), Data Analytics System Design (5.4.1)
1.22	Digital Supply Chains			Digital Supply Chains	1.22.1	Nil
1.23	Horizonrtal Integration			Horizontal integration	1.23.1	Supply Chain Solutioning/Modelling/Planning/Strategising

AM Tech/Skills Taxonomy Domain 2: Automation & Robotics

AMTA Tech/Skill Taxonomy		SSF Economy	SFS Skills Domain	SFS Skills Topics	S/No.	Skills Title (TSC)
2.1	Sensors	I4.0	Industrial IoT, Robotics & Automation	Sensors	2.1.1	Robotics and Automation Application
					2.1.2	Embedded System Integration (2.9.5)
					2.1.3	Smart Facilities Management
					2.1.4	Condition-based Assets Monitoring Management
					2.1.5	Manufacturing Process Management
					2.1.6	Automation Process Control
					2.1.7	Automated Equipment and Control Systems Configuration
					2.1.8	Automated Process Design
					2.1.9	Control System Programming
					2.1.10	Embedded Systems Programming (2.9.3)
2.2	Actuators			Actuators	2.2.1	Robotics and Automation Application (2.2.1)
					2.2.2	Electrical Fundamentals Application
					2.2.3	Automated Equipment and Control Systems Configuration
					2.2.4	Automated Operation Monitoring (2.11.5)
					2.2.5	Instrumentation and Control System Design
					2.2.6	Embedded System Integration (2.9.5)
2.3	Motion control				2.3.1	Instrumentation and Control System Design
2.4	Positioning Systems				2.4.1	Instrumentation and Control System Design
2.5	Instrumentation meansurement and Controls				2.5.1	Instrumentation and Control Design Engineering Management
					2.5.2	Instrumentation and Control Field Maintenance Management
					2.5.3	Instrumentation and Control Maintenance Management
					2.5.4	Instrumentation and Control System Design
2.6	Programmable Logic Controller			Programmable Logic Controller	2.6.1	Applications Development
					2.6.2	Applications Integration
					2.6.3	Control System Programming (2.1.9)
					2.6.4	Automated System Design (2.11.6)
					2.6.5	Automated Operation Monitoring (2.11.5)
					2.6.6	Instrumentation and Control System Design (2.2.5)
2.7	Human machine interface			Human machine interface	2.7.1	Human-Robot Collaboration
					2.7.2	Intelligent Reasoning
					2.7.3	Programming and Coding (7.8.1)
					2.7.4	Software Configuration
2.8	Embedded Systems Design and Programming			Embedded systems Design and Programming	2.8.1	Applications Development (2.6.1)
					2.8.2	Applications Integration (2.6.2)
					2.8.3	Embedded Systems Programming
					2.8.4	Embedded Systems Interface Design
					2.8.5	Embedded System Integration
					2.8.6	Control System Programming (2.6.3)
					2.8.7	Programming and Coding (7.8.1)
					2.8.8	Software Configuration
2.9	Firmware Programming			Firmware Programming	2.9.1	Embedded Systems Programming (2.9.3)
2.10	Industry Robotic Systems			Industry Robotic Systems	2.10.1	Human-Robot Collaboration (2.7.1)
					2.10.2	Robotic and Automation System Maintenance
					2.10.3	Robotic and Automation Technology Application
					2.10.4	Robotics and Automation Application
					2.10.5	Automated Operation Monitoring
					2.10.6	Automated System Design
					2.10.7	Automation Systems Maintenance

2.11	Robotic Safety			Robotic Safety	2.11.1	Human-Robot Collaboration (2.7.1)
2.12	Collaborative Robots			Cobots	2.12.1	Human-Robot Collaboration (2.7.1)
2.13	Robot Operating System (ROS)			Robot Operating Systems	2.13.1	Robot Operating System (ROS
2.14	Digital Twin and Simulation of Robots			Digital Twin for Robotics	2.14.1	Process Modelling
2.15	Autonomous Mobile Robot (AMR)				2.15.1	Autonomous Mobile Robot (AMR)
2.16	Autonomous Guided/Intelligent Vehicle (AGV/AIV)				2.16.1	Autonomous Guided/Intelligent Vehicle (AGV/AIV)
2.17	Robotic Process Automation				2.17.1	Data Mining and Modelling (5.4.1)
					2.1872	Artificial Intelligence Application (6.12.1)
2.18	Intelligent Process Automation			Self-Learning System	2.18.1	Computational Modelling
					2.18.2	Analytics and Computational Modelling
					2.18.3	Intelligent Reasoning
					2.18.4	Self-Learning Systems (6.6.2)
2.19	Automated Inspection			Automated Inspection System	2.19.1	Automated Inspection
2.20	Automated Materials Handling System				2.20.1	Automated Materials Handling System
2.21	Asset condition monitoring and fault detection				2.21.1	Condition-based Assets Monitoring Management
					2.21.2	Automated Operation Monitoring
2.22	Manufacturing Process Automation				2.22.1	Automated Process Design
					2.22.2	Process Modelling
					2.22.3	Manufacturing Process Management
2.23	Enterprise Automation System				2.23.1	Enterprise Automation System
2.24	Facility Automation System				2.24.1	Smart Facilities Management
2.25	Shopfloor Automation System				2.25.1	Shopfloor Automation System
2.26	Automation System Integration				2.26.1	Automation System Integration
2.27	Automation Diagnostics & Assessment				2.27.1	Automation Diagnostics & Assessment

AM Tech/Skills Taxonomy Domain 3: Connectivity and Cybersecurity

AMTA Tech/Skill Taxonomy		SSF Economy	SFS Skills Domain	SFS Skills Topics	S/No.	Skills Title (TSC)
3.1	Fieldbus [Ethernet IP, EtherCAT, TwinCAT, Modbus]	I4.0	Advanced Manufacturing & Supply Chain		3.1.1	Fieldbus [Ethernet IP, EtherCAT, TwinCAT, Modbus]
					3.1.2	Instrumentation and Control Field Maintenance
					3.1.3	Instrumentation and Control Maintenance Management
3.2	OPC-Unified Architecture (OPC-UA				3.2.1	OPC-Unified Architecture (OPC-UA)
3.3	Message Queuing Telemetry Transport (MQTT)				3.3.1	Message Queuing Telemetry Transport (MQTT)
3.4	Connectivity Standard (SS IEC 62541)	Digital Digital	Technology Application and Management		3.4.1	Connectivity Standard (SS IEC 62541)
3.5	OT Connectivity				3.5.1	OT Connectivity
3.6	IT Connectivity		System and Infrastructure		3.6.1	IT asset management
3.7	Shopfloor Connectivity		Technology Application and Management	Technology Management	3.7.1	Internet of Things Implementation
3.8	Edge Computing Connectivity				3.8.1	Edge Computing Connectivity
3.9	Enterprise Connectivity			Enterprise Architecture	3.9.1	Enterprise Architecture
					3.9.2	Process Integration
					3.9.3	Enterprise Database System Administration
					3.9.4	Organisational Design
					3.9.5	Enterprise Risk Management
3.10	Cloud Computing Connectivity		Data and Analytics	Data Analytics System Design	3.10.1	Data Analytics System Design (5.1.2)
			System & Infrastructure	Cloud Computing	3.10.2	Cloud Computing
3.11	Facility Connectivity				3.10.1	Facility Connectivity
3.12	IT-OT Connectivity Network	I4.0	Advanced Manufacturing & Supply Chain	IT-OT Platform	3.12.1	Network administration and maintenance
					3.12.2	Network Configuration
3.13	Cybersecurity Standard-SS IEC 62443			Connectivity and Cybersecurity	3.13.1	Cybersecurity Standard-SS IEC 62443
3.14	Cyber Risk Management	Digital	Cyber security and risk	Cyber Risk Management	3.14.1	Cyber Risk Management
				Cybersecurity Framework Application	3.14.2	Cybersecurity framework application
				Security Assessment and Testing	3.14.3	Security Assessment and Testing
				Security Strategy	3.14.4	Cyber security
3.15	IT-OT Network Security			IT and Network Security	3.15.1	Information Technology and Network Security
				Security Architecture	3.15.2	Security Architecture
				IT Governance	3.15.3	IT governance
				Security Administration	3.15.4	Operational Technology Security Audit Management

AM Tech/Skills Taxonomy Domain 4: Industrial Internet of Things (IIoT)

AMTA Tech/Skill Taxonomy		SSF Economy	SFS Skills Domain	SFS Skills Topics	S/No.	Skills Title (TSC)
4.1	Industrial IoT for Manufacturing	I4.0	Industrial IoT, Robotics & Automation	Industrial IoT for Manufacturing	4.1.1	Internet of things management (PE, FM)
					4.1.2	Internet of things management (Electronics)
4.2	IOT Systems			IOT Systems	4.2.1	Internet of things management (4.1.1)
					4.2.2	Internet of things implementation, 4.1.1
4.3	IIoT Sensor Network				4.3.1	IIoT Sensor Network
4.4	Security Architecture Design			Security Architecture Design	4.4.1	Security Architecture (3.15.2)
4.5	Smart Sensor Solutions			Smart Sensor Solutions	4.5.1	Smart Sensor Solutions
4.6	Video Analytics			Video Analytics	4.6.1	Video Analytics
4.7	IIoT Application Development			IIoT Application Development	4.7.1	Internet of things application
					4.7.2	Applications Integration
					4.7.3	Instrumentation and Control Design Engineering Management
4.8	IIoT Systems Network Design				4.8.1	Process Integration
					4.8.2	User Interface Design
4.9	Sensorization			Sensorization	4.9.1	Embedded System Integration (2.9.5)
					4.9.2	Embedded Systems Programming (2.9.3)
					4.9.3	Internet of things implementation, 4.1.1

AM Tech/Skills Taxonomy Domain 5: Data Analytics

AMTA Tech/Skill Taxonomy		SSF Economy	SFS Skills Domain	SFS Skills Topics	S/No.	Skills Title (TSC)
5.1	Data Analysis	I4.0	Industrial IoT, Robotics & Automation	Manufacturing Data Analytics	5.1.1	Data analytics (FM)
					5.1.2	Data analytics (PE/Electronics/Aero)
		Digital	Data and Analytics	Data Analysis	5.1.2	Data Analytics (IT)
					5.1.3	Data analytics system design
					5.1.4	Data and statistical analysis
					5.1.5	Pattern Recognition Systems
					5.1.6	Big Data Analytics
5.2	Data Collection and Management			Data Collection and Management	5.2.1	Data collection and analysis
5.3	Data Design and Engineering			Data Design and Engineering	5.3.1	Data Engineering
					5.3.2	Data Synthesis
5.4	Data Mining and Modelling			Data Mining and Modelling	5.4.1	Data mining and modelling (See transport)
					5.4.2	Data mining and modelling (PE/Electronic/FM)
					5.4.3	Pattern Recognition Systems (5.1.5)
5.5	Data Visualization and control			Data Storytelling and Visualization	5.5.1	Data storytelling and visualisation
5.6	Data Management			Data Management	5.6.1	Data management
					5.6.2	Data governance
5.7	Big Data Analytics			Big Data Analytics	5.7.1	Big Data Analytics
					5.7.2	Data analytics system design (FM)
					5.7.3	Data analytics system design (PE/Electronics)

AM Tech/Skills Taxonomy Domain 6: Artificial Intelligence (AI)

AMTA Tech/Skill Taxonomy		SSF Economy	SFS Skills Domain	SFS Skills Topics	S/No.	Skills Title (TSC)
6.1	AI and Machine Learning (ML)	I4.0	Advanced Manufacturing and Supply Chain	Machine Learning (ML)	6.1.1	Data Analysis and Interpretation
					6.1.2	Data Analytics
					6.1.3	Autonomous Systems Technology Application
					6.1.4	Intelligent Reasoning
6.2	Deep Learning (DL)			Deep Learning	6.2.1	Text Analytics and Processing
					6.2.2	Pattern Recognition Systems
					6.2.3	Intelligent Reasoning
6.3	Computer Vision			Computer Vision	6.3.1	Computational Modelling
					6.3.2	Computer Vision Technology
					6.3.3	Image Processing and Industrial Vision Inspection
					6.3.4	Laser and Optics Application
					6.3.5	Pattern Recognition Systems
6.4	Artificial Neural Networks			Artificial Neural Networks	6.4.1	Data Synthesis
					6.4.2	Manufacturing Process Management
					6.4.3	Pattern Recognition Systems
6.5	Self-Learning Systems	Digital	Technology Application and Management	Self-Learning Systems	6.5.1	Self-Learning Systems
6.6	Artificial Intelligence Application			Artificial Intelligence Application	6.6.1	Artificial Intelligence Applications
6.7	AI for Robotics, Intelligent Robots	I4.0	Industrial IoT, Robotics & Automation	AI for Robotics, Intelligent Robots	6.6.2	Human Robot Collaboration
6.8	Predictive Maintenance			Predictive Maintenance	6.6.3	Predictive Maintenance
6.9	AI-Enabled Facility Management System (FMS)				6.6.4	Smart Facilities Management
6.10	AI-enabled Autonomous Control				6.6.5	AI-enabled Autonomous Control
6.11	AI-Enabled Quality Control and Assurance	Digital	Product Innovation and Quality Management		6.6.6	AI-Enabled Quality Control and Assurance
6.12	AI-enabled Predictive Intelligence	I4.0	Advanced Manufacturing and Supply Chain		6.6.7	AI-enabled Predictive Intelligence
6.13	Intelligent Systems			Intelligent Systems	6.6.8	Pattern Recognition Systems (5.1.5)
					6.6.9	Information Technology and Network Security

AM Tech/Skills Taxonomy Domain 7: Industry 4.0 Leadership and Talent Development

AMTA Tech/Skill Taxonomy		SSF Economy	Skills Group	SFS Skills Topics	S/No.	Skills Title (TSC)
7.1	Industry 4.0		I4.0 Leadership		7.1.1	Industry 4.0
7.2	SIRI Framework				7.2.1	SIRI Framework
7.3	Digital Transformation Methods				7.3.1	Digital Transformation Methods
7.4	Industry 4.0 Implementation				7.4.1	Industry 4.0 Implementation
7.5	Industry 4.0 Standards for Manufacturing				7.5.1	Industry 4.0 Standards for Manufacturing
7.6	Lean Manufacturing		Productivity and innovation	Lean Manufacturing	7.6.1	Lean Manufacturing
				People Management	7.6.2	Effectiveness Management
7.7	Training Planning and Development			Staff Training Management	7.7.1	Developing People
					7.7.2	People Capability Development
7.8	Coding Skills [C, C#, C++, Python, Spark, Hadoop..etc]		Technology Application and Management	Programming and Coding	7.8.1	Programming and Coding
7.9	Change Management		Critical Core Skills (CCS)	Change Management	7.9.1	Change Management
					7.9.2	Adaptability
7.10	Creative Thinking			Thinking Critically	7.10.1	Creative Thinking
					7.10.2	Sense Making
7.11	Problem Solving				7.11.1	Problem Solving
					7.11.2	Decision Making
7.12	Communication			Interacting with Others	7.12.1	Communications
7.13	Collaboration				7.13.1	Collaboration
7.14	Supplier Relations Management (SRM)				7.14.1	Supplier Management and Capability Development
7.15	Customer Relations Management (CRM)				7.15.1	Customer Orientation
					7.15.2	Business Development
7.16	Digital Fluency			Staying Relevant	7.16.1	Digital Fluency
7.17	Learning agility				7.17.1	Learning Agility
					7.17.2	Adaptability

AM Tech/Skills Taxonomy Domain 8: Additive Manufacturing

AMTA Tech/Skill Taxonomy		SSF Economy	SFS Skills Domain	SFS Skills Topics	S/No.	Skills Title (TSC)
8.1	Additive Manufacturing Processes and Systems	I4.0 Metallurgy for Additive Manufacturing	Additive Manufacturing, Advanced Materials & Processes	Additive Manufacturing and 3D Printing [Metals, Ceramic, Polymers, Composites, Concrete]	8.1.1	Additive Manufacturing
8.2	Additive Manufacturing for Metallic Components				8.2.1	Metal-based Additive Manufacturing
8.3	Additive Manufacturing for Polymer-Based Components				8.3.1	Polymeric Additive Manufacturing
8.4	Additive Manufacturing and 3D Printing Methods [Ceramics, Composites, Cement]				8.4.1	Additive Manufacturing and 3D Printing Methods [Ceramics, Composites, Cement];
8.5	Hybrid Manufacturing (Subtractive and Additive)			Hybrid Manufacturing	8.5.1	Hybrid Additive Manufacturing Design and Process
					8.5.2	Additive Manufacturing
8.6	Design for Additive Manufacturing			Design for Additive Manufacturing	8.6.1	Design for Manufacturing and Assembly
					8.6.2	Design for Additive Manufacturing
8.7	Additive Manufacturing Standard			Product Qualification for Additive Manufacturing	8.7.1	Additive Manufacturing Standard
8.8	Additive Manufacturing Qualification and Certification				8.8.1	Equipment Qualification
					8.8.2	Material Qualification
					8.8.3	AM Product Qualification and Certification
8.9	Additive Manufacturing Safety			AM Safety	8.9.1	Additive Manufacturing Safety

AM Tech/Skills Taxonomy Domain 9: Advanced Manufacturing Processes and Materials

AMTA Tech/Skill Taxonomy		SSF Economy	SFS Skills Domain	SFS Skills Topics	S/No.	Skills Title (TSC)
9.1	Advanced Materials	I4.0	Additive Manufacturing, Advanced Materials & Processes	Advanced Materials	9.1.1	Aerospace Materials and Hardware Selection
					9.1.2	Non-metallic Materials Manufacturing
					9.1.3	Material Studies and Production Processes
9.2	Functional Materials			Functional Materials	9.2.1	
9.3	Advanced Composites			Advanced Composites	9.3.1	Composite Structures Design and Maintenance
9.4	Advanced Manufacturing Processes [Forming/Forging/ Welding/ Machining /Coating methods]			Advanced Processes [Forming methods, Forging methods, Welding methods, Surface Coating methods]	9.4.1	Forming
					9.4.2	Metal Forming
					9.4.3	Material Joining
					9.4.4	Welding Process
					9.4.5	Machining
					9.4.6	Coating
9.5	Advanced Material Treatment Processes [Heat Treatment, Surface Finishing and Modification]			Advanced Processes [Surface Modification methods, Heat Treatment methods]	9.5.1	Heat Treatment Process
					9.5.2	Aerospace Heat Treatment Process
					9.5.3	Surface Enhancement
						Surface modification
9.6	Smart Mold Design and Fabrication				9.6.1	Injection Mould Design
						Smart Mold Design
9.7	Flexible / Hybrid Materials Engineering and Processes				9.7.1	Flexible / Hybrid Materials Engineering
9.8	Remanufacturing	Green	Resource Circularity & Decarbonization	Design for Disassembly	9.8.1	Engine Disassembly and Assembly
						Design for remanufacturing
9.9	Integrated Engineering for MRO	I4.0	Additive Manufacturing, Advanced Materials & Processes		9.9.1	Integrated Engineering for MRO
9.10	Advanced Metrology			Advanced Metrology	9.10.1	Metrology Management
9.11	Advanced Inspection for Manufacturing			Advanced Inspection for Manufacturing	9.11.1	Image Processing and Industrial Vision Inspection
					9.11.2	Engine Component Parts Inspection
					9.11.3	Image Processing and Industrial Vision Inspection
					9.11.4	Non-destructive Testing (Ultrasonic Inspection)
9.12	Materials Characterisation			Materials Characterisation	9.12.1	Metallic Material Characterisation
					9.12.2	Polymeric Material Characterisation
					9.12.3	Materials Inspection
9.13	Green Manufacturing Design and Implementation	Green	Green Infrastructure & Mobility	Green Manufacturing Design and Implementation	9.13.1	Green Manufacturing Design and Implementation
9.14	Green / Sustainable Manufacturing			Green / Sustainable Manufacturing	9.14.1	Sustainable Manufacturing
9.15	Sustainable Manufacturing Assessment			Sustainable Manufacturing Assessment	9.15.1	Resource Management
					9.15.2	Environmental Sustainability Management

AM Tech/Skills Taxonomy Domain 10: Product Innovation and Quality Management

AMTA Tech/Skill Taxonomy		SSF Economy	SFS Skills Domain	SFS Skills Topics	S/No.	Skills Title (TSC)
10.1	Product Design and Modelling	I4.0	Product Innovation & Quality Management	Product design and modelling	10.1.1	Composite Structures Design and Maintenance
					10.1.2	Engineering Product Design Facilitation
					10.1.3	Computer-aided Design Application
					10.1.4	3D Modelling
					10.1.5	New Product Introduction
					10.1.6	Marine Design Customisation
					10.1.7	Engineering Product Design
					10.1.8	Product Design and Development
					10.1.9	Innovation Management
10.2	Design Thinking for Product Innovation			Design Thinking	10.2.1	Design Thinking Practice
					10.2.2	Logistics Solution Design Thinking
					10.2.3	Solutions Design Thinking
10.3	Process innovation			Process innovation	10.3.1	Green Manufacturing Design and Implementation
					10.3.2	Lean Manufacturing
					10.3.3	Manufacturing Process Design
					10.3.4	Pharmacovigilance Integration
					10.3.5	Food Manufacturing Process Design
10.4	Operation Management and Innovation			Operations Innovation	10.4.1	Manufacturing Systems Operation and Control
					10.4.2	Process Improvement and Optimisation
					10.4.3	Technology Road Mapping
					10.4.4	Process Optimisation
10.5	Plant Simulation and Manufacturing Process Analysis			Plant Simulation and Manufacturing Process Analysis	10.5.1	Production Planning
					10.5.2	Data Mining and Modelling
					10.5.3	Systems Engineering Thinking
10.6	Manufacturing Product Lifecycle Management (PLM)			Product Lifecycle Management	10.6.1	Carbon Footprint Management
					10.6.2	Product Lifecycle Management
					10.6.3	Resource Management
10.7	Failure Analysis				10.7.1	Failure Analysis
					10.7.2	Reliability Engineering Management
					10.7.3	Engineering Problem Solving
10.8	Testing, Inspection and Certification			Testing, Inspection and Certification	10.8.1	Visual Testing
					10.8.2	Non-destructive Testing
					10.8.3	Non-metallic Materials Testing
					10.8.4	Equipment and Systems Testing
					10.8.5	Test Planning
					10.8.6	Product Testing
					10.8.7	Product Testing Management
					10.8.8	Raw Materials and Utilities Testing
					10.8.9	Equipment and Systems Installation and Commissioning Management
					10.8.10	Product and Production Engineering
					10.8.11	Electrical Field Maintenance Management
					10.8.12	Materials Qualification
					10.8.13	Laboratory Management
					10.8.14	Geometric Dimensioning and Tolerancing
					10.8.15	Materials Inspection
					10.8.16	Sample Management

					10.8.17	Inspection Engineering Management
					10.8.18	Image Processing and Industrial Vision Inspection
10.9	Quality Control & Assurance			Quality Control & Assurance	10.9.1	Quality Control Management
					10.9.2	Quality Control and Assurance
					10.9.3	Quality Assurance Management
					10.9.4	Logistics Process Quality Management
					10.9.5	Quality System Management
					10.9.6	Laboratory Data Analysis
					10.9.7	Quality Process Control
					10.9.8	Analytical Method Validation
					10.9.9	Non-Conformance Management
					10.9.10	Food and Beverage Quality Assurance Framework Development
					10.9.11	Process Validation
					10.9.12	Quality Assurance
					10.9.13	Project Quality Management
10.10	Product Qualification and Standards			Product Qualification and Standards	10.10.1	Materials Qualification
					10.10.2	Product qualification and standard

Annex D: Mapping Training Courses to AM Tech/Skills Taxonomy

By AMTA Programme Office, 8 Nov 2022

AM Tech/Skills Taxonomy Domain 1: Smart Manufacturing Platform and Tools

AMTA Tech/Skills Taxonomy Topics		Course Title	Training Institute	Training Duration (hours)	Link to Course
1.1	Enterprise Resource Planning (ERP)	SAP ERP Production Planning & Manufacturing	TP	142	Link
		Production Planning and Scheduling for Smart Manufacturing	SIMTech	24	Link
1.2	Manufacturing Execution System (MES)	Manufacturing Execution System 4.0: Applications, Technologies, and Benefit	TUV SUD	8	Link
1.3	Cloud Platforms	Amazon Web Services Cloud Computing Architecture	SP	56	Link
1.4	5G	Envisioning 5G IoT Solutions	NUS (ISS)	20	Link
		Introduction to 5G Technology and Applications	SP	16	Link
1.5	Cyber Physical production System				
1.6	Real-Time Operating Systems (RTOS)				
1.7	Digital Twin for Manufacturing System	Virtual Manufacturing and Digital Twin	TP	40	Link
		Manufacturing Process Simulation	NYP	28	Link
1.8	Augmented Reality	Augmented Reality for Enhancing Work Productivity	TP	24	Link
		Virtual & Augmented Reality in Manufacturing	NTU	14	Link
1.9	Virtual Reality	Go-VR Basic: VR Learning Content Creation Using 360 Cameras	RP	16	Link
1.10	Smart solution architecture				
1.11	Overall Equipment Effectiveness (OEE)	Real-Time OEE for Industry 4.0	SIMTech	40	Link
1.12	Production Planning and Scheduling	Production Planning & Scheduling for Smart Manufacturing	SIMTech	24	Link
1.13	Smart Inventory Planning	Inventory Management for Smart Manufacturing & Services	SIMTech	40	Link
1.14	Microservices for Manufacturing				
1.15	DevOps and Containeri-zation in I4.0 application				
1.16	Dynamic scheduling				
1.17	Supervisory Control and Data Acquisition	Industrial Internet of Things with SCADA and PLC	RP	24	Link
1.18	Production Supply Chain	goDCE(Distribution Centre Excellence)	RP	88	Link
1.19	Machine Learning for Supply Chain	Machine Learning for Supply Chain Analytics & Operations Management	SIMTech	40	Link
1.20	Supply Chain Analytics	Machine Learning for Supply Chain Analytics & Operations Management	SIMTech	40	Link
1.21	Digital Supply Chains				
1.22	Horizontal Integration				

AM Tech/Skills Taxonomy Domain 2: Automation & Robotics

AMTA Tech/Skills Taxonomy Topics		Course Title	Training Institute	Training Duration (hours)	Link to Course
2.1	Sensors	Programming IO Link Smart Devices (IEC61131-9)	NP	14	Link
		Industrial Automation in Practice	TP	24	Link
2.2	Actuators	Programming IO Link Smart Devices (IEC61131-9)	NP	14	Link
2.3	Motion control	Control in Automation Systems	SIMTech	40	Link
2.4	Positioning Systems	Enhance Control Performance of Precision Machines	SIMTech	39	Link
2.5	Instrumentation measurement and Controls				
2.6	Programmable Logic Controller	Controlling Automated System using PLC IEC61131-3	NP	21	Link
2.7	Human machine interface	Introduction to Programmable Logic Controller and web-based Human Machine Interface for Industry 4.0	RP	14	Link
2.8	Embedded Systems Design and Programming	Automation Components and Systems for Advanced Manufacturing	SIMTech	40	Link
2.9	Firmware Programming				
2.10	Industry Robotic Systems	Robotics in Today's Digital World	NUS	7	Link
		Robotics & Automation 101	TP	8	Link
		Introduction to Robotics Fundamentals	SIT	8	Link
		Robotics Operation & Adaptation	TP	24	Link
2.11	Robotic Safety				
2.12	Collaborative Robots	Introduction to Collaborative Robotics	NYP	7	Link
		Collaborative Robot Programming and Applications	SP	40	Link
2.13	Robot Operating System	Robot Operating System Industrial (ROS-I)	SP	32	Link
		ROS-Industrial ROS2 Navigation	ARTC	32	Link (to be updated)
2.14	Digital Twin and Simulation of Robots	Creating Digital Twin in Advanced Manufacturing (NEW)	SP	16	Link
2.15	Autonomous Mobile Robot (AMR)	Autonomous Mobile Robots for Industrial Applications	ARTC	32	Link (to be updated)
		Autonomous Robotics in Advanced Manufacturing	TP	32	Link
2.16	Autonomous Guided/Intelligent Vehicle (AGV/AIV)	Autonomous Robots & Vehicles	NUS-ISS	33	Link

2.17	Robotic Process Automation	Robotic Process Automation	SP	10	Link
		Robotic Process Automation for Beginners	TP	14	Link
		goRPA - UiPath	RP	28	Link
2.18	Intelligent Process Automation				
2.19	Automated Inspection	Advanced Inspection Methods in Manufacturing	NTU	7	Link
2.20	Automated Materials Handling System				
2.21	Asset condition monitoring and fault detection	Develop Machine Health Monitoring Techniques	SIMTech	42	Link
2.22	Manufacturing Process Automation				
2.23	Enterprise Automation System				
2.24	Facility Automation System				
2.25	Shopfloor Automation System				
2.26	Automation System Integration	Automation Components and Systems for Advanced Manufacturing	SIMTech	40	Link
		Automation Design and Simulation	SIMTech	40	Link
2.27	Automation Diagnostics & Assessment	Understand Automation Assessment and Adoption Methodologies	SIMTech	40	Link

AM Tech/Skills Taxonomy Domain 3: Connectivity and Cybersecurity

AMTA Tech/Skills Taxonomy Topics		Course Title	Training Institute	Training Duration (hours)	Link to Course
3.1	Fieldbus [Ethernet IP, EtherCAT, TwinCAT, Modbus]				
3.2	OPC-Unified Architecture (OPC-UA)	Open Platform Communications Unified Architecture (OPC UA) for Advanced Manufacturing	SP	12	Link
3.3	Message Queuing Telemetry Transport (MQTT)				
3.4	IEC 62541				
3.5	OT Connectivity	NB-IOT – Understanding Low Power Cellular LTE	NYP	7	Link
		Low-Power Wide-Area Network (LPWAN) - Making It Work	NYP	7	Link
3.6	IT Connectivity	Connectivity for Visibility and Decision Making in Smart Factories	SIMTech	24	Link
3.7	Shopfloor Connectivity				
3.8	Edge Computing Connectivity				
3.9	Enterprise Connectivity				
3.10	Cloud Computing Connectivity				
3.11	Facility Connectivity				
3.12	IT-OT Connectivity Network				
3.13	Cybersecurity Standard-SS IEC 62443				
3.14	Cyber Risk Management	Industry 4.0 Cybersecurity Management for Operation/ MES/IT Managers	SIMTech	16	Link
		Cybersecurity Bridging Programme	TP	21	Link
3.15	IT-OT Network Security				

AM Tech/Skills Taxonomy Domain 4: Industrial Internet of Things (IIoT)

AMTA Tech/Skills Taxonomy Topics		Course Title	Training Institute	Training Duration (hours)	Link to Course
4.1	Industrial IoT for Manufacturing	Adopting Internet of Things into Operations	RP	8	Link
		IoT for Electronics Industry	SP	8	Link
		Building an IoT (Internet of Things) Project	SP	15	Link
		IOT Dashboard in Practice	TP	24	Link
4.2	IOT Systems				
4.3	IIoT Sensor Network	Practical Applications of Condition Monitoring for Industry 4.0	SP (BRRTC)	16	Link
		Smart IOT Technology & Application	NYP	28	Link
4.4	Security Architecture Design				
4.5	Smart Sensor Solutions				
4.6	Video Analytics				
4.7	IIoT Application Development	Advanced Manufacturing and Industrial IoT	SP	7	Link
4.8	IIoT Systems Network Design				
4.9	Sensorization				

AM Tech/Skills Taxonomy Domain 5: Data Analytics

AMTA Tech/Skills Taxonomy Topics		Course Title	Training Institute	Training Duration (hours)	Link to Course
5.1	Data Analysis	Data Analytics Begins With Me	NUS	7	Link
		Data Analytics for Electronics Industry	SP	8	Link
		Data Analytics for Industrial Applications	SP	16	Link
5.2	Data Collection and Management				
5.3	Data Design and Engineering	Data Engineering for Effective Data Analytics	SP	16	Link
5.4	Data Mining and Modelling	Data Mining for Correlation Analysis (DM-LITE)	SIMTech	16	Link
		Implement Manufacturing Data Mining Techniques	SIMTech	40	Link
5.5	Data Visualization and control	Data Visualization with Tableau	SP	16	Link
		Visual Analytics using Power BI	SP	14	Link
		Data Visualisation	TP	8	Link
		Fundamentals of Data Visualisation using Tableau	ITE	7	Link
5.6	Data Management				
5.7	Big Data Analytics	Big Data & Analytics	TP	15	Link
		Big Data Engineering for Analytics	NUS (ISS)	33	Link

AM Tech/Skills Taxonomy Domain 6: Artificial Intelligence (AI)

AMTA Tech/Skills Taxonomy Topics		Course Title	Training Institute	Training Duration (hours)	Link to Course
6.1	AI and Machine Learning (ML)	Introduction to AI and Machine Learning	SP	7	Link
		Artificial Intelligence for Everyone - A Practical Experience	RP	8	Link
		goML	RP	32	Link
		Pattern Recognition and Machine Learning Systems	NUS (ISS)	33	Link
		Practical AI in Manufacturing	TP	32	Link
6.2	Deep Learning (DL)				
6.3	Computer Vision	Introduction to Machine Vision	NYP	7	Link
		Machine Vision and Pattern Recognition in Advanced Manufacturing	TP	28	Link
		Vision Systems	NUS (ISS)	33	Link
6.4	Artificial Neural Networks				
6.5	Self-Learning System	Self-Learning Systems	NUS(ISS)	26	Link
6.6	Artificial Intelligence Application	Accelerating Deploying and Scaling Artificial Intelligence (AI) Applications	NYP	7	Link
6.7	AI for Robotics, Intelligent Robot				
6.8	Predictive maintenance	Data driven Predictive Maintenance and Optimal Plan	SIMTech	37	Link
		Introduction to Predictive Analytics for Maintenance	SP	8	Link
6.9	AI-enabled Facility Management System [FMS]				
6.10	AI-enabled Autonomous Control				
6.11	AI-enabled Quality Control and Assurance				
6.12	AI-enabled Predictive Intelligence				
6.13	Intelligent Systems				

AM Tech/Skills Taxonomy Domain 7: Industry 4.0 Leadership and Talent Development

AMTA Tech/Skills Taxonomy Topics		Course Title	Training Institute	Training Duration (hours)	Link to Course
7.1	Industry 4.0	Advanced Manufacturing Learning Journey & Workshop	TP	8	Link
		Advanced Manufacturing (i4.0) Learning Journey	SP	7	Link
		Industry 4.0 In Action	RP	16	Link
7.2	SIRI Framework	I4.0 Learning Journey with SIRI	SP	7	Link
		Industry 4.0 Assessment through SIRI Framework	ARTC	16	Link (to be updated)
7.3	Digital Transformation Methods	AHK i4.0 Industry Specialist	SP (Rexroth)	79	Link
		Understand Digital Transformation & Innovation	SIMTech	40	Link
7.4	Industry 4.0 Implementation	Industry 4.0 Human Capital Initiative (IHCI) Enabler Programme	SBF (McKinsey/EY)	64	Link Note: Link to SBF Website
7.5	Industry 4.0 Standards for Manufacturing				
7.6	Lean Manufacturing	Value Stream Mapping (VSM)	RP	8	Link
		Implement Fundamental Lean at Workplace	SIMTech	26	Link
		Go Lean Transformation	RP	56	Link
7.7	Training Planning and Development				
7.8	Coding Skills [C, C#, C++,Python, Spark, Hadoop..etc]	Python Utilization in Advanced Manufacturing	SIMTech	16	Link
7.9	Change Management	Fundamentals of Change Management for Industry 4.0: Overview and Methodologies	TUV SUD	8	Link Note: Link to TUV SUD Website
7.10	Creative Thinking				
7.11	Problem Solving				
7.12	Communication				
7.13	Collaboration				
7.14	Supplier Relations Management (SRM)				
7.15	Customer Relations Management (CRM)				
7.16	Digital Fluency				
7.17	Learning agility				

AM Tech/Skills Taxonomy Domain 8: Additive Manufacturing

AMTA Tech/Skills Taxonomy Topics		Course Title	Training Institute	Training Duration (hours)	Link to Course
8.1	Additive Manufacturing Processes and Systems	Smart Additive Manufacturing System	SIMTech	45	Link
		Direct Deposition 3D Printing for Manufacturing and Remanufacturing	ARTC	40	Link (to be updated)
		Industrial Additive Manufacturing for Practitioners	ARTC	24	Link (to be updated)
		Essential Skills of 3D Printed Electronics for Smart Device	NTU	14	Link
8.2	Additive Manufacturing for Metallic Components	Powder-Bed Additive Manufacturing Processes for Complex Functional Metallic Components	SIMTech	45	Link
		High Speed Additive Manufacturing Processes for Metallic Components	SIMTech	45	Link
		Fundamentals and Essential Skills in Metal 3D Printing	NTU	14	Link
8.3	Additive Manufacturing for Polymer-Based Components	Polymer-Based Additive Manufacturing Processes for Flexible Mass Customisation	SIMTech	45	Link
		3D Printing of Carbon Fiber Composite and Advanced Multi-Material Polymers	NTU	14	Link
8.4	Additive Manufacturing and 3D Printing Methods [Ceramics, Composites, Cement];	3D Concrete Printing for Building and Construction	NTU	13	Link
8.5	Hybrid Manufacturing (Subtractive and Additive)				
8.6	Design for Additive Manufacturing (DfAdM)				
8.7	Additive Manufacturing Standard	Qualification of Parts Printed by Metal Additive Manufacturing	NTU	7	Link
8.8	Additive Manufacturing Qualification and Certification	Qualification of Parts Printed by Metal Additive Manufacturing	NTU	7	Link
8.9	Additive Manufacturing Safety	Additive Manufacturing Professional Certificate Course	SP	56	Link

AM Tech/Skills Taxonomy Domain 9: Advanced Manufacturing Processes and Materials

AMTA Tech/Skills Taxonomy Topics		Course Title	Training Institute	Training Duration (hours)	Link to Course
9.1	Advanced Materials	3D Printing of Carbon Fiber Composite and Advanced Multi-Material Polymers	NTU	14	Link
9.2	Functional Materials				
9.3	Advanced Composites	Composite Repair Design with Practical Application	NYP	14	Link
9.4	Advanced Manufacturing Processes [Forming/Forging/ Welding/ Machining/Coating methods]	Evaluate Advanced Metal Welding Processes	SIMTech	42	Link
		Advanced Smart Machining Technology	SIMTech	40	Link
		Introduction to CNC Machining Processes	NYP	21	Link
		Advanced Manufacturing Processes for Sustainable Polymer-Based Materials	SIMTech	40	Link
		Apply Advanced Coating Technologies for Corrosion and Wear Protection	SIMTech	42	Link
		CoC in Machining Analytics	ITE	8	Link
9.5	Advanced Material Treatment Processes [Heat Treatment, Hot-Isostatic Pressing, Surface Finishing and Modification]	Industrial Robotic Finishing – Best Practices	ARTC	40	Link (to be updated
		Apply Surface Enhancement and Finishing Technologies	SIMTech	40	Link
9.6	Smart Mold Design and Fabrication				
9.7	Flexible/Hybrid Materials Engineering and Processes				
9.8	Remanufacturing				
9.9	Integrated Engineering for MRO				
9.10	Advanced Metrology	Engineering Optics & Optical Measurements	SIMTech	45	Link
		Process Monitoring and Inspection for Industrial Applications	NTU	14	Link
9.11	Advanced Inspection for Manufacturing	Advanced Inspection Methods in Manufacturing	NTU	7	Link
9.12	Materials Characterisation	Materials Characterisation	SIMTech	45	Link
9.13	Green Manufacturing Design and Implementation	Sustainability Transformation through Green Compass	SIMTech	16	Link
9.14	Green / Sustainable Manufacturing	Smart Energy Management for Sustainability	SIMTech	42	Link
9.15	Sustainable Manufacturing Assessment	Carbon Footprinting through Lifecycle Assessment	SIMTech	42	Link

AM Tech/Skills Taxonomy Domain 10: Product Innovation and Quality Management

AMTA Tech/Skills Taxonomy Topics		Course Title	Training Institute	Training Duration (hours)	Link to Course
10.1	Product Design and Modelling	Product Design, Innovation and Fabrication	SIMTech	42	Link
		Design Methodologies and Innovation for Additive Manufacturing	NTU	14	Link
10.2	Design Thinking for Product Innovation	Apply Design Thinking for Product Innovation	SIMTech	24	Link
		Design Thinking 101	SP	7	Link
10.3	Process innovation				
10.4	Operation Management and Innovation	Apply Operations Improvement Fundamentals	SIMTech	40	Link
10.5	Plant Simulation and Manufacturing Process Analysis				
10.6	Manufacturing Product Lifecycle Management (PLM)	Integrated Product Lifecycle Processes – Opportunities & Challenges	SP	8	Link
10.7	Failure Analysis	8 Disciplines (8D) and Failure Mode Effect Analysis (FMEA) in High Volume Manufacturing	TP	14	Link
10.8	Testing, Inspection and Certification	Functional Safety Machinery in Advanced Manufacturing Certification Programme	TP	56	Link
		Advanced Inspection Methods in Manufacturing	NTU	7	Link
10.9	Quality Control & Assurance	Review Welding Operation & Quality Control	SIMTech	42	Link
		Review Coating Failure Prevention and Coating Improvement	SIMTech	42	Link
10.10	Product Qualification and Standards				

Advanced Manufacturing Training Academy (AMTA)

Your Partner in Advanced Manufacturing Training

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