Employee Qualification as Key Success Factor in Digitalised Factories

– A Sino-German Skill Development Guideline

Sino-German Company Working Group on Industrie 4.0 and Intelligent Manufacturing (AGU)
Expert Group Training 4.0

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This publication is a result of close cooperation between multiple entities in Germany and China including the Sino-German Company Working Group on Industrie 4.0 and Intelligent Manufacturing (AGU) Expert Group Training 4.0 (EG Training 4.0) in support of the MoU signed in 2015 between BMWi and MIIT following the 2014 joint action plan "Shaping Innovation Together".

Since 2016, the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, commissioned by BMWi, and the China Center for Information Industry Development (CCID) are the implementing bodies for the cooperation on the German and the Chinese side, respectively.

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Executive Summary

Industrie 4.0 is reshaping the way of product manufacture and value creation in a digital and connected work environment. The application of smart manufacturing technologies will change employment and work environment and raise new requirements on workforce qualification and management on an ongoing basis. It is still not clear what and how changes will take place. In this context, the identification of central skill needs, the assessment of a company's current skill set, and the challenge of closing the gap with the help of suitable training systems and units come to light. The Sino-German Company Working Group on Industrie 4.0 and Intelligent Manufacturing Expert Group Training 4.0 (hereinafter referred to as AGU EG Training 4.0), composed of experienced Chinese and German professionals from industry, research, and government, worked out this White Paper in order to address these action fields that can be summarised under the field of “Training 4.0”. As a result, an overview of the state of the art is given, future action fields are determined and recommendations for industry, policymakers, and training providers are made. The team of Chinese and German experts addressed the topics from different angles and brought both German and Chinese perspective together.

Based on an extensive analysis of current research in Germany and China, it becomes obvious that skill needs for Industrie 4.0 do not differ significantly in both countries. Moreover, there is a common agreement on central skill needs in literature. The research of the EG Training 4.0 pointed out that the required skill needs cover a wide range—from technological, managerial, interdisciplinary competencies, leadership to soft skill competency. Assembly workers and maintenance personnel are thereby just as affected as engineers and managers. A wide variety of Industrie 4.0 related courses in universities and colleges in both countries show, that students are going to be well trained to master necessary Industrie 4.0 skills in the future. The focus of industry, policymakers, and training providers needs to be set on the existing workforce at various levels.

In order to empower the workforce for smart manufacturing, it is necessary to get an overview of the existing skill level of the affected workers. For this purpose, various maturity models already exist in Germany as well as in China. Several use cases successfully prove that they are very well suited to assess the Industrie 4.0 maturity of plants and suggest improvement potentials. But so far there lack commonly accepted standards among industry players, and a link between workforce skills and qualification measures is missing. The EG Training 4.0 suggests developing a maturity model that fulfils the special requirements of workforce assessment linked with qualification measures, which could be standardised in the future.

In order to close the skill gaps identified by appropriate maturity assessment, various course systems in industry and research are already in use. They are consolidated in this White Paper and serve as a reference. Standards for further education curricula for the existing workforce are helpful and necessary in this context.

Overall, Chinese and German employees already have foundations of their existing skills. Thus, in terms of training, different channels and mechanisms need to be used. Several use cases show that big companies in Germany and China are already well prepared to develop their own training programs and provide their workforce with the necessary knowledge. In contrast, small and medium-sized enterprises (SMEs) need support and guidance. For this purpose, several training centres were established with the strong support of the authorities. In Germany, these competence centres run quite successful, but in China, there are quite some examples that the training centres are more of technological showcases and not often used for trainings. Instead of investing in technological showcases, the government and companies should give more incentives to promote training offers and build Train-the-Trainer systems in order to establish training curricula coherent with existing technologies.

1 Introduction

In July 2015, the German Federal Ministry for Economic Affairs and Energy (BMWi) and the Chinese Ministry of Industry and Information Technology (MIIT) signed a Memorandum of Understanding (MoU) to support German and Chinese companies by creating a favourable business environment for Intelligent Manufacturing and Industrie 4.0. This MoU emphasises the importance of industry cooperation and highlights the shared interest in facilitating further dialogue at all levels among representatives from government, industry and academia.

BMWi and MIIT commissioned the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and the China Centre for Information Industry Development (CCID) to support the implementation of the MoU. Under the direction of BMWi and MIIT, GIZ and CCID jointly established the Sino-German Company Working Group on Industrie 4.0 and Intelligent Manufacturing as a platform for German and Chinese experts to discuss challenges and opportunities of Industrie 4.0 and Intelligent Manufacturing with the goal of better understanding relevant business environment and policies, exchanging best practices and developing joint policy recommendations. The discussion results are directly delivered to the bilateral political dialogue.

The Sino-German Expert Groups focus on four Industrie 4.0 areas. These include:

- Digital Business Models
- Training 4.0
- Industrial Internet
- Artificial Intelligence

The task of the EG Training 4.0 is to gather the best practices and develop guidelines on how companies should react to the changing demands on their workforce brought by the ongoing digitalisation and how they should equip the personnel with the necessary skillset. Furthermore, recommendations are given to the respective governments on how to provide favourable environments to foster this development. The results with specific consideration of German and Chinese companies are described in this White Paper. In the following chapter, the motivation and the objective, as well as the structure of the White Paper, are introduced.

1.1 Motivation and Objective

Industrie 4.0 is meant to change the way value is created in the world's factories. It is an ongoing journey and yet it is still not clear how this substantial change will affect the role of the human worker in a digital and connected work environment in detail. There is a common agreement in industry and research that the implementation of smart manufacturing technologies will affect employment, work environment, work organisation, and qualification of the workforce. These impacts require a specific set of competencies in order to enable the workforce to adjust to the new Industrie 4.0 setting.

The work of the AGU EG Training 4.0 incorporated in this White Paper, therefore, aims at analysing the influence of Industrie 4.0 on the workforce and capabilities in Germany as well as in China, based on a wide-ranging literature review and the discussion between experts from industry, research, and government. Central skill needs are identified, and possibilities of assessing the company's current skill set and ways to close potential skill gaps are described. On this basis, recommendations are given to industry, policymakers and training providers. Industry decision-makers can use the results to better assess the existing skill set of their employees and derive appropriate qualification measures. Policymakers can get an overview of the current status of training concepts on smart manufacturing and identify action fields. Training providers can use the outcome of this White Paper to overthink their training focus and further improve their training mechanisms.

1.2 Structure of the White Paper

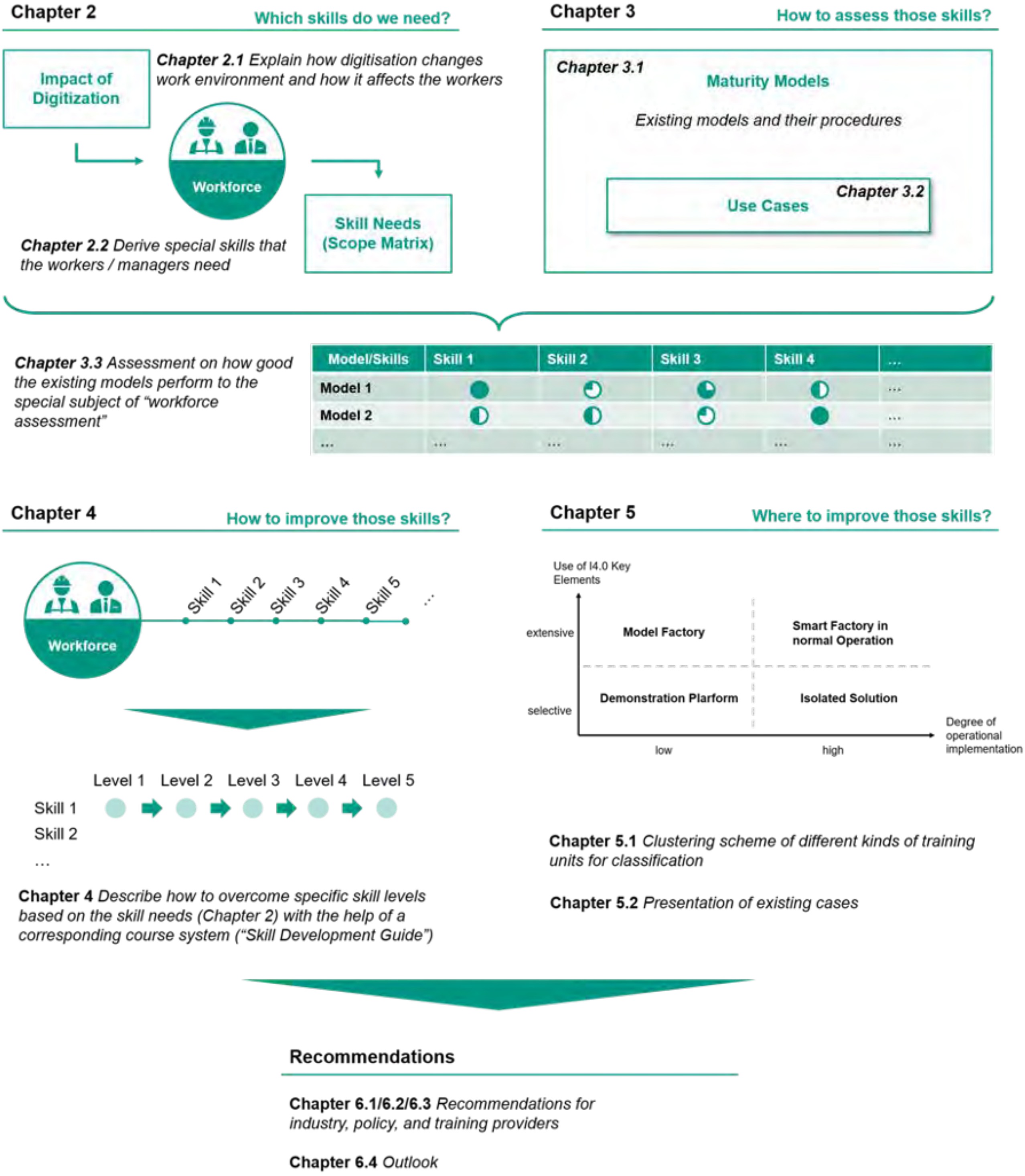
The White Paper is structured into four chapters with four central questions to be answered. An overview is given in Figure 1.

The first work package asks the question “Which skills do we need?”, and is divided into two chapters: In Chapter 2.1 the impact of digitisation on today’s workforce is described and it explains how this changes the work environment. From these impacts special skill needs are derived, which are explained in Chapter 2.2.

Work package two is led by the question “How to assess those skills?”. As the answer, existing maturity indices and corresponding use cases are explored in Chapter 3.1 and 3.2. The existing models are then assessed against their applicability to the special subject of workforce assessment in Chapter 3.3 by bringing together maturity models and skill needs from Chapter 2. In Chapter 3.4, recommendations about the development of a fitting maturity model are made.

“How to improve those skills” is the central question of Chapter 4 which comprises a detailed description on how to overcome specific skill levels based on the skill needs from Chapter 2 and the assessment levels from Chapter 3. For this, a skill development guide with a corresponding course system is presented.

Chapter 5 centres on the question “Where to improve those skills”. Chapter 5.1 provides a classification scheme in order to generalise existing institutions. Chapter 5.2 uses cases of existing training units in China and Germany are presented and integrated into the scheme. The White Paper concludes with a final chapter, in which recommendations are derived and an outlook on further activities of the EG Training 4.0 is given.



Chapter 2.1 *Explain how digitisation changes work environment and how it affects the workers*

Chapter 2.2 *Derive special skills that the workers / managers need*

Existing models and their procedures

Chapter 3.3 *Assessment on how good the existing models perform to the special subject of "workforce assessment"*

Model/Skills	Skill 1	Skill 2	Skill 3	Skill 4	...
Model 1	●	◔	◕	◑	...
Model 2	◑	◑	◔	●	...
...	...	...	...	...	...

Chapter 4 *Describe how to overcome specific skill levels based on the skill needs (Chapter 2) with the help of a corresponding course system ("Skill Development Guide")*

Chapter 5.1 *Clustering scheme of different kinds of training units for classification*

Chapter 5.2 *Presentation of existing cases*

Chapter 6.1/6.2/6.3 *Recommendations for industry, policy, and training providers*

Chapter 6.4 *Outlook*

Figure 1: Structure of the White Paper

2 Skill Needs in the Age of Digital Transformation

Chapter 2 focuses on the impact of digital transformation on the workforce and resulting skill needs, and its structure is illustrated in Figure 2.

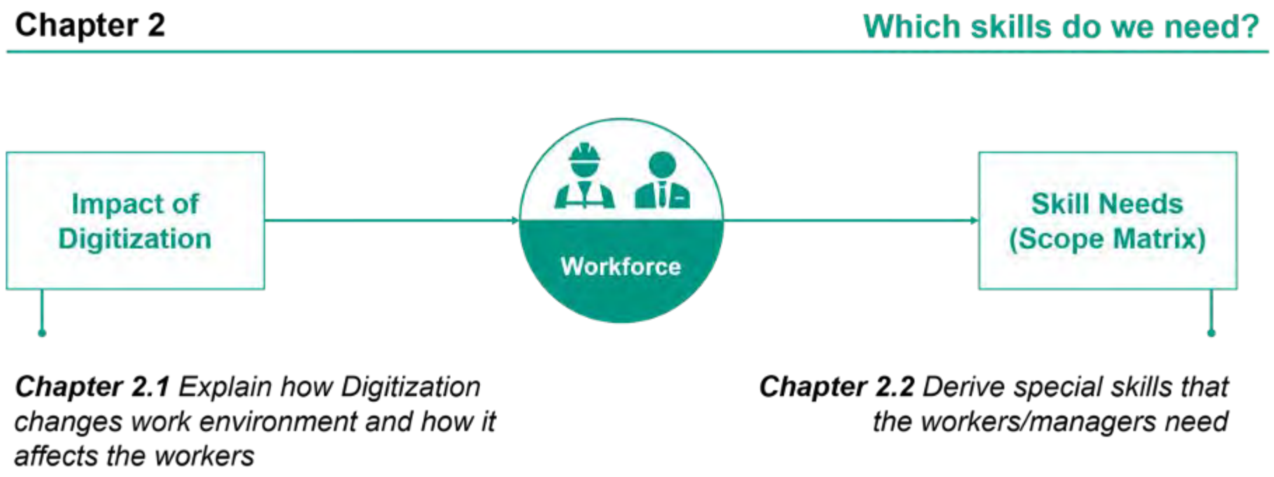


Figure 2: Structure of Chapter 2

2.1 Overview of the Impacts of Digitization on the Workforce

Digitalisation has a profound impact on how people live and work, and the corresponding technologies promoted a new round of industrial revolution. In the context of Industrie 4.0, the requirements for the workforce have also changed dramatically. Under Industrie 4.0, companies covering the segments and links throughout the manufacturing supply chain achieve not only the interconnection between different products and customers but also all-level integration. The data processed by the system can assist manufacturing, while a transparent, personalised and self-optimised Intelligent Manufacturing system can improve the utilisation efficiency of resources and energy. Driven by technology such as Artificial Intelligence (AI), Industrial Big Data, IoT, Cloud Services etc., specific work changes take place at the same time. Examples include remote office, intelligent decision, visual management, etc. According to Ittermann et al. (2015), three different fields of action regarding the work in the Industrie 4.0 environment are affected by smart manufacturing trends. These fields focus on employment, work organisation and environment, as well as qualification [Ittermann et al. (2015)]. Moreover, the introduction of new business models will shift parts of the value creation. Job profiles and whole occupation groups come under pressure to change. At the same time, this development enables new opportunities for companies and individuals. [Allianz Industrie 4.0 Baden-Württemberg (2017)]

Employment

Regarding the long-term development in employment, the key question is whether overall employment is going to grow, stabilise or decrease through the implementation of Industrie 4.0 [Ittermann et al. (2015)]. It is predicted, according to some sources, that industrial jobs will increase by 390,000 through Industrie 4.0 from 2015 to 2025, while other institutions predict a loss of more than 50% of all jobs in Germany [Pfeiffer & Surphan (2015)]. A detailed and quantifiable impact is thus not reliably predictable, since different researchers come to totally different results, based on different assumptions. However, it can be concluded that most industrial companies still believe that human work will be of central importance in the upcoming years. [Spath et al. (2013)]. It is also clear, that the increasing digitalisation in the industrial production will substitute some work positions on the one hand while creating new jobs on the other. This also illustrates how important it is to equip the affected workforce with the right skills for the digital age.

To give an example, two studies have illustrated, which jobs are most affected by the technological changes in Germany [IAB (2015)]. In these studies, the so-called substitution potentials were calculated for different occupations. It's defined as the share of job activities, that could be done by a machine or computer instead of a human worker. Figure 3 gives an overview of the results. As shown, jobs in the production/manufacturing sector are most affected by the technological changes in terms of the substitution effects. This further accentuates the importance of the workforce in the manufacturing sector to develop the right skills so that their skills don't become obsolete.

The use of digitalisation, automation and interconnected machines tend to shift workloads from human workers to machines, which are noticeable in the world's factories today [Allianz Industrie 4.0 Baden-Württemberg (2017)]. Machines are known to be more efficient in executing repetitive tasks. And with the help of machine learning, for example, robots will be able to perform even more complex tasks in the future. This potentially shifts the workers' role from work execution to process controlling and supervising. Therefore, qualified workers, against the current trend, are those who are equipped with the required skills.

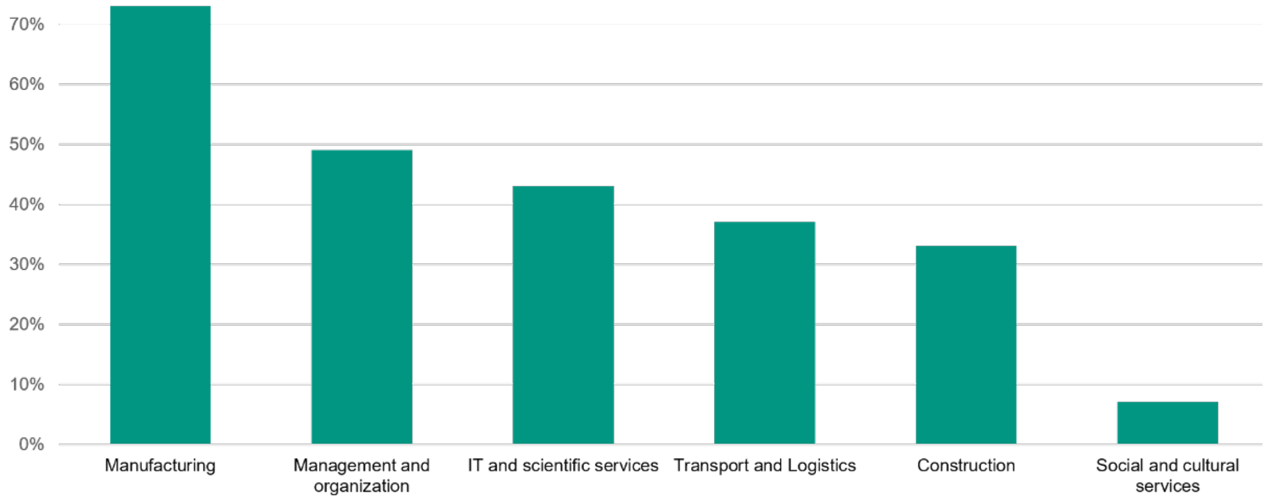


Figure 3: Substitution potential by occupation group in Germany

Work organisation and environment

The above-mentioned shift of workload from human workers to machines highlights the importance of coordination between humans and intelligent machines, so-called human-machine-interaction. Special skills are necessary in order to handle the complex interaction [Ittermann et al. (2015)]. Again, Industrie 4.0 is meant to combine the advantages of humans and machines. Thus, great importance is attached to human-machine interaction in order to exploit their full potential. Thus, it is important to clarify the division of roles for the two [Allianz Industrie 4.0 Baden-Württemberg (2017)].

Regarding the use of autonomous interacting, highly automated, and interconnected objects on the shop floor, it is important to assure workers action and self-confidence in critical and unpredictable situations [Allianz Industrie 4.0 Baden-Württemberg (2017)]. In this context, Pfeiffer & Suphan (2015) highlight the importance of experienced workers on the shop floor, who can bring a wide-ranging process knowledge and deep understanding of complex relationships and interdependencies in production systems and processes. Experience, in order to handle the unpredictable, gains even more importance in the complex and highly automated work environment. However, other authors also state, that in the future, even these complex tasks may be done by machine, e.g. with the help of machine learning algorithms [Brynjolfson & McAfee (2014)].

The workers in future factories not only have to be able to handle unpredictable situations, but also must continuously adapt to a flexible and quick-changing work environment. The German Academy of Science and Engineering (acatech) describes the vision of a smart factory and thus a full implementation of Industrie 4.0 as "adoptability". Adoptability in this context means that data from sensors and actuators on the shop floor is used to create a digital shadow of the real world. This shadow is then used to predict future scenarios. An "adoptable" manufacturing plant is able to autonomously react to this prediction and to adjust different parameters in order to optimise production processes. The resulting flexibility and quick-changing environment are not easy to handle and set high standards regarding the workforce [acatech (2016)].

Regarding a company's organisational structure, different characteristics become of central importance. Swarm organisation and self-organised teams are required in an Industrie 4.0 environment. For these highly flexible elements in a situational-working mode acting groups, cross-functional and cross-departmental skills are necessary [Ittermann et al. (2015)]. While new employees or young professionals are already used to those agile work methods, this new work culture is still unknown to many traditional companies and their old employees.

Hence, they must be guided on their way to this new work culture [Bosch (2018)]. Moreover, a distinct division of labour is shaping the new system and requires a highly specialised workforce for solving complex problems [Ittermann et al. (2015)].

Another focus on work organisation is about leadership. The Industrie 4.0 work environment can be characterised by the VUCA principles- (V)olatility, (U)ncertainty, (C)omplexity, and (A)mbiguity. It affects decision-making as well as leadership. Coupled with other challenges such as insecure workers, changing work organisation and content, as well as the implementation of new software and assistance systems, an even stronger leadership and managerial role is required for a resulting changing corporate. Moreover, demographical changes, value changes and increasing globalisation further add to the complexity. [Allianz Industrie 4.0 Baden-Württemberg (2017)]

Qualification

Although the employment prospect (in Germany) is not totally clear in literature, all studies commonly agree on the fact that high qualification will play an important role in the future and that digitalisation of the industrial production is closely linked to a shift in the workforce's competencies and qualification requirements [Ittermann et al. (2015)].

In general, two development paths of qualification development can be distinguished: upgrading and polarisation of qualifications. Upgrading of qualifications means the enrichment of jobs at all levels through information technology. As processes are affected by the increasing complexity, every worker needs to be equipped with knowledge in the overall process. Upgrading of qualifications results in an overall better-trained workforce at all levels. On the other hand, polarisation of qualifications means that simple work contents will remain in industrial production and activities that require a high level of qualification will gain more importance. The substitution of human work will mainly take place in activities that require mid-qualification such as assembly or the control of single processes. Polarisation of qualifications results in the shift of qualifications to the two poles of low- and high-qualification [Ittermann et al. (2015)]. No matter which path is more realistic, those new competency and qualification requirements involve appropriate training for the affected workforce and high qualification will be of central importance.

The scientific board of Plattform Industrie 4.0 describes the impacts of Industrie 4.0 on the workforce as follows: New opportunities regarding a human-oriented work concept emerge. Especially self-organisation and autonomy as well as age-appropriate work design play an important role in this context. Industrie 4.0 has the potential to help workers expand their range of tasks, gain access to know-how, and thus enhance capability (qualification). Through access to intelligent assistance and learning systems, their learning productivity increases as well, which also makes it possible to integrate low-qualified workers. In order to realise the full potential of Industrie 4.0, it is important to encourage workers to make use of the respective new technologies and concepts. [Plattform Industrie 4.0 (2017)]

The focus of this White Paper is set on the action field of workforce qualification.

2.2 Skill Needs and Workers Most Affected

The impacts described in Chapter 2.1 result in a specific set of competence with which workforce of the future should be equipped. Current literature has shown, different competence profiles a company's workforce should develop in order to handle a complex Industrie 4.0 work environment are presented. Although differing in detail, a common agreement seems to have been reached on core skills important for the future of work, regardless of their geographical application (in Germany or China).

The following is a list of competence profiles consolidated from the literature and expert inputs:

Competence profile by MIIT (2018)

Mechanical: R&D and design of mechanical systems and components, Process design for mechanical systems and components, Manufacturing equipment application and operation, System and equipment maintenance and repair

Electronic: R&D and design of electronic systems and components, Process design for electronic systems and components, Manufacturing equipment application and operations, System and equipment maintenance and repair

Automation: Control system R&D design, Control system programming, Control system debugging, AI development and application, Machine vision development, Machine vision application

Telecommunication: Planning and design of network architecture, Network system debugging, Network system operation and maintenance

Industrial software: System architecture of industrial software, System integration of industrial software, User-specific development of industrial software, Industrial software application and operation, Application of information security technology, Industrial Big Data development and application, Industrial Big Data analysis, Human-computer interaction development and application

System engineering: Smart Factory System Architecture, Intelligent factory system integration and operation, Intelligent factory system assessment, Production line planning and design, Production system management operation, Intelligent warehousing and logistics planning and design, Warehousing and logistics management

Management: Discover new user needs, Organisational structure and adjustment, Resource allocation and mobility, Ability to use new business models, Ability to expand through online and offline diversification, Ability to use new technology to accurately target positioning

Soft skills: Self-learning, Knowledge self-renewal, Adaptability, Communication, Teamwork, Project management

Competence profile by Allianz Industrie 4.0 Baden-Württemberg (2017)

IT skills: Production and corresponding services, Acquisition and processing of huge amounts of data

Process skills: Understand physical and digital processes, Real-time synchronisation

Technical skills: Mechanical, Mechatronics, Electrical engineering, Microtechnology, IT and its integration

Soft skills: Interdisciplinary communication, Cooperation and organisation in teams and networks, Handling of permanent changes and renewals

Leadership: Transformation and change, Vision and mission orientation, Cross-functional and cross-national coordination, Relationship and network management, Coaching, Decision-making under uncertainty, Openness to experiments

Competence profile by Dworschak B., & Zaiser, H. (2016)

Professional skills: Cloud computing, Server and storage technologies, Software, databases, IT security and data protection, Network infrastructure and connection technology, Network protocols/IP addressing, Software-supported control technology, System development/test, System integration, System implementation, System architecture, System optimisation, Production technology, Production plant, Lightweight robotics, Generative processes, 3D printing

Methodical skills: Media and information, (Big) data, Physical-digital processes

Social skills: Communication, Cooperation, Teamwork, Industrie 4.0 as a socio-technical system

Personal skills: Interdisciplinary thinking, Cross-departmental thinking, Structured nature, Systematical thinking, Self-management, Self-guided learning, Self-motivation, Creativity, Decision-making power

Competence profile by Plattform Industrie 4.0 (2018)

Information technology: Cloud computing, Databases, Infrastructure and integration, Security, server and storage technologies, Network protocols/IP addressing, Network technology, virtualisation, Software development, Application development

Interdisciplinary skills: Lean, Media, Project management, Process management, Self-guided learning, Self-management, Systematic thinking, Knowledge management

Electronics: Embedded systems, Identification systems, Sensors/actuators, Robotics

Business administration: Data analytics, Business model development and planning

Mechanical engineering: Product Lifecycle Management (PLM) software

Competence profile by acatech (2016)

Technology-/Data-oriented: Interdisciplinary thinking and acting, Handling of complex work content, Capable of communication with machines, Problem solving and optimisation

Process-/Customer-oriented: Process knowledge, Participation in innovation processes, Coordination of (work) processes, Service-orientation

Infrastructure-/Organisation-oriented: Leadership, Self-responsible decision-making, Social & communication

Consolidated competence profile

Based on the literature review on the competence profiles from both Germany and China, it can be concluded that the skill needs do not differ between the two countries for an Industrie 4.0 environment. Nevertheless, it is important to note that the existing skill foundation/baseline for Industrie 4.0 differs between China and Germany. Especially when it comes to the workers on the shop floor, German workforce appears more experienced, informed and better equipped on skills in the subject of smart manufacturing. Thus, differentiated training methods and mechanisms are needed for the two systems. This topic will be discussed in Chapter 4 in more detail.

Based on a literature review and inputs from the experts, the AGU EG Training 4.0 developed a consolidated competence profile. In terms of skills, it is distinguished among the dimensions as mechanical, electronic, automation, IT, industrial software, systems engineering and management, interdisciplinary competencies, leadership as well as soft skills.

As not all personnel are affected by the same skill needs, it is important to distinguish the types of workers into engineers, workers, managers and functional workers. Each category can be divided into several levels. The full matrix is depicted in Figure 4.

Skills	Engineers				Workers		Management			Business	
	System level	Subsystem level	Equipment level	Key technology level	Operational level	Maintenance level	Decision-making level	Executive level	Implementation level	Marketing	Sales
Mechanical											
Electronic											
Automation											
IT											
Industrial software											
Systems engineering											
Management											
Interdisciplinary											
Leadership											
Soft skills											

Figure 4: Workforce and skills classification matrix

Each skill field is further elaborated into sub-skills to study which specific skills are required in Industrie 4.0. The outcome is a matrix of personnel skills. An example is shown in Figure 5 for the skill fields of mechanical and electronic skills.

Skills		Workforce						
		Engineers				Workers		...
		System level	Subsystem level	Equipment level	Key technology level	Operators	Maintainers	...
Mechanical	R&D design skills of mechanical systems and components		◔	◑ - ●				...
	Process design skills for mechanical systems and components	◔	◔	◑ - ●	◔			...
	Manufacturing equipment application and operation skills	◔	◔	◔		●	◔	...
	System and equipment maintenance and repair skills			◔		◔	●	...
Electronic	R&D design skills of electronic and electrical systems and components		◔	◑ - ●				...
	Process design skills for electrical and electronic systems and components	◔	◔	◑ - ●	◔			...
	Manufacturing equipment application and operation skills	◔	◔	◔		●	◔	...
	System and equipment maintenance and repair skills			◔		◔	●	...
...	...	...	...	...	...	...	...	...

Figure 5: Personnel skills matrix

In general, there is a common agreement that Industrie 4.0 changes employment, work organisation and environment requiring a specific set of skills There are no differences regarding skill needs in Germany and China, but a different skill foundation/baseline points to a differentiated approach on skill development in the respective countries.

A large variety of courses at universities and colleges seem to indicate that the target group of the students is going to be well prepared with necessary Industrie 4.0 skills for future work. But the direct challenges for both the industry and workers currently rest on the shop floor — finding the right workers who are able to execute the tasks. Therefore, a systematic approach and guidance for the skill development of the existing workforce would be helpful and necessary against this background.

3 Maturity Models

Based on the skill needs described in the previous chapter, systematic methods to assess a company's maturity on Industrie 4.0 are described in this chapter. For this purpose, existing German and Chinese maturity indices are presented and supported by the description of the respective exemplary use cases. At the end of the chapter, existing maturity models are assessed based on their application in the field of workforce assessment (according to the defined skill needs in Chapter 2). Figure 6 shows the structure of this chapter.

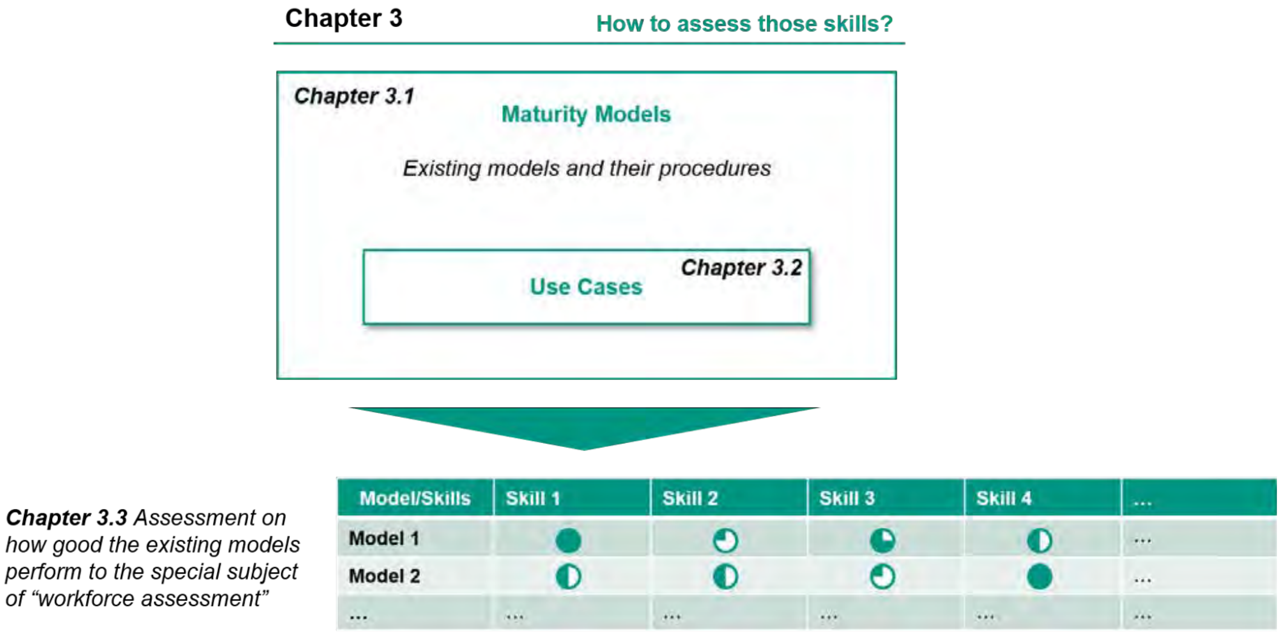


Figure 6: Structure of Chapter 3

3.1 Existing Maturity Models

acatech – Industrie 4.0 Maturity Index [Schuh et al. (2017)]

Concept

The model's approach is based on a succession of maturity stages, i.e. value-based development levels that help companies navigate their way through every stage in the transformation, from the basic requirements for Industrie 4.0 to full implementation. The six development stages a company can achieve in the model are Computerisation, Connectivity, Visibility, Transparency, Predictability and Adaptability. Today, companies are still confronting the challenge of creating the basic conditions for Industrie 4.0. Accordingly, the development path begins with digitalisation. Digitalisation does not itself form part of Industrie 4.0. Instead, Computerisation and Connectivity lay the foundation for Industrie 4.0. These two initial stages are followed by four further stages in which the skills required for Industrie 4.0 are developed progressively. They are described in the following.

The first stage in the development path is **Computerisation**, since this provides the basis for digitalisation. In this stage, different information technologies are used in isolation from each other within the company. Computerisation is already well advanced in most companies and is primarily used to perform repetitive tasks more efficiently.

In the **Connectivity** stage, the isolated deployment of information technology is replaced by connected components. Widely used business applications are all connected to each other and mirror the company's core business processes. Parts of the Operational Technology (OT) systems provide connectivity and interoperability, but full integration of the IT and OT layers has been not fully achieved.

Sensors enable processes to be captured from the beginning to the end with large numbers of data points. The falling prices of the sensor, microchip and network technology mean that real-time information of events and states can now be recorded in real-time throughout the entire company, rather than just in the limited areas such as manufacturing cells, as was the former case. This makes it possible to keep an up-to-date digital model of factories at all times in the Visibility stage. This digital shadow can help to show what is happening in the company at any given moment so that management decisions can be based on real-time data.

The next stage is for the company to understand why something is happening and use this understanding to produce knowledge by means of root cause analysis. We refer to this as the **Transparency** stage. To identify and interpret interactions in the digital shadow, the captured data must be analysed with the application of engineering knowledge. The semantic linking and aggregation of data to create information and the corresponding contextualisation provide the process knowledge required to support complex and quick decision-making.

Building on the transparency stage, the next development stage is the **Predictive** stage. Once a company has reached this stage, the company is able to simulate different future scenarios and identify the most likely ones. This involves projecting the digital shadow into the future in order to depict a variety of scenarios that can then be assessed in terms of how likely they are to occur. As a result, companies can anticipate future developments so that they can make decisions and implement appropriate measures in good time.

Predictive capacity is a fundamental requirement for automated actions and decision making. Continuous **Adaptation** allows a company to delegate certain decisions to IT systems so that it can adapt to a changing business environment as quickly as possible.

The different development stages are summarised in the following figure.

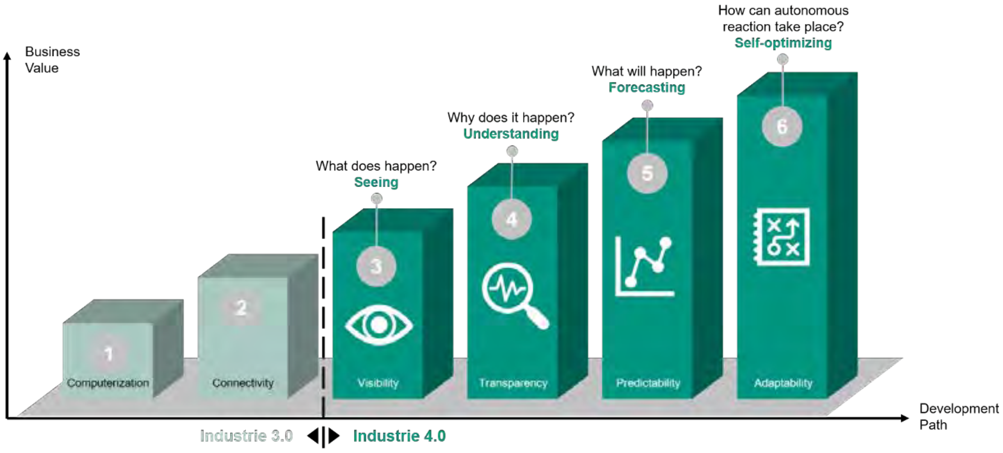


Figure 7: acatech – six value-based development stages

Assessment dimensions

In the acatech Industrie 4.0 Maturity Index, a company's different functional areas are investigated separately. For each functional area, four structural areas are assessed with the help of characterising principles and capabilities. Since the structural areas represent the model's assessment dimensions, the focus is set on them in the following. Figure 8 shows how different elements are interconnected with each other.

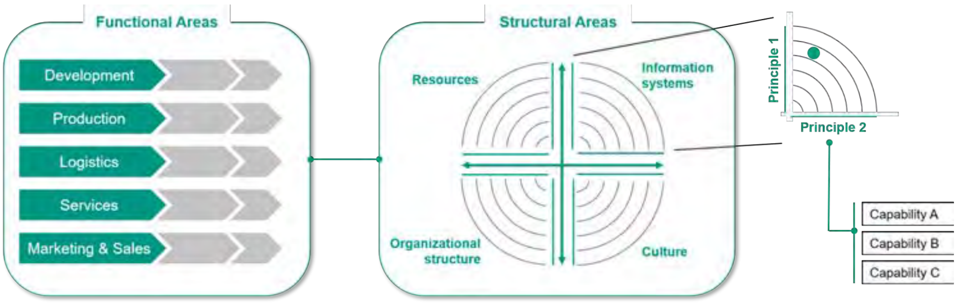


Figure 8: acatech – overview assessment dimensions and process

The acatech Industrie 4.0 Maturity Index breaks a company's structure down into the four structural areas: Resources, Information systems, Culture and Organisational structure. Each structural area has two principles as two axes that serve as a guide for continuous development. Each principle comprises several capabilities that must be successively developed for each value-based development stage. The extent to which these capabilities are realised determines the maturity stage of the relevant principle. In Figure 9, the assessments of the structural areas are depicted by the four green dots. In the following, each structural area and corresponding principles are described more precisely.

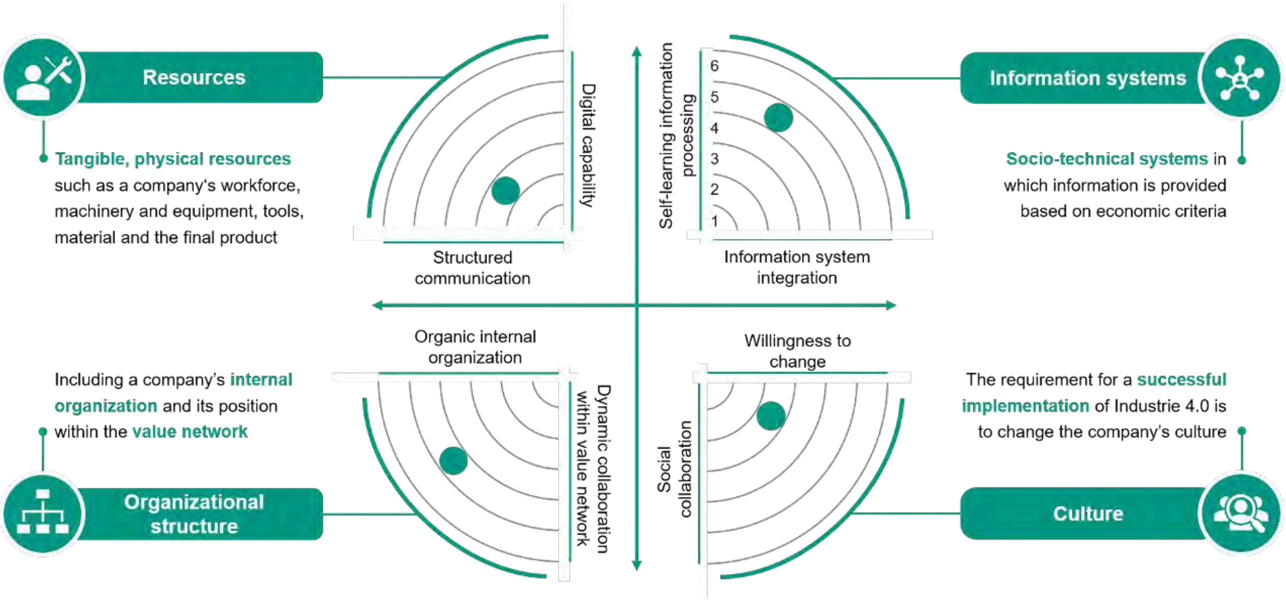


Figure 9: Four assessment dimensions

In the acatech Industrie 4.0 Maturity Index, **Resources** refer to tangible, physical resources. These include a company's workforce (human resources), machinery and equipment, tools, materials and the end products. In addition to fulfilling their particular function, companies should try to ensure that their resources have an interface between the physical and digital world. This creates an information viewpoint in the digital world (the digital shadow) which facilitates the learning process required to increase the company's agility. The following two principles are based on the requirements concerning resources in the Industrie 4.0 environment: Firstly, the resources must possess the necessary capabilities to function in an information-based manner. Employees should therefore be able to identify data sources and potential processing techniques. In this context, information refers to data that is interpreted in order to support decision-making. The resulting principle of **Digital capability** facilitates an information-driven way of working that creates an awareness of the real situation on the ground.

Secondly, a clear overall picture only emerges once different pieces of information are put together. This requires appropriate interfacing, as well as a consensus regarding the purpose of the communication. Accordingly, the principle of **Structured communication** describes the technical approach to communication media for employees and the interfaces between both people and machines as well as among different machines.

Companies will be unable to achieve the desired agility if they simply introduce digital technologies without addressing their **Culture**. Instead, they must begin by deciding how they want their company to do things in the future and which skills their employees should possess.

Moreover, **Willingness to change** should not be confined to situations where changes are already being implemented. Importantly, it also means that people should study their environment and the corporate environment with open eyes and initiate relevant actions themselves.

An environment characterised by trust and social relationships provides the basis for open, knowledge sharing among employees. Consequently, the second principle of culture, **Social collaboration**, helps to accelerate knowledge sharing within the company. See Figure 10 for an overview of the described principles and the corresponding capabilities.

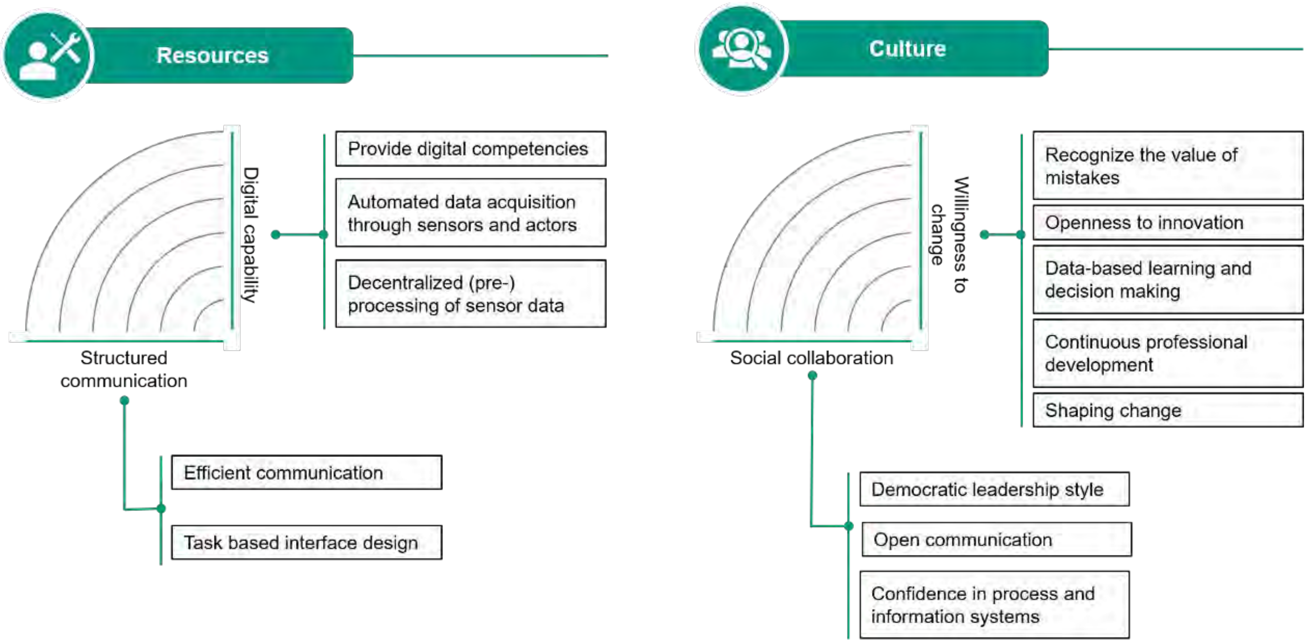


Figure 10: Principles and capabilities - resources and culture

Information systems are socio-technical systems in which information is provided based on economic criteria by both people and information and communication technology. They prepare, process, store and transfer data and information. However, many manufacturers are still failing to use data and information to support their decision-making. There are two reasons for this:

Firstly, the captured data is not processed into information and, because it is not delivered in a suitable form, employees cannot use it to support their work. As a result, the first principle of information systems is defined as: **data should be prepared and processed in a manner that supports decision-making.**

Secondly, centralised data is not used throughout the different parts of the company. Regarding this problem, the second principle requires **integration in order to enhance data use and increase agility.**

Whilst the transformation into a learning, agile company is enabled by the technologies described above, its implementation requires the right organisational structure. **Organisational structure** establishes mandatory rules that organise collaboration both within and outside the company.

The structural area **Organisational structure** is spanned by the two principles of **Organic internal organisation** and **Dynamic collaboration within the value network.** It, therefore, describes the organisation from both an internal and an external perspective. See Figure 11 for an overview of the described principles and the corresponding capabilities.

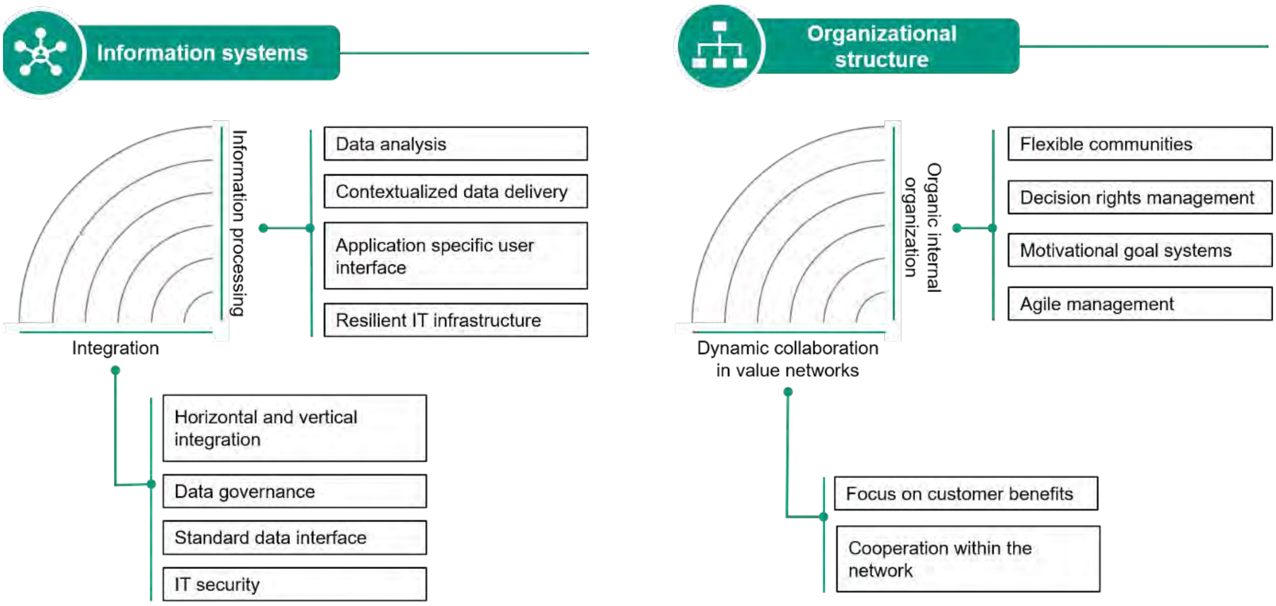


Figure 11: Principles and capabilities - information systems and organisational structure

VDMA - Industrie 4.0 Readiness Check [Lichtblau et. al (2015)]

Concept

The readiness defines a set of criteria through which companies are classified into six levels and three types according to their Industrie 4.0 maturity stages. This classification is based on the following six key dimensions of Industrie 4.0: Strategy and organisation, Smart factory, Smart operations, Smart products, Data-driven services and Employees. Each of these six dimensions is further delineated into fields, which in turn are operationalised with appropriate indicators.

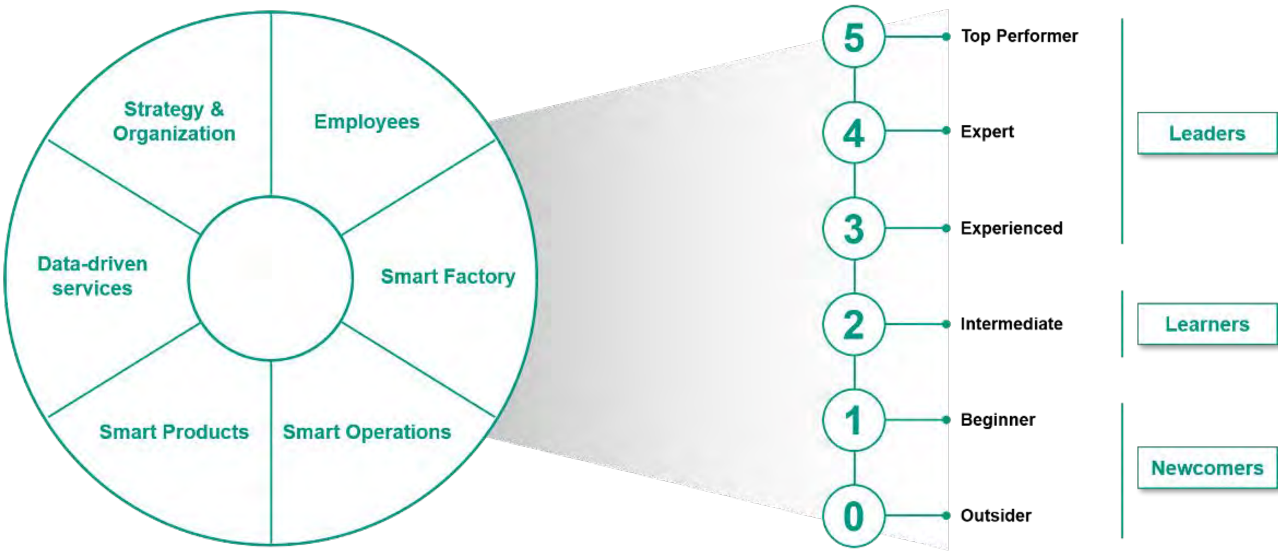


Figure 12: Assessment dimensions and maturity stages

The different levels are described as follows:
A company at **level 0** does not meet any of the requirements for Industrie 4.0. Level 0 is also automatically assigned to those companies that assume Industrie 4.0 is either unknown or irrelevant to them.

A company at **level 1** is involved in Industrie 4.0 through pilot initiatives in various departments and investments in a single area. Only a few of the production processes are supported by the IT system, and the existing equipment infrastructure only partially realises future integration and communications requirements.

An intermediate-level company (**level 2**) incorporates Industrie 4.0 into its strategic orientation. It is developing a strategy to implement Industrie 4.0 and use the appropriate indicators to measure the implementation status.

A company at **level 3** has formulated an Industrie 4.0 strategy. It is making Industrie 4.0-related investments in multiple areas and promoting the introduction of Industrie 4.0 through department-oriented innovation management.

A company at **level 4** is already using an Industrie 4.0 strategy and monitoring it with appropriate indicators. Investments are being made in nearly all relevant areas, and the process is supported by interdepartmental innovation management.

A company at **level 5** has already implemented its Industrie 4.0 strategy and regularly monitors the implementation status of other projects. This is supported by investments throughout the company. The company has established company-wide innovation management. It has implemented comprehensive IT system support in its production and automatically collects all the relevant data.

The six readiness levels can further be grouped into three types of companies: Newcomers, Learners, and Leaders. This grouping also makes it easier to conclude progress and conditions relating to Industrie 4.0 and identify specific actions based on the level of implementation.

Newcomers (level 0 and 1): Newcomers include those companies that have done either nothing or very little to deal with Industrie 4.0 and are therefore assigned to levels 0 or 1 in the readiness measurement.

Learners (level 2): Learners is the name for companies that are at level 2 and have thus already taken the first step in implementing Industrie 4.0.

Leaders (level 3 and up): Leaders include companies that have reached at least level 3 in the readiness model. They are already well on the way to implementing Industrie 4.0 and are therefore far ahead of most companies in the German mechanical engineering industry. They represent the benchmark group.

Assessment dimensions
The six assessment dimensions can be further broken down into overall 18 associated fields of Industrie 4.0. The following figure gives an overview.

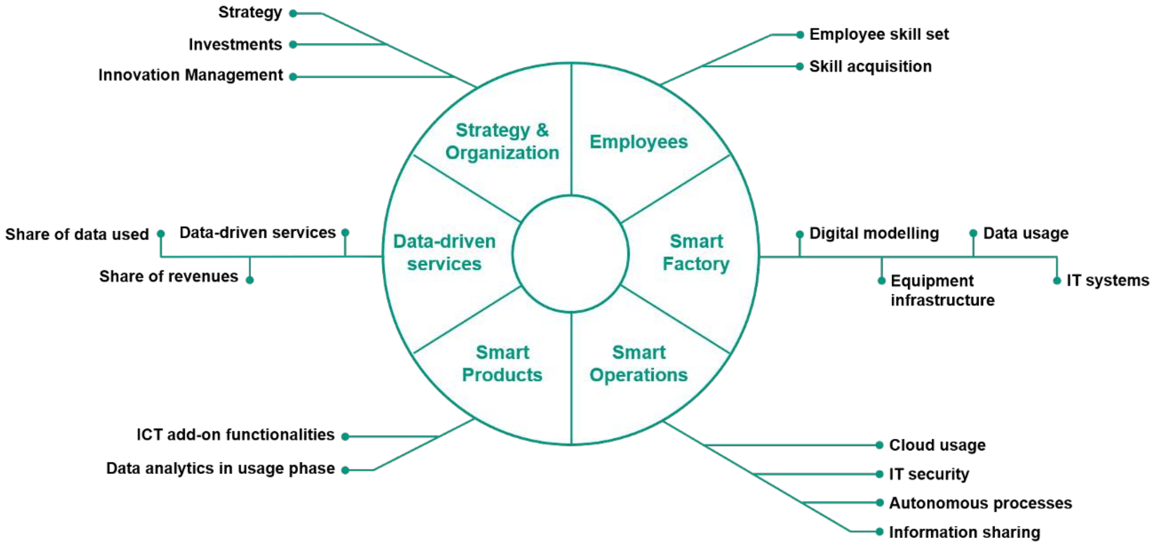


Figure 13: Assessment dimensions

VDMA, DiK, wbk – Guideline Industrie 4.0 [VDMA, DiK, wbk (2016)]

Concept

The Guideline Industrie 4.0 is a far-reaching approach of guiding principles for the implementation of Industrie 4.0 in SMEs. It aims to provide the companies with a tool for developing their own Industrie 4.0 business models. For this reason, the guideline is divided into five different sections: preparation, phase of analysis and creativity, evaluation and implementation of the developed business models. Regarding the subject of maturity models, the focus in this White Paper is set on the evaluation phase.

The objective of the evaluation phase is the assessment of the previously elaborated concepts for business models. For this purpose, the participants classify the concepts for business models elaborated in a workshop according to their market potential or to their potential for production respectively as well as according to the required resources for implementation. The aim is to identify business models with high potential and a low resource input or a valuable utilisation of the company's strengths.

For this purpose, the guideline provides the Toolbox Industrie 4.0 to assess a company's current state and support in the generation of new ideas. The toolbox is separated into two dimensions: A company's production and a company's products. Each dimension can be further broken down into several criteria. Figure 14 provides an overview of the Toolbox Industrie 4.0.

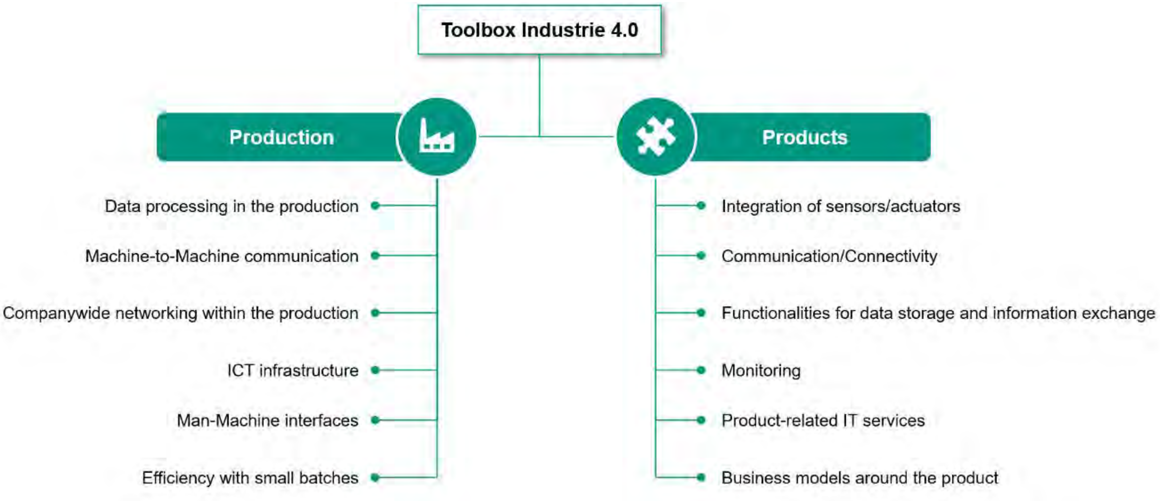


Figure 14: Assessment criteria of the Toolbox Industrie 4.0

Assessment dimensions

The different assessment dimensions can be described as follows:

The **Integration of sensors and actuators,** as well as computing capacities in physical objects, is one central idea of Industrie 4.0 or that is to say of cyber-physical systems. Suitable **Communication** interfaces give rise to new applications that can be provided physically decoupled and that benefit from improved availability of the collected data. Products can differ in terms of differently designed functions for Data storage and information exchange. The spectrum includes simple barcodes, rewritable data storage devices as well as information presentation and exchange as an integral product component. The wide application range of **Monitoring** represents a key aspect of many Industrie 4.0 applications. The often-discussed **Product-related IT services** in the context of Industrie 4.0 can be physically decoupled from the product (for example in online portals for presenting lists of spare parts) or they can be directly linked to the product. Innovative technologies allow the development of new **Business models.**

The data processing for various applications is of essential importance to achieve Industrie 4.0 in production. **Data processing in production** can be used for not only simple documentation but also objectives aiming at process monitoring, autonomous process planning and control. Interfaces for automated data exchange between machines, namely **Machine-to-machine communication** form the basis for numerous Industrie 4.0 applications. An improvement on the **Companywide networking within the production** brings synergies and avoids duplication of work. **Information and communication technology (ICT) infrastructure** determines the possibilities of implementing innovative applications and potential improvements for technical and organisational processes. With the increasing complexity of production systems, **Human-machine interfaces** move into focus. In industrial reality, the starting point is often represented by local display units that do not have user-friendly operating concepts. New operating concepts such as mobile tablets or data glasses that conveniently provide the right information at the right place have great potentials for simplifying the work and increasing production efficiency. The trend towards personalised production and small-batches ordering leads to rising complexity of production processes. Reaching higher **Efficiency with small batches** is thus becoming a decisive competitive factor. The toolbox identifies five different development stages of Industrie 4.0. The description and specification of each criterion vary within those five periods. The most fitting one can be chosen by the evaluator. Figure 15 gives an example on the assessment of the criteria “Companywide networking within the production” and “Man-machine interfaces”.

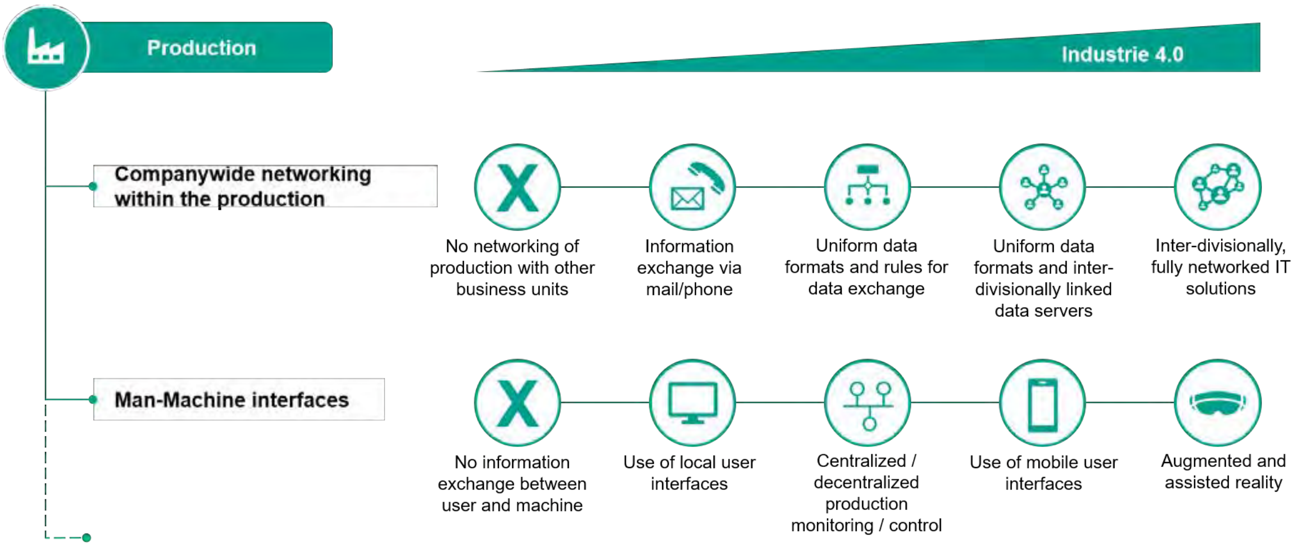


Figure 15: Exemplary assessment

DiK – Toolbox Workforce Management 4.0 [Galaske et al. (2018)]

The Toolbox Workforce Management 4.0 (WM4.0) is following a similar approach as the formerly mentioned Toolbox Industrie 4.0. But other than assessing the company as a whole, the Toolbox WM4.0 focuses on human factors and provides a structured method to assess the Industrie 4.0-readiness of a company regarding the workforce competencies and work conditions. Similar to the Toolbox Industrie 4.0 it is structured in a matrix with application fields as vertical elements and development stages as horizontal elements. The application fields of the Toolbox WM4.0 are organised in four categories: 1) hard skills, 2) soft skills, 3) usability & operability, and 4) Work environment Figure 16 gives an overview of the different categories with corresponding application fields. Each category is described in detail in the following. [Galaske et al. (2018)]

The category of **Hard skills** represents all the workforce capabilities that can be acquired through formal education and work experience. It can be broken down into the application fields of IT knowledge, business process knowledge and manufacturing knowledge. The **Soft skills** sector shows all the qualifications of workers regarding their personal characteristics and the behaviour in interpersonal relationships. Its application fields are personal competence, social competence and methodical competence. The category **Usability & Operability** considers the application of information-based assistance systems in manufacturing in order to support workers in fulfilling their task and decision-making. It can be further broken down into the application fields of assistance systems, human-machine-interaction and decision support. The last category **Work environment** takes into account all the general conditions regarding security, safety and satisfaction of the worker on the shop floor. This includes the application fields of security & privacy, organisational flexibility and the automation degree of documentation. [Galaske et al. (2018)]

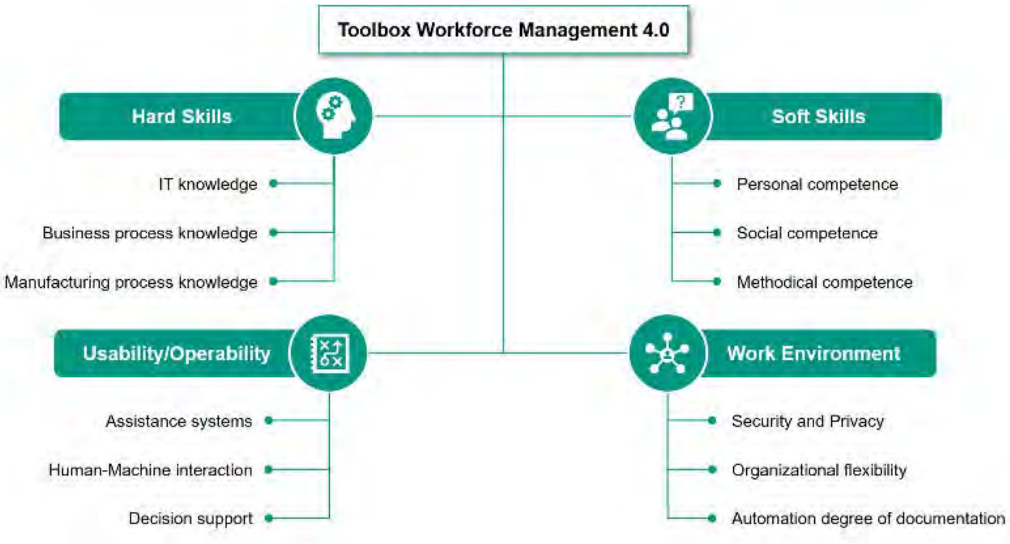


Figure 16: Assessment criteria for the Toolbox Workforce Management 4.0

Figure 17 shows an example of how the different application fields are brought together with a five-staged assessment of the corresponding Industrie 4.0 maturity in a matrix structure. The toolbox can also be used to define a company's targets regarding the workforce's Industrie 4.0 maturity.

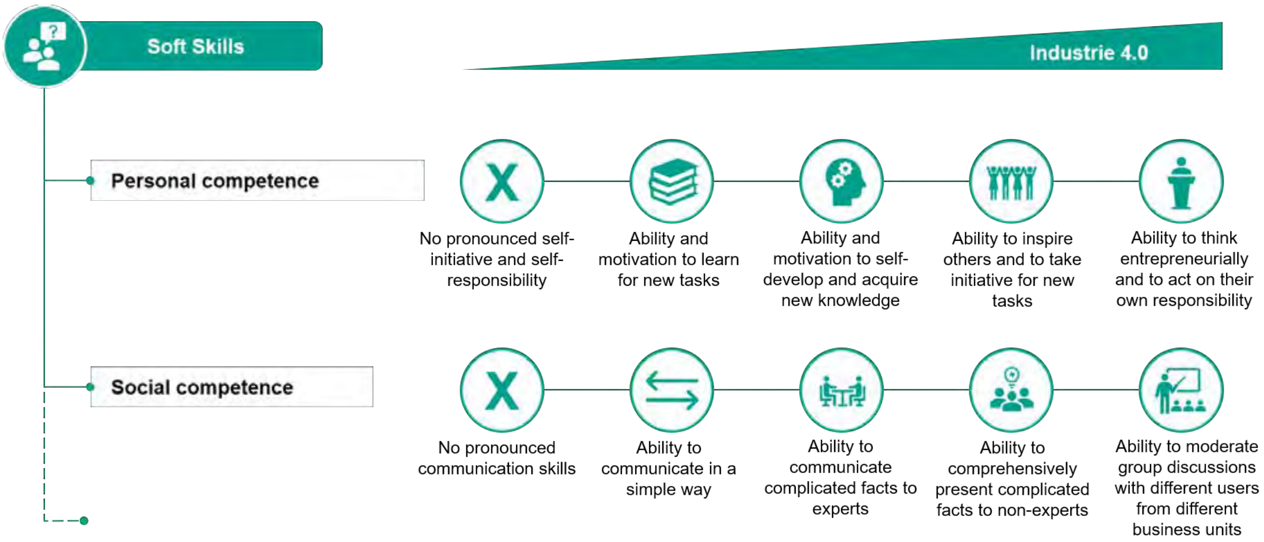


Figure 17: Exemplary assessment

Singapore EDB & TÜV SÜD – Smart Industry Readiness Index [Singapore EDB &TÜV Süd (2017)]

The Smart Industry Readiness Index, jointly published by the Singapore Economic Development Board and TÜV SÜD, serves as a tool for all companies regardless of size and industry to assess the readiness of their Industrie 4.0 core elements. For this purpose, the overall 16 assessment dimensions are structured into eight pillars and three building blocks under three layers. Figure 18 gives an overview of the structure of the assessment dimensions. [Singapore EDB & TÜV Süd (2017)]

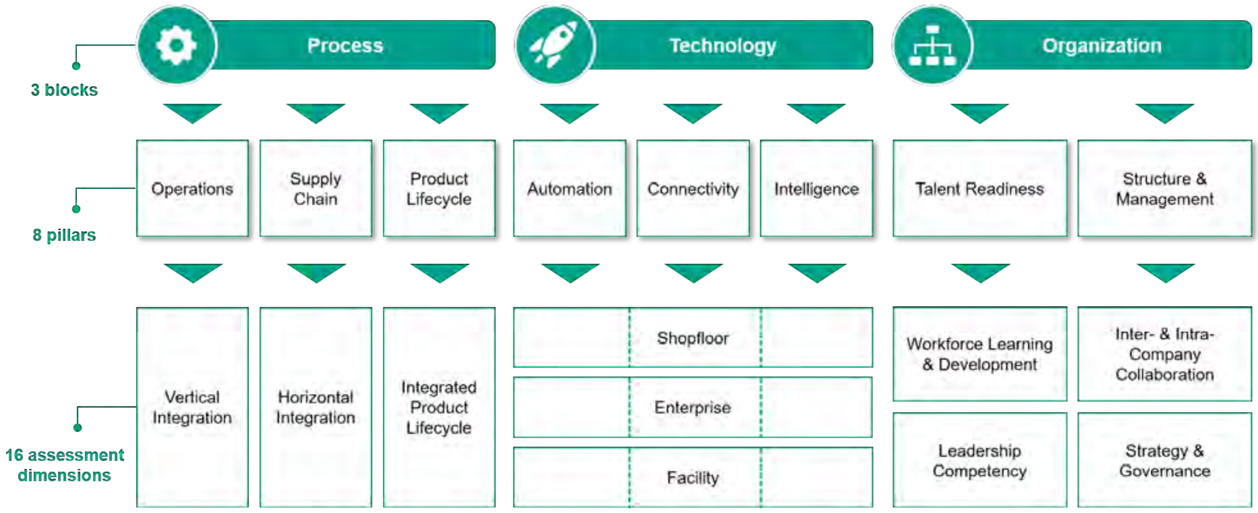
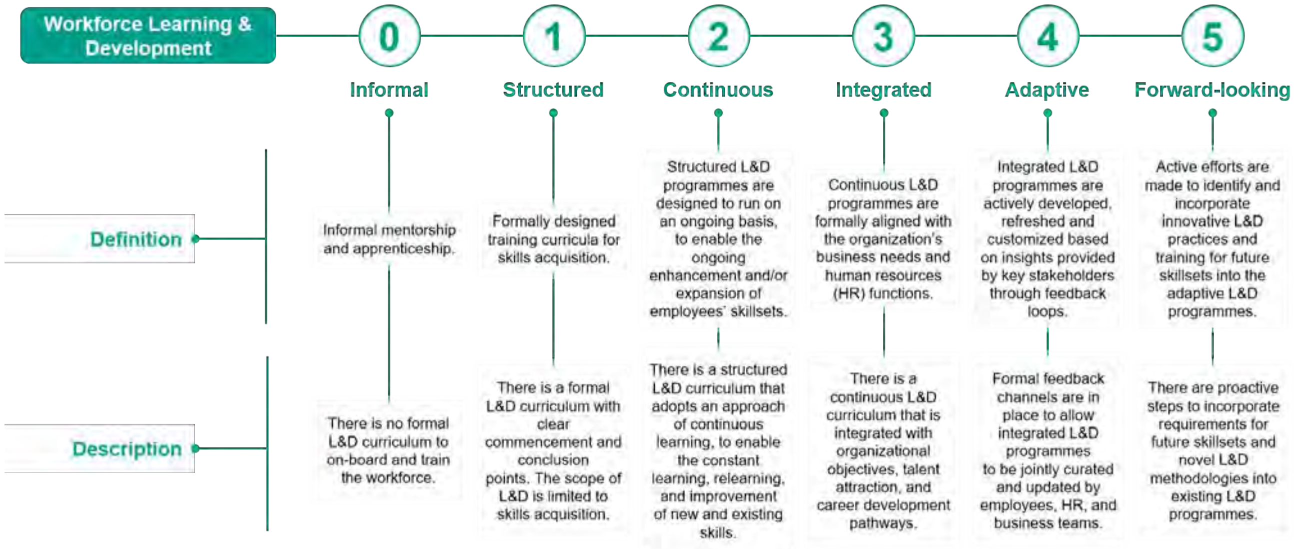


Figure 18: Structure of the Smart Industry Readiness Index

In order to assess a company's readiness, the index provides a tool that defines six stages of maturity, each of which is composed of 16 assessment dimensions. Thereby the approach also follows a matrix-based assessment structure similar to the previous two toolboxes. An example of the dimension—Workforce Learning & Development is given in Figure 19. [Singapore EDB & TÜV Süd (2017)]

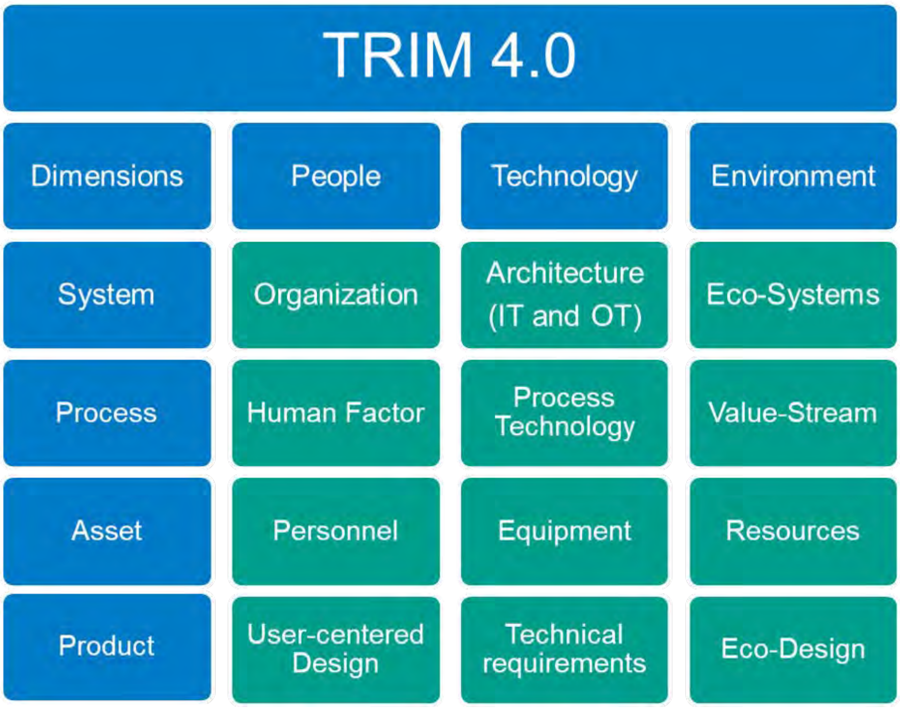


Workforce Learning & Development	0 Informal	1 Structured	2 Continuous	3 Integrated	4 Adaptive	5 Forward-looking
Definition	Informal mentorship and apprenticeship.	Formally designed training curricula for skills acquisition.	Structured L&D programmes are designed to run on an ongoing basis, to enable the ongoing enhancement and/or expansion of employees' skillsets.	Continuous L&D programmes are formally aligned with the organization's business needs and human resources (HR) functions.	Integrated L&D programmes are actively developed, refreshed and customized based on insights provided by key stakeholders through feedback loops.	Active efforts are made to identify and incorporate innovative L&D practices and training for future skillsets into the adaptive L&D programmes.
Description	There is no formal L&D curriculum to on-board and train the workforce.	There is a formal L&D curriculum with clear commencement and conclusion points. The scope of L&D is limited to skills acquisition.	There is a structured L&D curriculum that adopts an approach of continuous learning, to enable the constant learning, relearning, and improvement of new and existing skills.	There is a continuous L&D curriculum that is integrated with organizational objectives, talent attraction, and career development pathways.	Formal feedback channels are in place to allow integrated L&D programmes to be jointly curated and updated by employees, HR, and business teams.	There are proactive steps to incorporate requirements for future skillsets and novel L&D methodologies into existing L&D programmes.

Figure 19: Exemplary assessment

TÜV Rheinland – TRIM 4.0 [TÜV Rheinland (2018)]

The TÜV Rheinland Integrated Maturity Model 4.0 (TRIM 4.0) is another maturity assessment model and is derived from Design Thinking. It is again a matrix structure consisting of **3 key aspects** (People, Technology, and Environment) on the horizontal axis and **4 areas** (Systems, Processes, Assets, and Products) on the vertical axis. They lead to overall 12 assessment dimensions, which are summarised in Figure 20. [TÜV Rheinland (2018)]



TRIM 4.0			
Dimensions	People	Technology	Environment
System	Organization	Architecture (IT and OT)	Eco-Systems
Process	Human Factor	Process Technology	Value-Stream
Asset	Personnel	Equipment	Resources
Product	User-centered Design	Technical requirements	Eco-Design

Figure 20: Assessment dimensions of TRIM 4.0

The dimensions can be further broken down in order to allow standardisation through modules on the one hand and realise customisation of scope and scale on the other hand. In order to assess each of the defined dimensions, **5 levels of maturity** are introduced:

At **level 1**, a general commitment towards Industrie 4.0 is made but there is no formal approach. **level 2** involves a reactive approach, where an understanding of the basic elements exists but the scope is missing or only partially determined, monitored, and improved. At **level 3**, a company has established a stable formal system regarding smart manufacturing capabilities and compliance. The scope is determined, and measures are applied, monitored and improved. **Level 4** describes an Industrie 4.0-ready company. In this stage, the scope could be integrated into a smart manufacturing system but has not been integrated yet. A mature company (**level 5**) then has integrated its scope in a smart manufacturing system. Figure 21 gives an overview of the different development stages. [TÜV Rheinland (2018)]

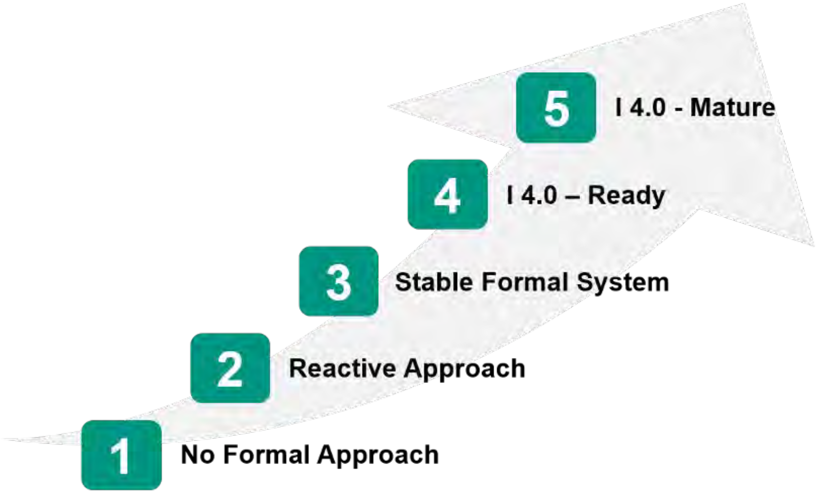


Figure 21: Development stages of TRIM 4.0

Intelligent Manufacturing Capability Maturity Model [China Electronics Standardisation Institute / CESI (2016)]

The Intelligent Manufacturing Capability Maturity model is a tool to evaluate the current state of Intelligent Manufacturing, establishing a framework for Intelligent Manufacturing strategy and implementation planning. Based on the Intelligent Manufacturing System Architecture, the Intelligent Manufacturing Capability Maturity Model can be used for diagnostic evaluation, statistical analysis, and improvement. It is used by industry authorities, manufacturing companies, solution providers, third-party organisations, and it applies to all manufacturing companies, regardless of industry restrictions.

In December 2015, the MIIT and Standardisation Administration of China (SAC) jointly issued the National Intelligent Manufacturing Standard System Construction Guidelines (Version 2015). The Intelligent Manufacturing System Framework, Structural Diagram of Intelligent Manufacturing Standard System and Framework of Intelligent Manufacturing Standard System are herein clarified.

The Intelligent Manufacturing System Framework describes the activities, equipment, features and other factors involved in Intelligent Manufacturing from three dimensions, namely, Life cycle, System hierarchy and Intelligence features. It is mainly used to clarify the standardisation requirements, objects and scope of Intelligent Manufacturing and guide the construction of the National Intelligent Manufacturing Standard System. Intelligent Manufacturing System Framework is shown in Figure 22.

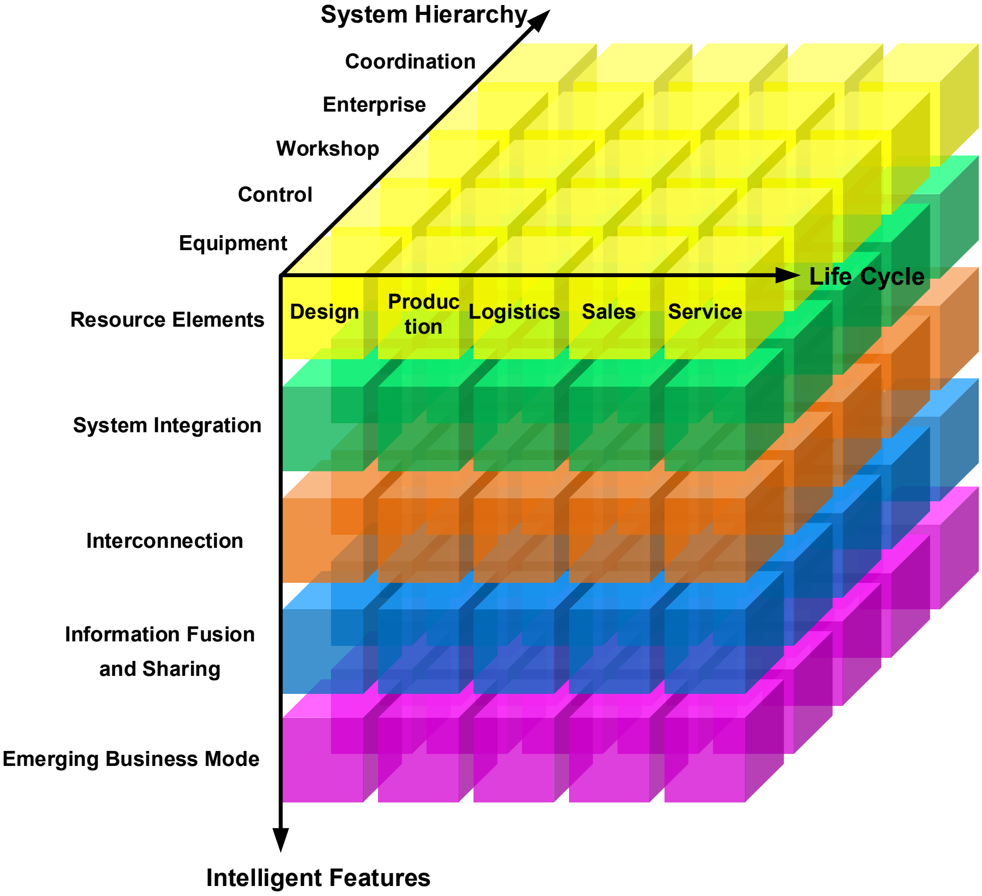


Figure 22: Intelligent Manufacturing System Architecture (2015)

Life cycle refers to a series of interrelated value creation activities from product development to product recycling and remanufacturing, including Design, Production, Logistics, Sales and Service, etc. The activities can be iteratively optimised and have the characteristics of sustainable development. The lifecycle components vary across different industries. The following are descriptions of dimensions of the life cycle:

1. Design refers to the R&D activity process of constructing, simulating, verifying, optimising, etc. according to all the constraints of the company and the selected technology.
2. Production refers to the process of creating the respective products.
3. Logistics refers to the flow of goods from the place of supply to the entity receiving the goods.
4. Sales refers to the business activities of transferring products or commodities from the respective company to the customers.
5. Service refers to the process and results of a series of activities generated by the provider in contact with the customer, including the recycling and remanufacturing process.

System hierarchy refers to the hierarchical division of the organisational structure related to the production activities of the company. It demonstrates the intelligent equipment, Internet protocol suite, and the trend towards a flat Internet structure.

1. Equipment refers to the level at which a company uses sensors, instrumentation, machines, devices, etc. to realise actual physical processes and perceive and control physical processes.
2. Control refers to the level regarding implementing supervising and monitoring of physical processes, consisting of PLC, SCADA, DCS, FCS, etc.
3. Workshop involves production management in the factory or workshop.
4. Enterprise is the level at which the business-oriented management of the company is realised.
5. Coordination is the level at which companies conduct interconnection and share the process of their internal and external information.

Intelligent features refer to the hierarchical division of one or more functions such as self-awareness, self-learning, self-decision, self-execution and self-adaptation based on the new generation of ICT. Dimensions of intelligent features are described in the following.

1. Resource elements refer to the level of resources or tools that the company needs to use for production and its digital model.
2. System integration refers to the level of integration of intelligent equipment, intelligent production units, intelligent production lines and smart factories.
3. Interconnection refers to the level of interconnection and information exchange between equipment, between equipment and control systems, between companies through wired, wireless and other communication technologies.
4. Information fusion and sharing refers to the level that realises information collaborative sharing through next-generation ICT such as cloud computing on the premise of ensuring information security.
5. Emerging business mode is the level at which companies integrate the value chain of different companies to form new industry conformations.

In 2016, CESI released the White Paper version 1.0 (draft) of China Manufacturing Maturity Model. This maturity model was developed to illustrate the architecture of Intelligent Manufacturing based on the definition in National Intelligent Manufacturing Standard System Construction Guidelines (Version 2015). The architecture is summarised into three dimensions: 1) Life cycle, 2) System Hierarchy and 3) Intelligent Features and each of which is further delineated into different fields. The dimensions of the life cycle and intelligent features cover the scope of Intelligent Manufacturing and represent the core components of Intelligent Manufacturing in the maturity model. Both dimensions consist of ten key elements that reflect Intelligent Manufacturing capabilities: Design, Production, Logistics, Sales, Service, Resource elements, Interconnection, System integration, Information fusion and sharing and Emerging business mode.

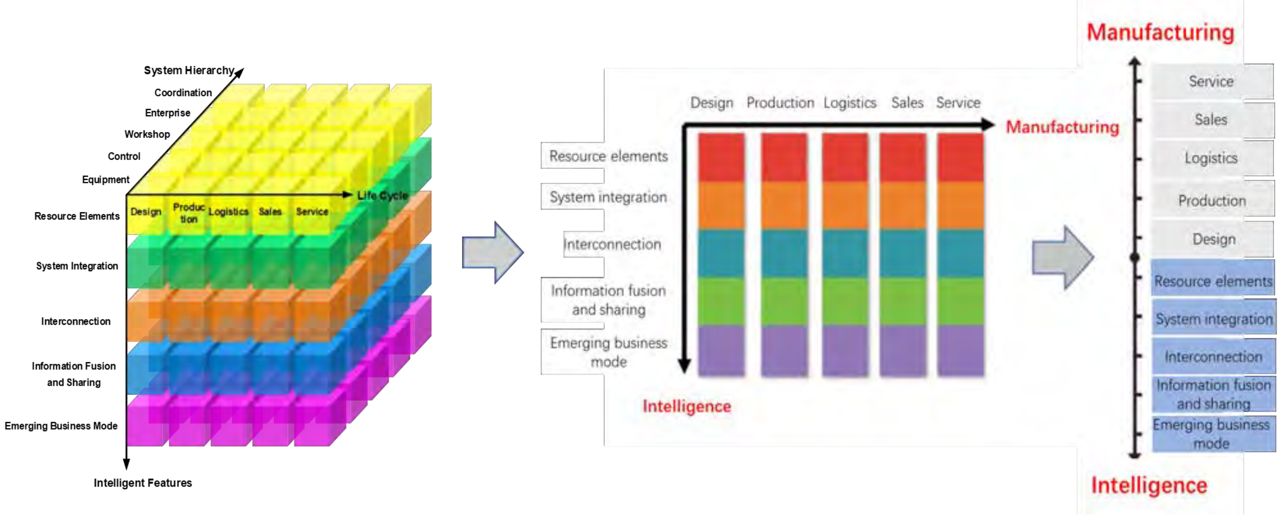
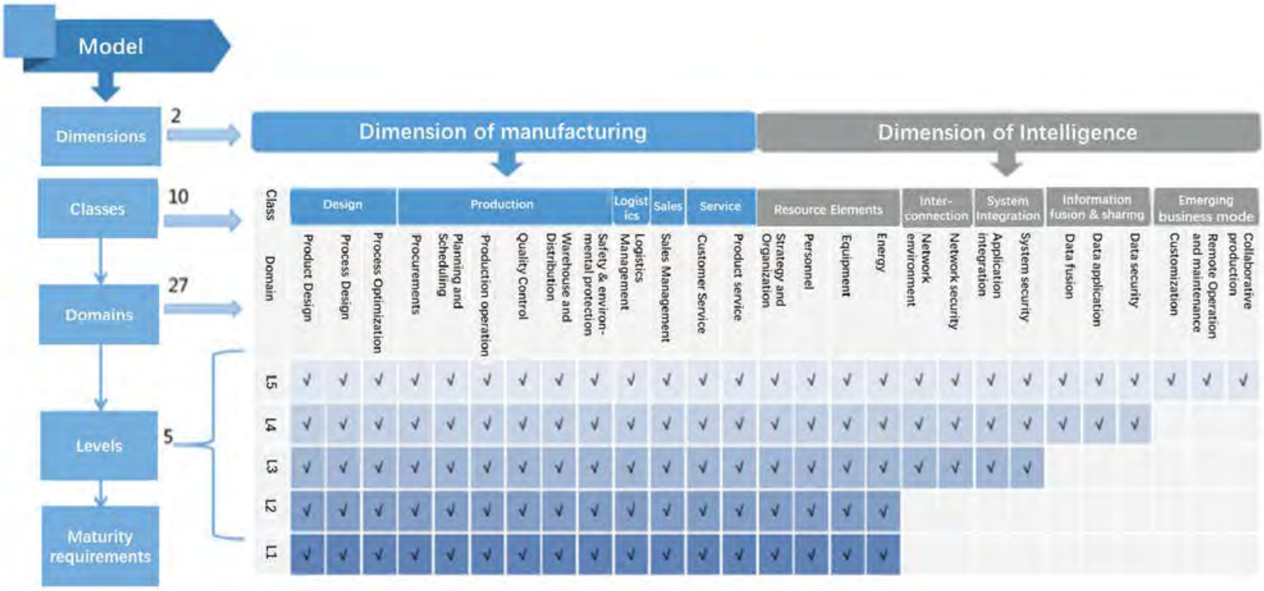


Figure 23: Elements of maturity of Intelligent Manufacturing capabilities

The model is composed of dimensions, classes, domains, levels, and maturity requirements. As the subdivisions of the two dimensions of Intelligence and Manufacturing, the ten classes symbolise ten core capability elements and can also be decomposed into 27 capability domains. Each capability domain is graded into five levels, corresponding to the extent to which a range of requirements are met. The array of maturity requirements means a set of characteristics that reflect a company's capability of Intelligent Manufacturing at different levels. The maturity model of Intelligent Manufacturing capabilities is shown in the following figure.



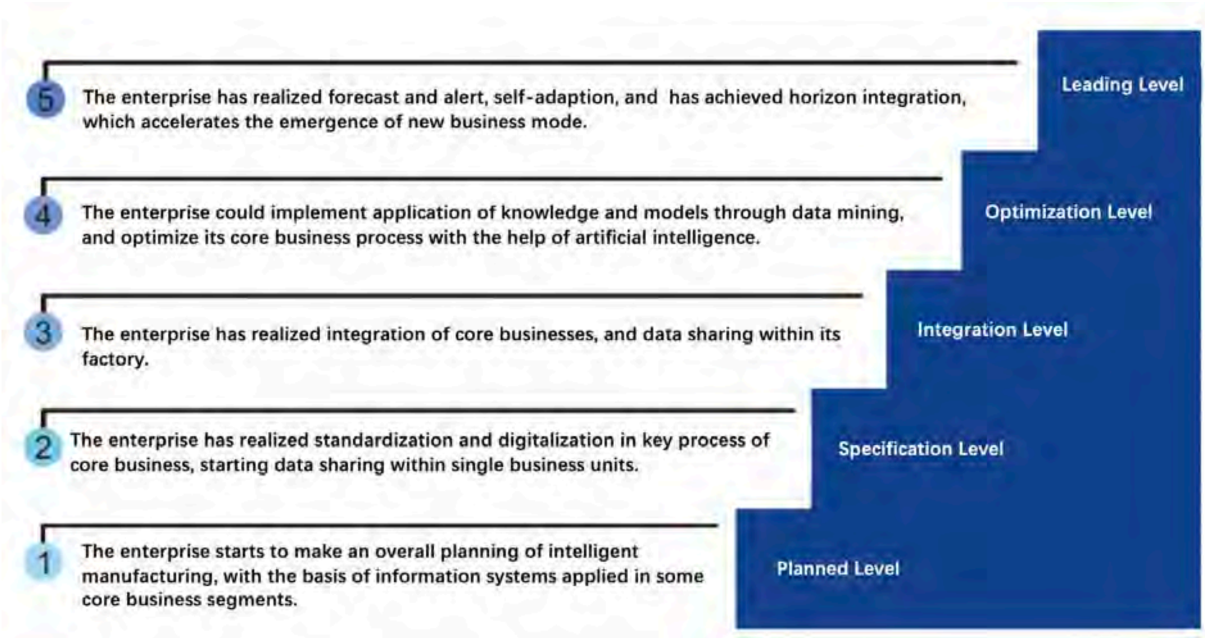
Class	Design			Production						Logistics	Sales	Service		Resource Elements				Inter-connection		System Integration		Information fusion & sharing			Emerging business mode		
Domain	Product Design	Process Design	Process Optimization	Procurements	Planning and Scheduling	Production operation	Quality Control	Warehouse and Distribution	Safety & environ-mental protection	Logistics Management	Sales Management	Customer Service	Product service	Strategy and Organization	Personnel	Equipment	Energy	Network environment	Network security	Application integration	System security	Data fusion	Data application	Data security	Customization	Remote Operation and maintenance	Collaborative production
L5	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
L4	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√			
L3	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√						
L2	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√										
L1	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√										

Figure 24: Intelligent Manufacturing Maturity Model (2016)

Based on the evaluation criteria, a company is scored from 0-5 points in every domain of Intelligent Manufacturing capability. The weighted summation of domain scores represents the performance of the class. A company's maturity of Intelligent Manufacturing capabilities can be defined by the weighted summation of class scores.

According to the evaluation criteria of the model (as shown in Figure 24), the Intelligent Manufacturing capability of the company can be divided into five levels: 1) Plan, 2) Specification 3) Integration 4) Optimisation 5) Leading. The higher the level a company reaches, the higher the maturity of the Intelligent Manufacturing capability is. Compared with the actual situation of the company, the Intelligent

Manufacturing level is obtained, which is conducive to the organisation to find the gap, and thus combines the level with corporate Intelligent Manufacturing strategic goals to seek improvement programs.



5 The enterprise has realized forecast and alert, self-adaption, and has achieved horizon integration, which accelerates the emergence of new business mode.

4 The enterprise could implement application of knowledge and models through data mining, and optimize its core business process with the help of artificial intelligence.

3 The enterprise has realized integration of core businesses, and data sharing within its factory.

2 The enterprise has realized standardization and digitalization in key process of core business, starting data sharing within single business units.

1 The enterprise starts to make an overall planning of intelligent manufacturing, with the basis of information systems applied in some core business segments.

Figure 25: Intelligent Manufacturing Capability Maturity

In 2018, the MIIT and SAC jointly issued the National Intelligent Manufacturing Standard System Construction Guidelines (Version 2018) to update the Intelligent Manufacturing Standard System Architecture. The updated model is shown in the following figure.

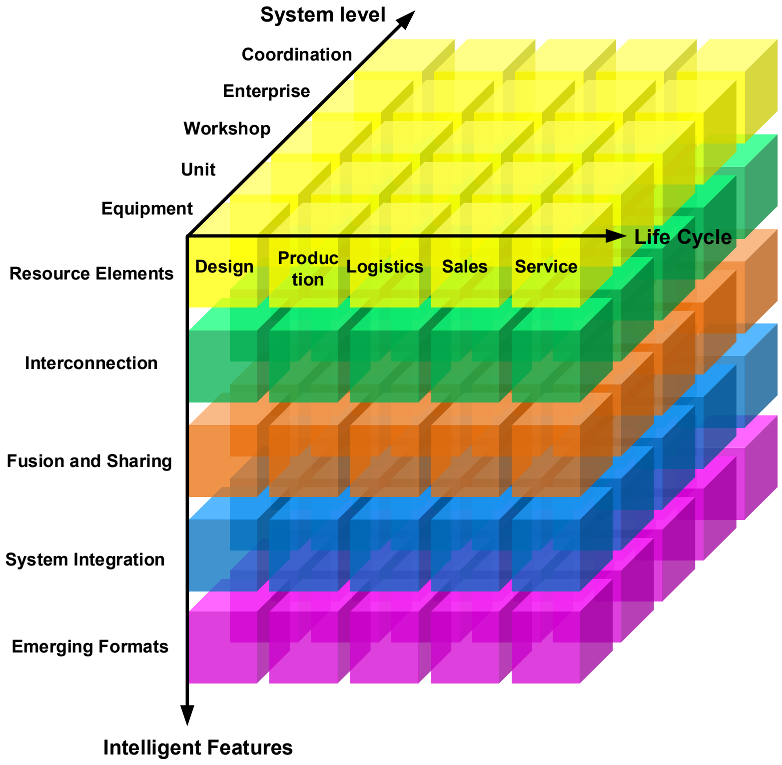
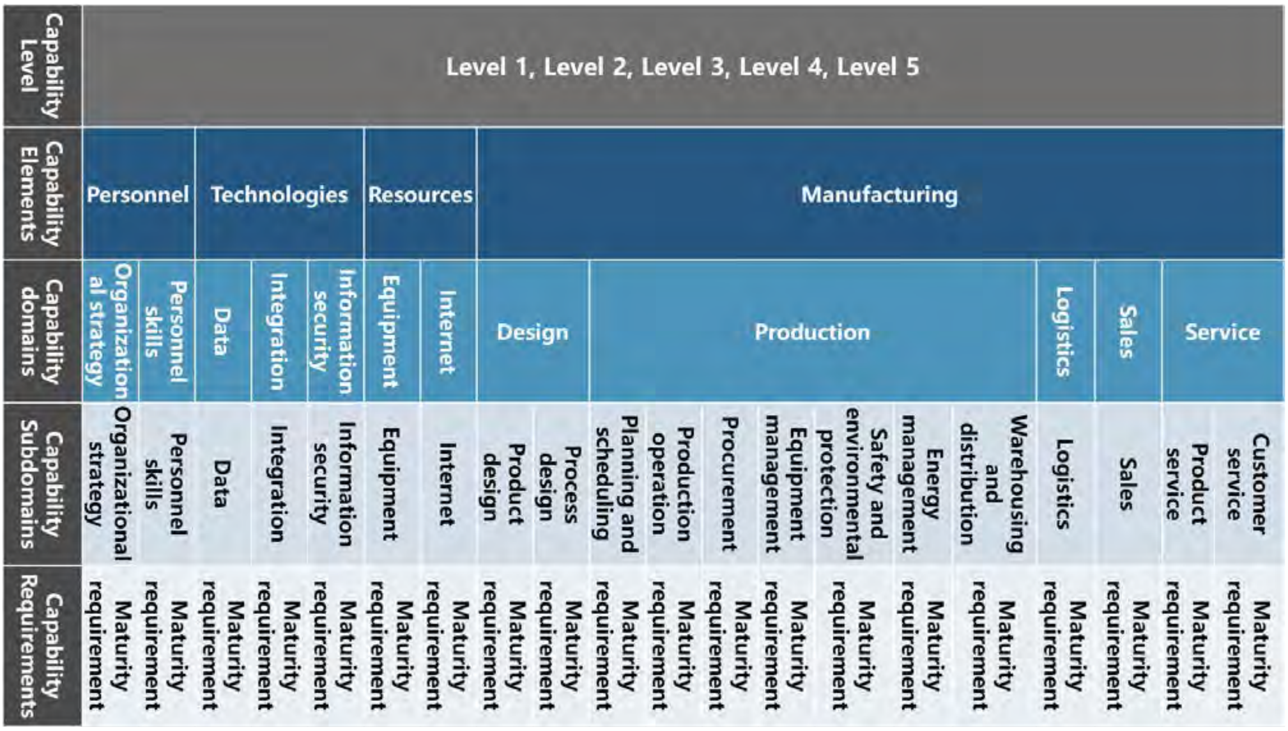


Figure 26: Intelligent Manufacturing System Architecture (2018)

Later in the same year, the SAC issued the draft on Intelligent Manufacturing Capability Levels Requirements which updated the maturity model of the above-mentioned Intelligent Manufacturing capabilities accordingly. The updated model is shown in the following figure.



Capability Level	Level 1, Level 2, Level 3, Level 4, Level 5																			
Capability Elements	Personnel		Technologies			Resources		Manufacturing												
Capability domains	Organization al strategy	Personnel skills	Data	Integration	Information security	Equipment	Internet	Design		Production							Logistics	Sales	Service	
Capability Subdomains	Organizational strategy	Personnel skills	Data	Integration	Information security	Equipment	Internet	Product design	Process design	Planning and scheduling	Production operation	Procurement	Equipment management	Safety and environmental protection	Energy management	Warehousing and distribution	Logistics	Sales	Product service	Customer service
Capability Requirements	Maturity requirement	Maturity requirement	Maturity requirement	Maturity requirement	Maturity requirement	Maturity requirement	Maturity requirement	Maturity requirement	Maturity requirement	Maturity requirement	Maturity requirement	Maturity requirement	Maturity requirement	Maturity requirement	Maturity requirement	Maturity requirement	Maturity requirement	Maturity requirement	Maturity requirement	Maturity requirement

Figure 27: Intelligent Manufacturing Maturity Model (2018)

3.2 Use Cases

Use cases of Intelligent Manufacturing Capability Maturity Model

The Intelligent Manufacturing Capability Maturity Model has been implemented in many companies throughout China. CESI and related units, with the support of the Intelligent Manufacturing Integrated Standardisation Project of the MIIT, have tested and verified the model in manufacturing companies, and related training and evaluation work has been carried out to promote effective application of the model.

At present, the maturity distribution of the platform shows that nearly 85% of companies are below the Specification Level (2nd Level). Among the eight companies in the first batch of pilots, one was rated at the Specification Level, six were at the Integration Level (3rd Level), and only one was at the Optimisation Level (4th Level).

The following are two cases of assessment on the maturity of Intelligent Manufacturing of companies according to the evaluation criteria of the model.

Case 1: An evaluation project of a discrete manufacturing company

In 2017, a company in discrete manufacturing industry in China conducted a maturity assessment on the company's Intelligent Manufacturing level.

The following is a summary of the evaluation of one individual capability of the company´s Intelligent Manufacturing. As an example, the design ability evaluation is presented. The other capabilities are calculated similarly.

The evaluation of the company's design capabilities consists of three domains, namely **Product design, Process design and Simulation design.** Among them, product design and process design have reached the Planned Level (1st Level), with scores of 1.85 and 1.6 respectively. In comparison to other categories, the level of simulation design is higher, reaching the Specification Level with a score of 2.5. The comprehension score regarding the design capacity reaches 1.98, at the Planned Level. This shows that the company's R&D design capability is at a low level and needs to be improved. It is illustrated in Figure 28.

Category	Level	Points
Product design	Planned level	1.85
Process design	Planned level	1.6
Simulation design	Specification level	2.5
Comprehensive evaluation design	Planned level	1.98

Figure 28: Scores of companies' design capability

Based on the scores of the 10 individual abilities, the overall level of smart manufacturing of the company is shown in the following Figure 29. It summarises all abilities and calculates an overall score out of them to evaluate smart manufacturing ability of the company.

Class	Level	Points
Design	Planned level	1.98
Production	Planned level	1.87
Logistics	Planned level	1.33
Sales	Specification level	2.3
Service	Integration level	3.0
Resource element	Specification level	2.2
System integration	Below Planned level	0.53
Interconnection	Planned level	1.85
Information fusion	Below Planned level	0.45
Emerging business	Below Planned level	0
Overall evaluation	Planned level	1.55

Figure 29: Overall level of the company's Intelligent Manufacturing

On the whole, the company's Intelligent Manufacturing level is still low. In most abilities, it is still at the Planned Level. The ability development in various fields is not balanced (as shown in Figure 30). According to the capability level, the capabilities of the company can be divided into three categories.

Less than 1.0 points: The ability is lower than the Planned Level. System integration, information fusion and emerging formats are relevant in this stage. In addition to the emerging formats that can be explored in other categories in the later stages, system integration and information integration urgently need to be upgraded and development should be given high priority.

1.0-2.0 points: In this case, the ability is at the Planned Level. This stage involves abilities such as design, production, logistics, interconnection and interoperability. The development of these fields should be accelerated in the future. Design and production are very important links in the field of Intelligent Manufacturing and should be regarded as the most important component for the future development for the company.

2.0-3.0 points: In this case, the ability is at the Specification Level. Abilities such as sales, service and resource elements are relevant. These three categories are relatively well developed and can be simultaneously planned for development while prioritising other categories of development to further enhance the lower abilities of the company.

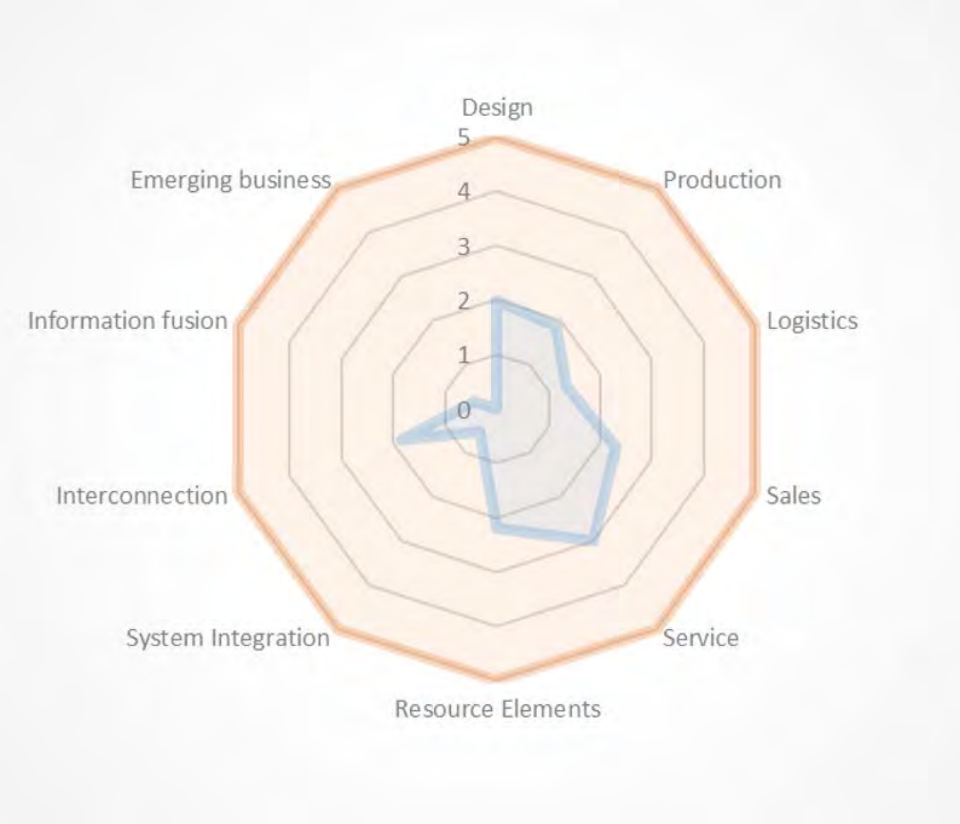


Figure 30: Company Intelligence Manufacturing single capability diagram

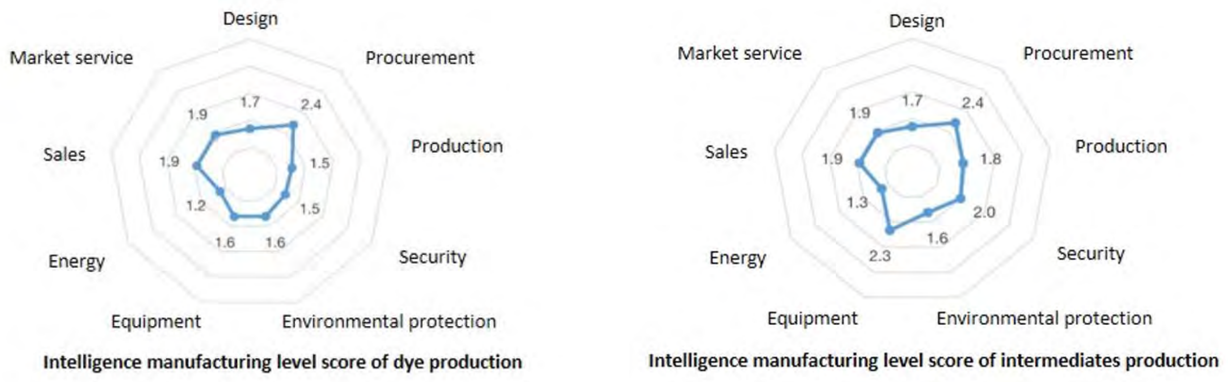
Case 2: An Intelligent Manufacturing consulting project of a chemical company

Focusing on the objectives and requirements of Intelligent Manufacturing in the process industry, the project conducted in-depth research on the company's three core business divisions, namely Product Research Division, Dye Business Division and Intermediate Business Division. It has also analysed the current situation of the business links such as product research and development, process design, raw material procurement, product production, safety management, environmental protection management, equipment management, energy management, sales and marketing service of dye/intermediate products. According to the detailed requirements of the standard of the Implementation Guide for Process Intelligent Manufacturing Capacity (draft), the maturity of sub-domains of the above business is scored for the purpose of determining the level and score of the sub-domains The weighted score of the class is calculated, and the corresponding scores are given.

This project evaluated the current informatisation and digitisation of each business of the company and the degree of information circulation between related businesses, in order to comprehensively evaluate and summarise the Intelligent Manufacturing level of companies in dye and intermediate production.

In general, the main businesses related to dye/intermediate production are in the initial stage of Intelligent Manufacturing and have carried out Intelligent Manufacturing planning in an all-round way. Most businesses have an information-based foundation, without obvious shortcomings, and a good foundation for intelligent upgrading.

In dye production, all business links are at either the Planned and or the Specification level. The average score of all business links is 1.7, and the average Intelligent Manufacturing level stay planned, which is in the primary stage of Intelligent Manufacturing. In the production of intermediates, all business links are basically at the Specification level. The average score of all business links is 1.9, and the average Intelligent Manufacturing level has reached the Specification Level.



Intelligence manufacturing level score of dye production

Intelligence manufacturing level score of intermediates production

Figure 31: Intelligence Manufacturing level score of dye and intermediates production

In terms of overall production and energy management, the main equipment of the company already has the functions of data collection and communication. The core business has been automated and digitally upgraded. Some single businesses have begun to realise data sharing internally. However, it is still necessary to further improve the information system of weak links. On the basis of the completion of the construction of the information system, the information circulation between related systems should be strengthened to realise the linkage or coordinated operation of multiple systems. Finally, by using the knowledge base and Big Data technology, the system should be intelligent to realise Intelligent Manufacturing.

VDMA, DiK, wbk – Guideline Industrie 4.0

This maturity model was applied on a project at a large machinery manufacturer in Germany in 2019. The focus was on a production site with high strategic importance in Southern Germany. The application of the model was carried out over a period of one week. The project was composed of IT structure assessment, preparation day and a two-day workshop.

During the IT structure assessment, an interview with four IT employees took place over 2 hours. In this interview, specific questions were asked that analysed the underlying IT infrastructure of the production site. This was necessary in order to understand the current status. Furthermore, potential extensions of the existing IT infrastructure could be identified at an early stage. In addition, obstacles in the implementation of cloud technologies and other boundary conditions for the acceptance of the maturity level could be identified. These inputs from the company side were processed in a structured manner by the consultants and used for further processing in the assessment.

In the course of the preparation day, 45-minute interviews were conducted with departments involved in production. The departments involved quality management, production planning and control, logistics, manufacturing and operations, factory automation and maintenance. The aim of the interviews was to get to know the departments and their recent developments in the area of Industrie 4.0 and digitisation. Thus, lighthouse projects could already be identified and important framework conditions for the further development of digitisation could be set. Potential and current development projects were addressed as well as risks, goals and a vision of digitisation. A structured questionnaire was used, which was intuitively adapted to the respective focuses of the departments during the interview. After the interviews, a shop floor visit was organised. In a 4-hour tour, all relevant areas of production were examined. Attention was also paid to adjoining areas such as incoming logistics, material handling and outgoing logistics. During the shop floor visit, the team filled out a structured Industrie 4.0 toolbox (see Figure 32) and assessed the respective maturity level. The areas of smart operations, smart planning and control, smart logistics and data management were considered in the maturity model. This provided an accurate description of the current state of digitisation in the company.

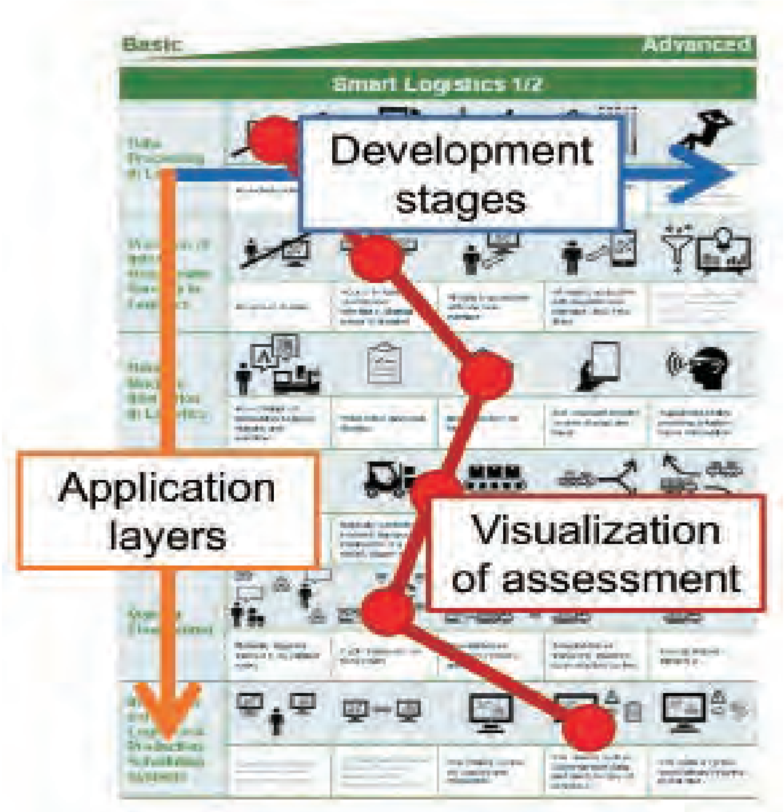


Figure 32: Exemplary toolbox of smart logistics

The first day of the workshop began with a keynote speech on Industrie 4.0 and digitisation delivered by the external team. This created a fundamental understanding of the current possibilities of digitisation in science and practice to ensures that all participants arrive at the same knowledge level on digitisation. Subsequently, the results of the shop floor visit were presented. These were then used as the basis for the next generation of new ideas to improve digitisation (see Figure 33). The ideas should help further develop the current level of maturity in individual dimensions of the toolbox so that the company can become more digital and can face the challenges of the future well prepared.

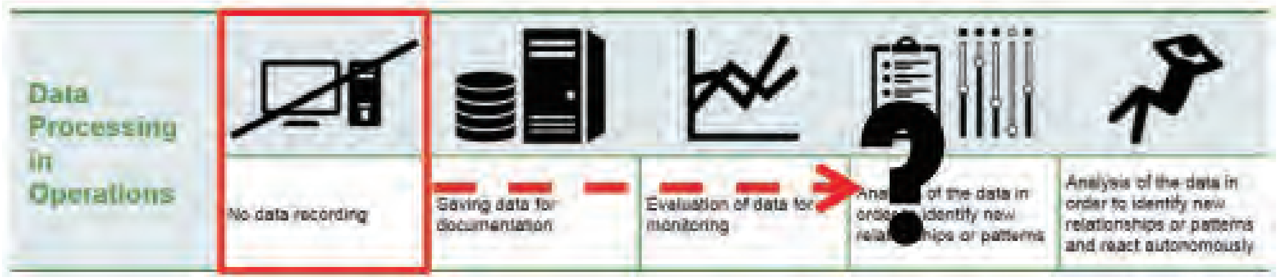


Figure 33: Improvement of the maturity level by idea generation

On the second day of the workshop, the ideas of the participants were prioritised by the entire group. Small groups, with the help of the St. Gallen Business Navigator, transferred their favourite ideas to business ideas. Finally, there was a ranking of benefit and effort making it easier for the top management to prioritise the ideas. Downstream some ideas were explored and utilised by the company afterwards in order to enhance the degree of digitisation of the factory.

Harting Industrie 4.0 Assessment [Schuh et al. (2017)]

The acatech Industrie 4.0 Maturity Index was validated by Harting AG & Co. KG in Espelkamp (Germany) at the beginning of August 2016. The manufacturer of industrial connectors, device connection technology and network components employs around 4,300 people (as of 2016) in 43 sales companies and 13 production facilities. The company is controlled from its headquarters in Espelkamp, which is also the largest production site.

At Harting, processes in all the functional areas are recorded in detail. In addition to the interviews with experts in the individual functional areas, a guided tour of the plant was conducted to simulate the production process of a regular product. This is to evaluate the transitions to different departments and the generation of information on the shop floor.

Harting has already worked intensively on the topic of Industrie 4.0, particularly in production. The expansion of the IT infrastructure in recent years and consistent feedback from production have resulted in a digital image of production in the information systems. The implementation of individual pilots in various areas of production creates a deep understanding of technology. In addition, the experience was gained with the integration of these pilots into the existing processes. An example of this is the automatic detection of the condition of the cutting edge by using structure-borne noise. Condition monitoring leads to a reduction in downtimes, as maintenance measures can now be initiated in good time and in line with requirements.

The use of Industrie 4.0 pilots in the value chain and the digital image resulted in the maturity level of transparency. Based on this status quo, measures were derived to stabilise the maturity level and to realise an expansion to the next level. The roadmap developed for this purpose comprised more than thirty measures, divided among the functional areas of the maturity index.

The measures from the production functional area include the integration and expansion of the existing pilots over the entire production process. The pilots are currently located in different production lines and lead to local process improvements. However, these are isolated and fragmented, as the potential is not exploited across the production lines. The defined measure comprises the integration of the individual pilots into an end-to-end process in order to realise the potential of Industrie 4.0. In concrete terms, this means enhanced transparency in the overall process, which makes data-based decision making possible. This is intended to improve concrete key figures such as overall plant effectiveness and flexibility, which in turn have a direct impact on adherence to schedules. For this purpose, a holistic approach for a product or a product group must be chosen and an extension of the pilot along the value-added process implemented. This does not only mean the implementation of further sensor technology, but also the integration into process and decision processes. This creates the possibility of data-based decision-making. Experiences with the implementation of the pilots help to implement an expansion for further areas and other production sites within the production network of Harting or at supplier plants. Through supplier plants analysis, the horizontal integration of Harting can also be further enhanced.

3.3 Assessment of Existing Models and Recommendations

Regarding the applicability of existing maturity models in the field of workforce's capabilities assessment, an evaluation of the presented models in Chapter 3.1 has been implemented. As assessment criteria, the fulfilment of the skill needs from Chapter 2.2 has been used on the one hand. On the other hand, additional requirements in regard to the assessment process have been defined. These include a clear link between the model's assessment dimensions and corresponding maturity stages. The assessment could either be based on a matrix structure with maturity levels on the horizontal and assessment dimensions on the vertical axis, or supported by a detailed textual description. Besides, it is important for the model to provide a detailed description of these steps, e.g. what could be achieved either by a written description or with the help of a questionnaire. Last, a supporting assessment tool, e.g. an online tool or ready-to-use questionnaire with aggregation logic, serves as an assessment criterion. Figure 34 summarises the assessment results.

Criteria		**Maturity Level Models**							
		Acatech	VDMA	VDMA, DiK, wbk	DiK	Singapore EDB & TÜV SÜD	TÜV Rheinland	Intelligent Manufacturing	Talent Cultivation
Assessment Dimensions	IT Competencies	◑	●	◑	◔	◑	◑	◑	◔
	Technical Skills	○	◔	○	◔	◑	◑	◑	◔
	Business Administration & Management	◔	◔	◔	○	◔	○	◑	◔
	Interdisciplinary Competencies	◔	○	◔	◔	◑	◔	○	◑
	Soft Skills	◑	◔	○	◑	○	◔	○	○
	Leadership	◔	○	○	○	◔	○	○	○
Assessment Process	Link between assessment dimensions and maturity steps	◔	◔	●	●	●	◔	●	○
	Detailed description of maturity steps	●	◔	◔	◔	◑	◑	◑	○
	Supporting assessment tool	○	●	○	○	○	○	◔	◔

Figure 34: Assessment of current maturity models

Regarding the assessment dimensions of the models, **it can be concluded that all of the maturity models lack a focus on workforce skills.** Apart from the observation that IT competencies has been touched upon by all the models, other important and necessary hard and soft skills are rarely considered. Especially leadership competencies are nearly neglected in existing maturity models. In general, the existing models assess a company based on the overall Industrie 4.0 maturity and are well suited for assessing plants as well as identifying improvement potentials. But they are not well suited for assessing a workforce's skills. The only maturity model that really focuses on workforce assessment is the model by DiK.

The AGU EG Training 4.0 recommends the development of a maturity model that focuses on the assessment dimensions defined in Chapter 2.2, links them with qualification measures and fulfils all the assessment process requirements in order to support self-assessment of the companies so that they can work out their individual action fields. Furthermore, intensifying standardisation efforts with regard to this maturity model could increase its acceptance and give companies a good guideline to enhance their workforce capability, similar to the EFQM (The EFQM excellence model is a non-prescriptive business excellence framework for organisational management, promoted by the EFQM (European Foundation for Quality Management) and designed to help organisations to become more competitive.)

4 Skill Development Guideline

This chapter focuses on the challenge of bridging the skill gaps with appropriate trainings. For this purpose, a wide-ranging skill development guide is presented. The structure of this chapter is presented in Figure 35.

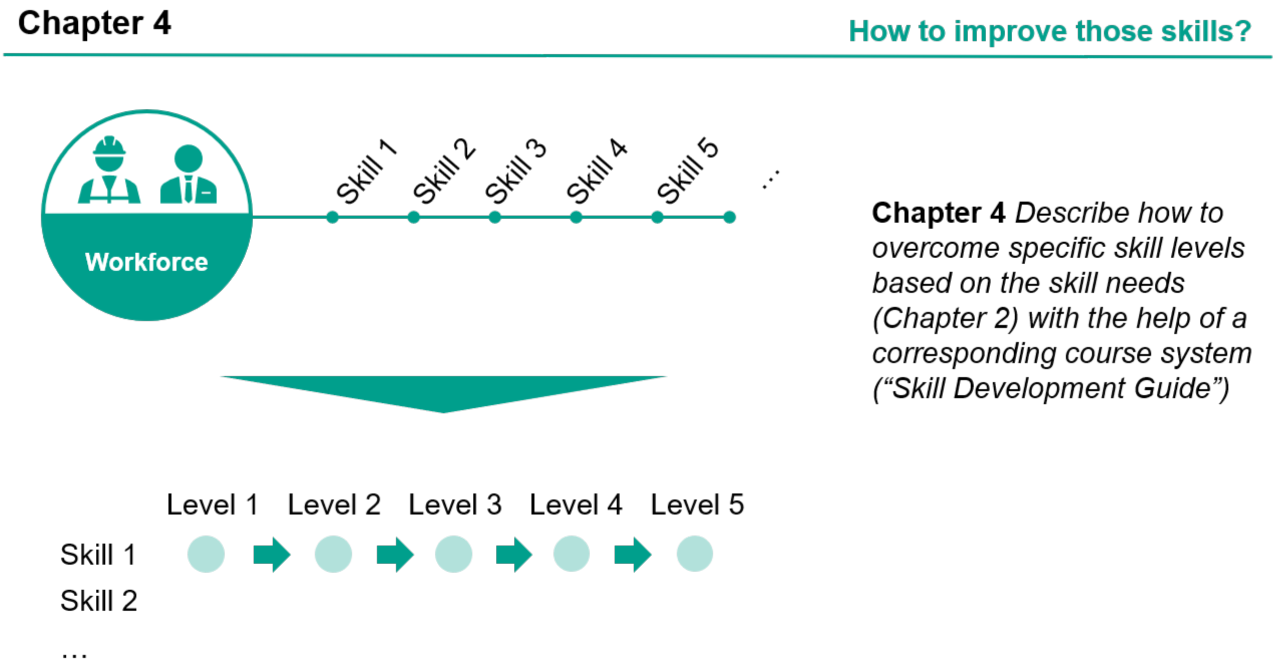


Figure 35: Structure of Chapter 4

The skill development guide of Chapter 4 consists of two central elements. On the one hand, a wide-ranging **course system** has been developed in order to enhance the necessary skill needs from Chapter 2. This serves as a guideline for companies. They can compare it to existing course systems of external training providers or to their own in-house training competencies and use it as a reference. On the other hand, this course system is matched with the skill needs from Chapter 2 and corresponding development stages in an **ability-course matrix**. This helps companies to pick the right courses based on their skill deficits in order to close the gap between the actual Industrie 4.0 maturity and the target state.

In the EG Training 4.0, a training course system with overall 80 courses was developed. These were mainly based on inputs by CCID and Bosch Rexroth. The course system by CCID is categorised in different dimensions such as mechanical engineering, automation control system, intelligent equipment, information technology, network & communication, system engineering, Industrial Big Data & AI, as well as management.

Bosch Rexroth provides a wide-ranging training catalogue including Industrie 4.0-related training courses for the future workforce, which is well established in Germany. Bosch Rexroth and AHK jointly developed the “Industrie 4.0 Specialist” training course, which is divided into four modules with 104 training units. After finishing the work on all the modules of the training course, the participants need to attend an IHK Test to get an official IHK certificate as a reward. In the training, Bosch Rexroth incorporates the main topics of Industrie 4.0 and the relation to the workforce such as: Principles of Industrie 4.0, Connected business models in production and logistics, Technologies for implementing Industrie 4.0 and Design of work and organisation in the age of digital change. [Bosch Rexroth AG (2019)]

The final courses are linked to the development of certain Industrie 4.0 skills in an ability-course matrix, which can be seen in Figure 36. The skills are derived from Chapter 2. As can be seen in the ability column, each skill is assigned a three-level maturity model, which is visualised by Harvey-Balls.

Ability			Course										
			Mechanical engineering			Automation Control System			Intelligent equipment			Information Technology		
			Mechanical Drawing	Manufacturing Technology	...	Hydraulic and pneumatic transmission and control	Electromechanical transmission control	...	Industrial robot	CNC machining	...	relational database	High-level language programming	...
IT Competencies	Information System Architecture	◔												
		◑												
		●												
	Network Infrastructure & Integration	◔									✓		✓	
		◑									✓		✓	
		●									✓		✓	
	Databases	◔										✓	✓	
		◑										✓	✓	
		●										✓	✓	
	Server & Storage Technologies	◔											✓	
		◑											✓	
		●											✓	
	...	◔			✓									
		◑			✓									
		●			✓									
System Engineering	Mechanical Systems and Components	◔	✓			✓	✓		✓	✓				
		◑	✓			✓	✓		✓	✓				
		●	✓			✓	✓		✓	✓				
	Electrical Systems and Components	◔					✓		✓	✓				
		◑					✓		✓	✓				
		●					✓		✓	✓				
	Automation Control Systems	◔		✓		✓	✓		✓	✓				
		◑		✓		✓	✓		✓	✓				
		●		✓		✓	✓		✓	✓				
	...	◔												
		◑												
		●												
...	...	◔												
		◑												
		●												

Figure 36: Ability-course matrix

As an example, the maturity development of the technical skill **Mechanical Systems and Components** will be described. The three levels of skills are summarised under ability column.

At **level 1** of skills, workers must have a basic understanding of mechanical systems. They should be able to read drawings and make them himself. Furthermore, they need a basic understanding of the exemplary sciences of mechanics, pneumatics and hydraulics.

At **level 2** of skills, a worker must also be able to adapt and interpret drawings. In the above-mentioned three exemplary sciences, it should be possible to recognise interrelations and draw conclusions about mechanical systems. The isolated consideration of mechanical components should also be mastered at level 2 of the skills mechanical systems and components.

At the last, **level 3** of skills, it should also be possible to carry out deep analyses in CAD drawings. Thus, it is possible that FE-methods (Finite-Elements-Methods) are applied, so that loading profiles of a mechanical system can also be calculated and used for the mechanical system. The worker with skills at level 3 can act autonomously and needs little instruction from a superior advisor. Interactions between mechanical components and their influence on complete systems can be analysed and interpreted, thus a deep understanding of the machine system is achieved. In the three exemplary science disciplines—Mechanics, Pneumatics and Hydraulics, interactions between the disciplines can also be estimated and classified into overall systems. Not only mechanical systems but also the connections to the infrastructure, e.g. hydraulic lines, are understood and addressed independently.

As you can see from the matrix the training “Mechanical drawing” is necessary for all three levels of skills. It can be argued that the drawing of machines and products is elementary in the training of a mechanician in the future. Even today, when many tasks can be done by computer instead, this is a basic skill that every mechanician should have. In the mentioned training the basics of drawing are taught by hand. In addition, CAD training courses are carried out, which are now widely used in industry practice. Further, the CAD work of a computer need to be understood by the mechanician. Without CAD experience, you will have little chance of being able to work well. Therefore, this training is recommended for every mechanician.

The next training in the list regarding “Mechanical engineering” is the “Manufacturing technology”. This training is not necessary for the skill “Mechanical systems and components”, but necessary for the skill “Automation control systems”. Because it focuses on the automation of production lines. Consequently, manufacturing technologies are also important, since one has to understand the various manufacturing processes in order to subsequently automate them.

The training "Hydraulic and pneumatic transmission and control" is considered relevant for the skill "Mechanical systems and components" at all levels. Also "Electromechanical transmission control", "Industrial robot" and "CNC machining" are important for all levels of the considered skills. Furthermore, it could also happen that some trainings are not important for all three skill levels. For example, training in "AI regarding mechanical systems" may only be necessary for the highest level of the skill, since AI is not an elementary skill that each level must fulfil.

The AGU EG Training 4.0 recommends developing a uniformed training portfolio that can be applied in both Germany and China. Despite that, the required skills don't differentiate between China and Germany, but the initial conditions/skill baseline of the workers are different. It is difficult to evaluate Chinese courses due to a limited number of issued certifications, while a small fraction of certified courses provided in Germany can be recognised and applied in China. Therefore, the working group will devote part of its efforts in 2020 to develop a training portfolio which directly matches with a maturity model framework to enable companies to derive a targeted development plan specifically for their employees, based on a maturity assessment.

5 Training Units

Chapter 5 focuses on presenting existing training units to develop the necessary skills with examples. For this purpose, a clustering scheme for such training units is presented before specific use cases from both countries are introduced. Figure 37 is showing the structure of the chapter.

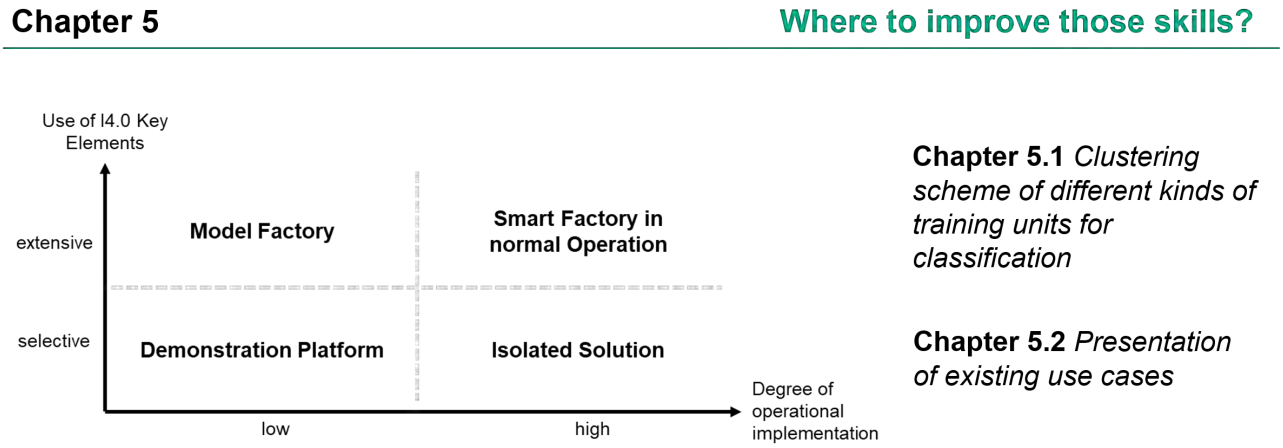


Figure 37: Structure of Chapter 5

5.1 Clustering Scheme

Existing training units can be clustered based on two dimensions: the extent to which Industrie 4.0 key elements are incorporated and their operational application. This gives rise to four types of training units: 1) Model Factories, 2) Demonstration Platforms, 3) Isolated Solutions and 4) Smart Factories in normal operation [Ittermann et al. (2015)], as shown in Figure 38.

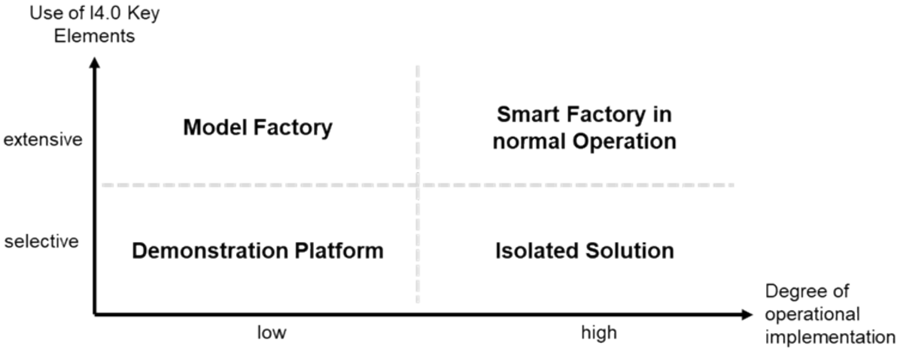


Figure 38: Clustering of different kinds of training units

5.2 Use Cases in China and Germany

Use cases in Germany

TU Darmstadt (TUDa)

The Department of Mechanical Engineering of the Technical University Darmstadt (TUDa) divides its Industrie 4.0 strategy into four sections. The first section is the research and development centre, wherein the technologies of the entire product-life-cycle are shown. The focus of the first three phases of the product life-cycle are: specification and requirements, design and virtual product development as well as virtual commissioning. The phase of production is shown with modular learning modules. The modular learning modules reflect and summarise the topics of two large factories: CiP and ETA. The combination of the first three virtual phases and the real production environment of two factories at the TU Darmstadt offers a unique foundation for a competence centre to experience the methods of Industrie 4.0—interacting with digital applications in a practical production environment with real products. Methodologically the Industrie 4.0 Toolbox series is used for university lectures, vocational training as well as short-term company workshops and seminars. Additionally, a testbed centre is established, wherein students and industrial participants can expand their abilities with small implementation projects. With its high use of Industrie 4.0 Key Elements and low degree of operational implementation, it can be classified as a model factory. An overview is shown in Figure 39.

Figure 39: Department of mechanical engineering of the Technical University Darmstadt (TUDa)

Darmstadt follows the principle, that training units need to be competence-oriented when training Industrie 4.0 skills should be based on the Toolbox Workforce Management 4.0. Based on knowledge and results gained from past trainings as well as projects with SMEs, a training unit with the following digitisation options of Cloud-Technology, Worker Assistance System and Traceability was developed in a Sino-German research project.

The training targets are divided into four major sections: technology, general learning targets depending on structured interviews and analysis, knowledge dimension as well as dimensions of cognitive processes. All sections combine theoretical lectures with practical applications. Firstly, the technology section includes the topics of Cloud-Technology, Worker Assistance System and Traceability. Secondly, the general learning targets section includes the topics of holistic Industrie 4.0 benefits, functional areas, environmental impact, influences on professions, basic technologies in Industrie 4.0, functionality and integration of specific operational implementations. Thirdly, the knowledge dimension section includes declarative knowledge and procedural knowledge. Finally, the dimensions of cognitive processes section include the topics of knowledge/comprehension, application, analysis, synthesis and evaluation.

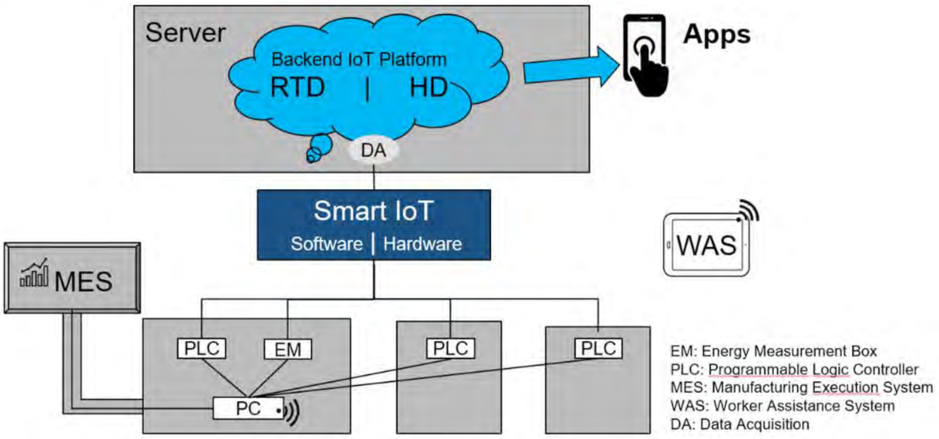


Figure 40: Hardware and software training architecture for Cloud-Technology, Worker Assistance System and Traceability

Bosch

At the Bosch plant in Blaichach, Germany, training modules are provided for all the staff, irrespective of their roles involved. These training modules are constantly being further developed, are designed according to the needs of the particular group of staff to be trained and, can be undertaken in a flexible manner. These training modules can range from short training videos on the basic principles of Industrie 4.0 or technical devices utilisation, to full-day seminars on new system management, specific methods for teamwork or management practices. The plant can be classified as a smart factory (in normal operation) due to its wide use of Industrie 4.0 key elements and a high degree of operational implementation. The Works Council (of the plant) not only attach importance to training, but also regards communication an essential element. They focus on making people understand Industrie 4.0 and to take away unnecessary fears and resistance due to lack of understanding. For better communication, they make use of the monitors in the staff rooms as well as on the information boards on the production floor. [Plattform Industrie 4.0 (2017)].

As the last use case shows, big companies in Germany and China can develop their training programs and provide the necessary knowledge to their workforce, supported by use cases from their smart factories. On the contrary, SMEs lack resources and need to be supported. A survey by acatech POSITION (2016) shows that so far 30,6% of the big companies have specific training programs regarding the subject of Industrie 4.0 while only 17,8% among the SMEs introduced such programs. Regarding the question—where to improve the necessary skills, acatech Position (2016) analysed different instruments and methodologies for skill development. The survey results can be seen in Figure 41.

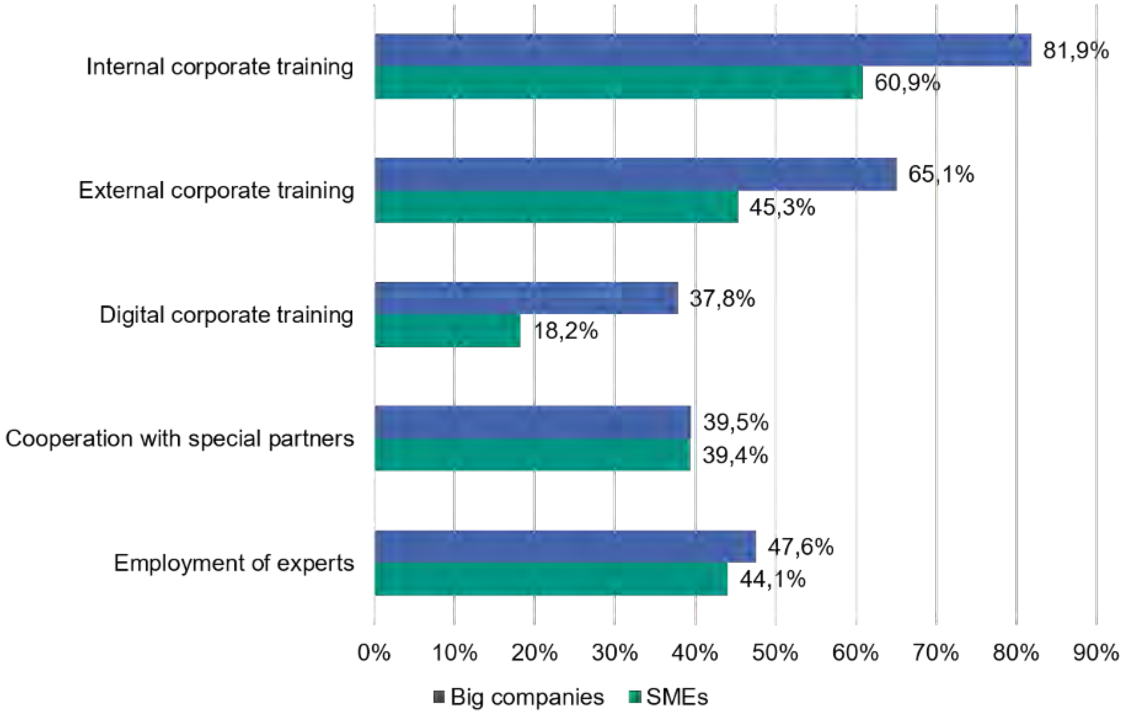


Figure 41: Used instruments for skill development in %

As the chart indicates, the most used instruments for skill development are internal trainings as well as external training partners. While large companies use those instruments extensively, SMEs usually don't have access to the instruments due to lack of resource. Since SMEs are the "backbone" of the German industry and employ a large share of labour, it can be fatal in the future if they are left behind in employee development. Due to limited resources, external corporate trainings are of special particular importance to them. In Germany, competence centres already run quite successful, but the policy is still needed to further SMEs to catch up with the big companies (in terms of work skills). This requires further investments in training units of SMEs to make use of the training offers.

In China, while various training units also already exist, strongly supported by the authorities, they are not frequently used as trainings platform but instead more of a showcase. Policies need to be in place to incentivise companies to use existing training centres for trainings instead of investing in showcases. Additionally, the existing units should be strongly supported by the government, together with relevant experts, to increase their systematic skill development capabilities, e.g. develop Train-the-Trainer concepts.

Use cases in China

Since 2015, the State Council of China officially announced the "Made in China 2025" strategy. The cultivation and training of Intelligent Manufacturing talents has attracted the attention from all levels of society, including the government, industry companies and colleges. Previously, China's manufacturing industry faced a huge gap in term of Intelligent Manufacturing talents.

At present, in China, Intelligent Manufacturing training units are mainly divided into four categories:

1. Social training units (companies), employment training centres, technical colleges

Mainly for the training of front-line technical personnel, the training content focuses on the training of Intelligent Manufacturing equipment operation, programming, debugging, maintenance and repair, and training basically relies on its own teachers and trainers.

2. Colleges and universities (including key laboratories of the state and ministries and commissions), vocational colleges

It is mainly targeted at middle-level managers, technicians and college teachers. The training content mainly focuses on high-end technologies in Intelligent Manufacturing, such as Intelligent Manufacturing planning, production system simulation, digital design, machine vision, AI, Big Data and machine learning, In terms of digital twins and lean management in Intelligent Manufacturing companies, they basically rely on their teachers and trainers.

3. Research institutes and industry associations (China Machinery Industry Federation, China Mechatronics Technology Application Association)

4. Digital factories of leading companies, national Intelligent Manufacturing demonstration companies, and Intelligent Manufacturing technology implementation companies

The latter two types of training units are mainly for senior management and technical personnel of companies, and the training content mainly focuses on Intelligent Manufacturing system evaluation, planning, implementation, management and exchange interviews with company managers. Most of these training units rely on their expert teams, except for industry associations and societies, which rely on the employment of domestic and foreign experts, scholars, and corporate executives.

At present, there exist a few problems in the training content and quality of Intelligent Manufacturing training units in China, including unevenness, poor quality, and inaccurate orientation etc. Among all the training units, only customised corporate training units have a clear target, while training units targeted at the society lack a clear goal and blindly follow the trends. Most of these training units focus on industrial robot training and haven't made adjustment according to the regional industrial structure and Intelligent Manufacturing development level.

College Training Units

Tongji University Industrie 4.0 Learning Factory Lab

Based on the concept of the first "Industrie 4.0-Laboratory" of Tongji University in China, the new-generation Industrie 4.0 training institution Tongji University Industrie 4.0 Learning Factory was built by Tongji, its Intelligent Manufacturing implementation team and CPS-Solution.

Tongji University Industrie 4.0 Learning Factory emphasises the combination of "factory" and "learning". Students can apply and internalise the learned manufacturing knowledge and technology through production practice in a real factory production environment so that students can be built into the future generations of engineers, able to adapt to the real production environment and think systematically and creatively to solve problems.

Tongji University Industrie 4.0 Learning Factory has the key technologies and features of Industrie 4.0, that covers product design, sales management, simulation, manufacturing management, maintenance and after-sales service.

With the utilisation of both advanced equipment, including a compound robot, smart camera, laser-guided Automated Guided Vehicle (AGV), etc. and cutting-edge technologies, including digital twins, predictive maintenance, dynamic scheduling, Industrial Big Data analysis and Virtual Reality (VR) and PLM system, order management, Manufacturing Execution Systems (MES), etc., the lab realises the Industrie 4.0 architecture of horizontal, vertical and end-to-end integration.

Based on the lab, experimental lessons are developed for students to learn key knowledge and skills of data acquisition & monitoring, robot system, machine vision, intelligent warehousing & logistics, Intelligent Manufacturing information systems, and other Industrie 4.0 technologies. This lab provides a comprehensive training platform for students to learn Industrie 4.0 technologies and Intelligent Manufacturing process. It is a multifunctional platform for demonstration, training and research. It can also provide major company platforms, universities and vocational schools with systematic and innovative Intelligent Manufacturing training platform, training system construction, Intelligent Manufacturing planning consulting, professional talent training and qualification certification.

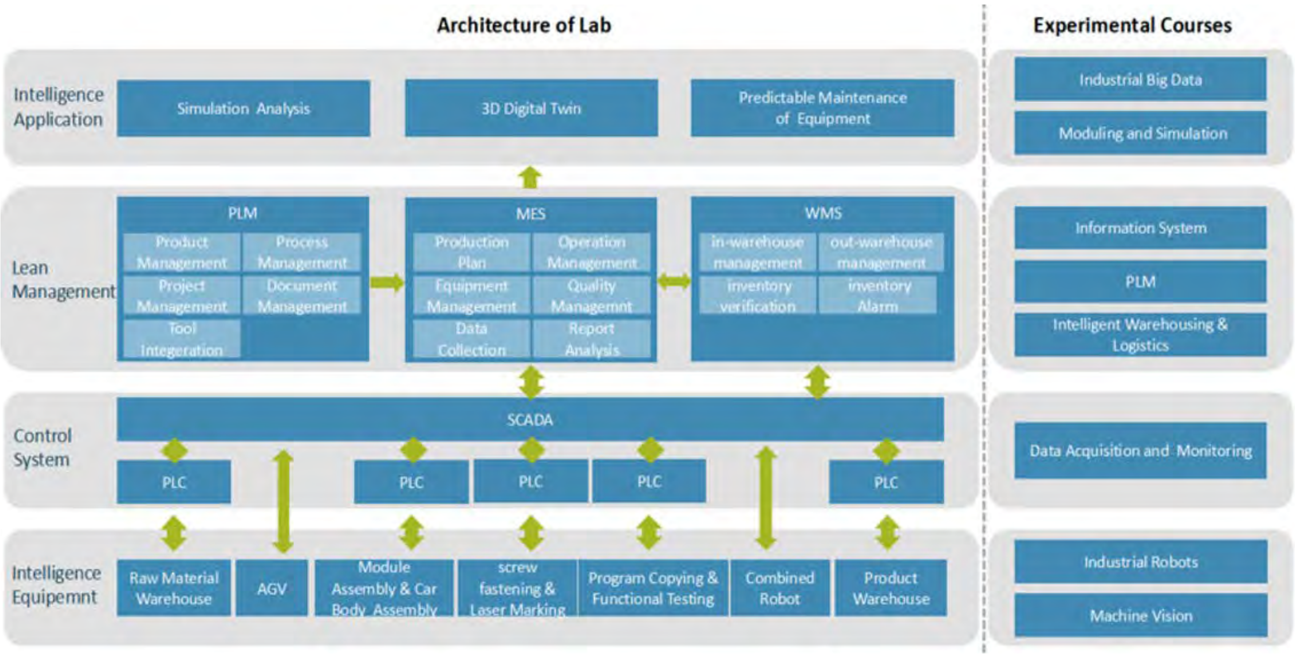


Figure 42: Laboratory structure and experimental curriculum system

The experimental teaching product in the learning factory is an intelligent cruise car with functions such as tracking, following and obstacle avoidance. Through the Intelligent Manufacturing production system, the personalised production of the car is completed throughout the experimental courses at all levels. The process includes the following seven steps: order arrival of from customers, production order generation by the manufacturing execution system (MES), AGV parts distribution, intelligent visual assembly and insertion, QR-Code marking by a laser printer, product function testing and storing of finished products in a warehouse.

The system architecture of Tongji University Industrie 4.0 Learning Factory is divided into four layers: intelligent equipment, control system, lean management and intelligent application. There are corresponding experimental courses at each level. The training is divided into a theoretical and practical part, both of which are oriented to actual projects, in order to cultivate students' project engineering ability and the practical application ability.

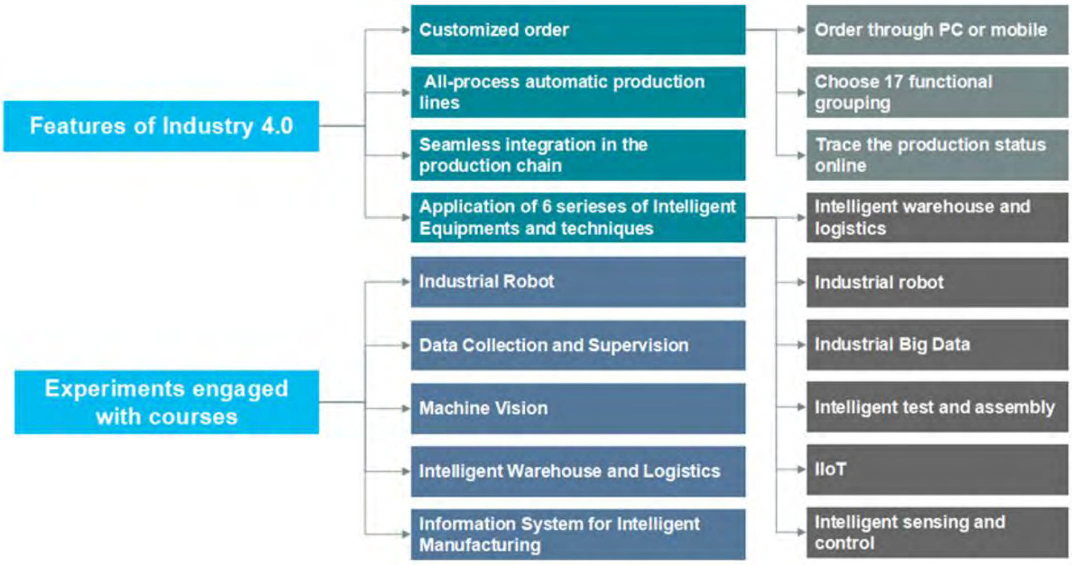
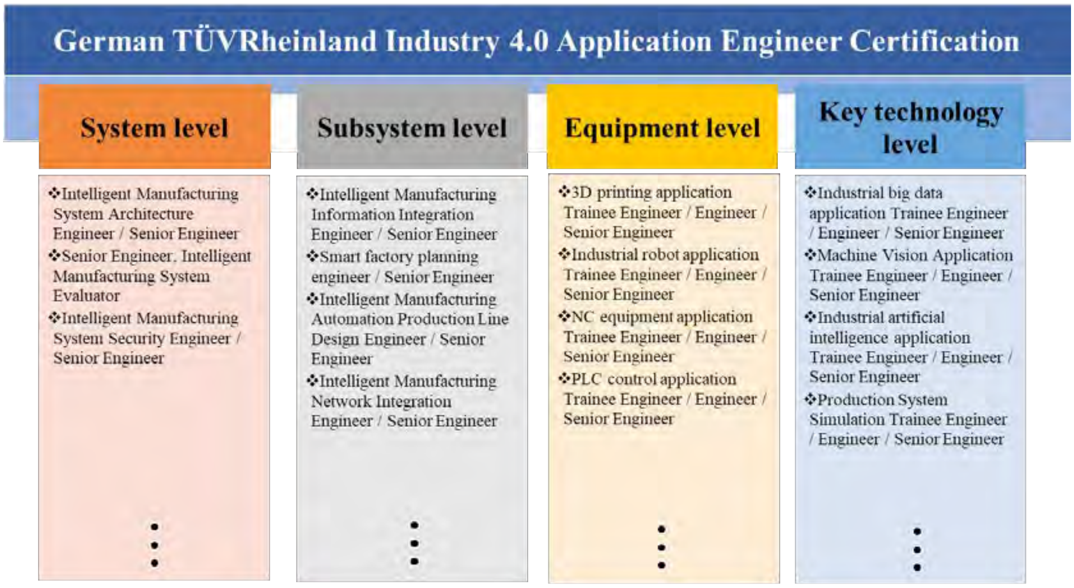


Figure 43: Features of Industrie 4.0 and experiments engaged with courses

To ensure the quality of training, Tongji University Industrie 4.0 Learning Factory Lab has introduced and developed the Industrie 4.0 application engineer certification system, relying on the talent advantages of TÜV Rheinland and Tongji University in the field of Industrie 4.0. The certification system divides Industrie 4.0 engineer positions into system level, subsystem level, equipment level and key technical level. Tongji University Industrie 4.0 Learning Factory Lab also signed with the Chinese Mechanical Engineering Society (CMES) a strategic cooperation agreement, laying a good foundation for the mutual recognition of the qualifications of Industrie 4.0 and Intelligent Manufacturing Engineers between China and Germany.

In terms of vocational skills, Tongji University Industrie 4.0 Learning Factory is developing the Industrie 4.0 and Intelligent Manufacturing Occupational Technical Worker Certification System that meets the TÜV Rheinland certification standards. It will also establish smart manufacturing vocational skill appraisal and guidance sub-centres authorised by the Chinese Machinery Industry Vocational Skills Appraisal and Guidance Centre, to empower vocational education for Intelligent Manufacturing in China and jointly promote Intelligent Manufacturing and talent training.



German TÜVRheinland Industry 4.0 Application Engineer Certification

System level	Subsystem level	Equipment level	Key technology level
❖Intelligent Manufacturing System Architecture Engineer / Senior Engineer ❖Senior Engineer, Intelligent Manufacturing System Evaluator ❖Intelligent Manufacturing System Security Engineer / Senior Engineer	❖Intelligent Manufacturing Information Integration Engineer / Senior Engineer ❖Smart factory planning engineer / Senior Engineer ❖Intelligent Manufacturing Automation Production Line Design Engineer / Senior Engineer ❖Intelligent Manufacturing Network Integration Engineer / Senior Engineer	❖3D printing application Trainee Engineer / Engineer / Senior Engineer ❖Industrial robot application Trainee Engineer / Engineer / Senior Engineer ❖NC equipment application Trainee Engineer / Engineer / Senior Engineer ❖PLC control application Trainee Engineer / Engineer / Senior Engineer	❖Industrial big data application Trainee Engineer / Engineer / Senior Engineer ❖Machine Vision Application Trainee Engineer / Engineer / Senior Engineer ❖Industrial artificial intelligence application Trainee Engineer / Engineer / Senior Engineer ❖Production System Simulation Trainee Engineer / Engineer / Senior Engineer
⋮	⋮	⋮	⋮

Figure 44: German TÜV Rheinland Industrie 4.0 application engineer certification system

Tianjin Sino-German University of Applied Sciences

Tianjin Sino-German Training Centre for Modern Industry Technology, which was founded in 1985 by Chinese and German government, was merged with Tianjin Sino-Japan Training Centre for Enterprise Management in 2009 into Tianjin Sino-German Vocational Technical College. It was recognised as one of the first national key bases for constructing a training centre for vocational education teachers in 1999 and became a national training base for vocation school and college teachers in 2000. In 2015, the college was founded under the approval of the Ministry of Education of P.R. China as Tianjin Sino-German University of Applied Sciences.

The Intelligent Manufacturing School of Tianjin Sino-German University of Applied Sciences has a robot generic technology platform, an intelligent product line teaching demonstration centre, and an industrial information security experimental teaching demonstration centre. It can undertake the installation, simulation, programming, and control system development of industrial robots. There are four kinds of students studying in the Intelligent Manufacturing School, namely secondary vocational students, vocational students, undergraduates and postgraduates. Based on Industrial Internet, Enterprise Big Data analysis and optimisation, customised technical services for cloud platform products as well as information security test of Industrial Control System, the school cultivates talents who contribute to the transformation and upgrading of manufacturing companies and industry after graduation.

The main teaching methods of Tianjin Sino-German University of Applied Sciences combine theoretical teaching and practice, and training forms include face-to-face seminars, training observation and live demonstrations, etc. In the theoretical teaching, students are required to master the concepts and meanings—know "what is it" and "when to use". In the practical part, the students are required to master the application methods and application scenarios of the knowledge—know “where to use” and “how to use”. The “help document” usage strategy is injected into teaching reasonably to improve the self-learning ability of students, transforming a “learner” into a “producer”. Tianjin Sino-German University of Applied Sciences also explores a step-by-step comprehensive training method that has three stages: “project independent training method”, “project team training method”, and “engineering project training method”. By completing the three-step scheme: “from individual to team”, “from simple project to comprehensive project”, and “from a school project to company project”, the students can gain a good command of the knowledge and skills gradually.

Figure 45: Robot generic technology platform

Figure 46: Intelligent product line teaching demonstration centre

Shenzhen Polytechnic

Founded in 1993, Shenzhen Polytechnic is a public institution registered with Shenzhen Municipal Bureau of Education to carry out training business and the seventh Vocational Skill Appraisal Institute of Shenzhen Municipal Bureau of human resources and social security. At present, it qualifies 12 occupations (types of work), and can carry out more than 30 domestic and international vocational qualification certification examinations. And there are 251 skills appraisal and qualification certification projects, including 67 international certificates.

Aiming at the development of Intelligent Manufacturing industry, Shenzhen Polytechnic has established the Innovation and Practice Centre of Intelligent Manufacturing. Relying on the Intelligent Manufacturing professional group (including professionals in the fields of mechatronics technology, industrial robot technology, mechanical design and manufacturing, intelligent control technology), the centre can carry out special skills training such as digital design, industrial control network, flexible Intelligent Manufacturing of industrial robot, etc. It has formed an open and multi-collaborative training and appraisal base for Intelligent Manufacturing skilled personnel, which focuses on the robot and integrates technology research and development, production, students’ practice, teacher cultivation and social training.

The Industrial Control Network Integrated Training System integrates robot control, visual control, frequency conversion drive control, servo drive control, RFID control, pneumatic control, programmable controller, sensor and other technologies. It is helpful for students to master a wide variety of Intelligent Manufacturing skills such as mechanical design, electrical automation, automatic control, computer technology, etc. Students can also improve their comprehensive ability of design, assembly and debugging by the application of PLC programming, sensor and detection technology, motor drive and control technology.

The Flexible Intelligent Manufacturing Integrated Training System is based on the integrated application of industrial robots and focuses on mechanical transmission technology. It can train students to be highly skilled personnel who master the basic theoretical knowledge and operation skills of industrial robot application and maintenance, who are able to independently engage in the installation, programming, debugging, maintenance, operation and management of mechanical and electrical equipment and industrial robots, and who possess good practical experience, and can carry out robot system maintenance, robot workstation installation, debugging, maintenance and operation management.

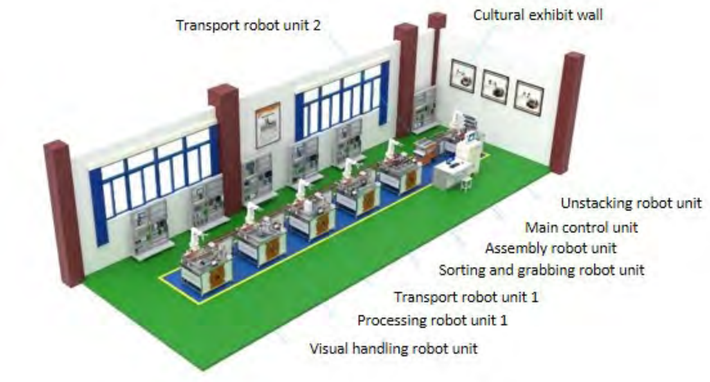


Figure 47: Multi-functional integrated production line integrated application training room

Figure 48: Industrial Control Network Integrated Training System

Enterprise training units:

Haier COSMOPlat Education Platform

In order to enhance the effectiveness of talent supply, Haier COSMOPlat Education Platform plans and implements the cultivation of trainees according to the targeted job requirements. After personnel incubation, talents will be sent to the targeted position. COSMOPlat Education Platform carries out order-based cultivation of interdisciplinary talents for intelligent production, Intelligent Manufacturing technological talents, intelligent equipment technicians, and knowledge-based talents for Internet factory transformation.

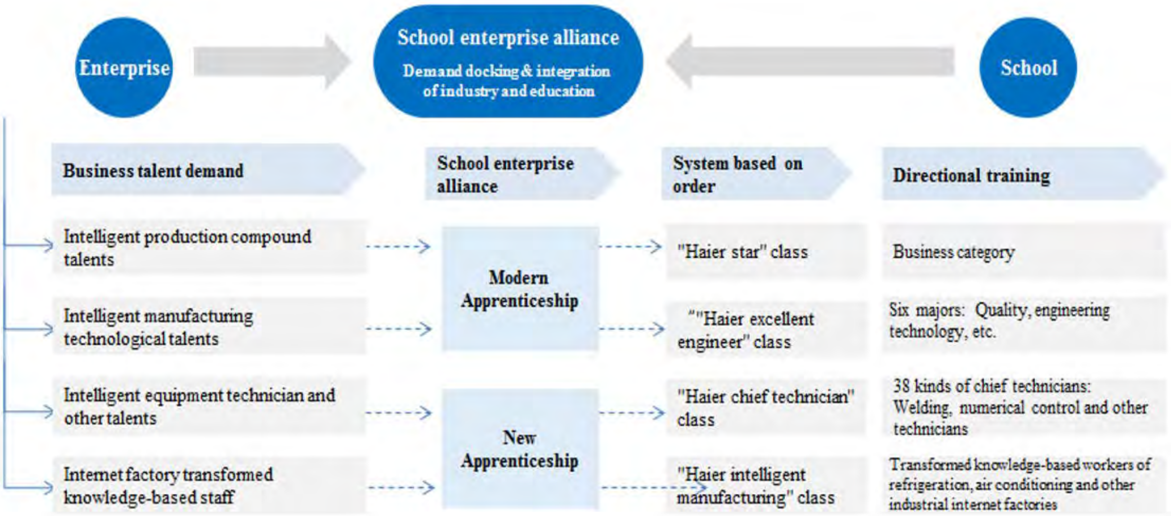


Figure 49: Training system of knowledge-based employee in Haier Internet factory

The directional cultivation system includes schools and enterprises. It builds cultural and intellectual education platform, practical training base and dual teachers training mode at school, while constructing Enterprise S-Centre, establishing knowledge-based staff “1 + X” post-learning system, and holding technician skills competition in the enterprise.

Among them, the cultural and intellectual education platform focuses on the innovative mode of intellectual education of “academic certification (1) + skill training (x)”, so as to realise the lifelong development of talents. The training base at school focuses on “industry support + mode leading innovation”, allows schools and enterprises to play the key role and build an intelligent technological application centre that integrates production, learning, research and application. Therefore, it can incorporate new technology, technique and specifications into the teaching standards and contents to strengthen students’ practical training promptly. Through the dual training mode of “famous teachers in school” and “famous trainers in enterprise”, the advantages of teaching resources of schools and enterprises can be given full play. It can, on the one hand, recommend famous trainers from the enterprise to give Haier customised courses and other excellent courses to the class in the cooperative school, coordinate the development of teaching materials, establish a teacher workstation, and connect the school and students with practical training resources. On the other hand, it can also invite experts and teachers from various colleges and universities to the enterprise in order to conduct innovative exploration (problem study, textbook compilation, patent research, etc.), and establish a craftsman workstation, so that the training can be based on the practical industrial chain.

According to the certification, learning and development system, Haier COSMOPlat Education Platform assesses the professional ability, operation ability and basic ability, and sets up two kinds of talent development channels for professional talents and operation-oriented talents, in order to meet the learning needs of knowledge-based employees in the Internet factory and the training needs of strategic talents.

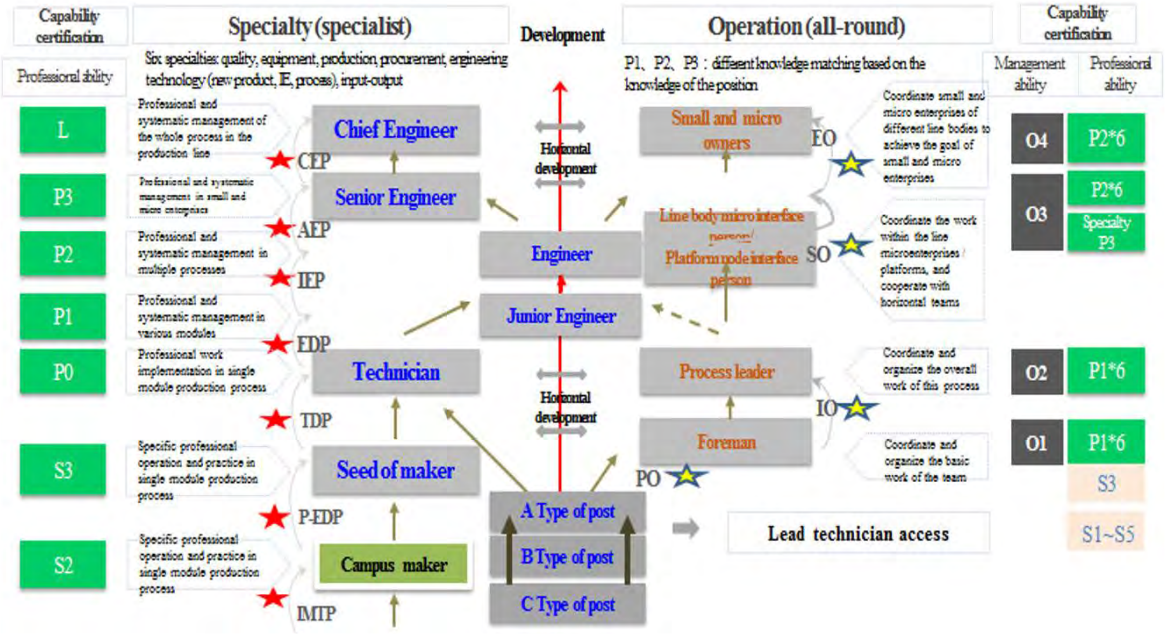


Figure 50: Employee development map

INDICS-based Intelligent Production in Learning Factory

Based on the self-developed public internet service platform, INDICS, CASICloud-Tech Co., Ltd (CASICloud) has set up a learning factory for intelligent production. The platform builds a miniaturised customised production scenario and combines demonstration with related teaching material. Therefore, it guides students to understand how companies improve automation, flexibility and informatisation level through modular production units, flexible control, precision logistics under the background that manufacturing is currently transforming from mass production to customised production, in order to achieve personalised order-driven multi-varieties and small-batch production mode.

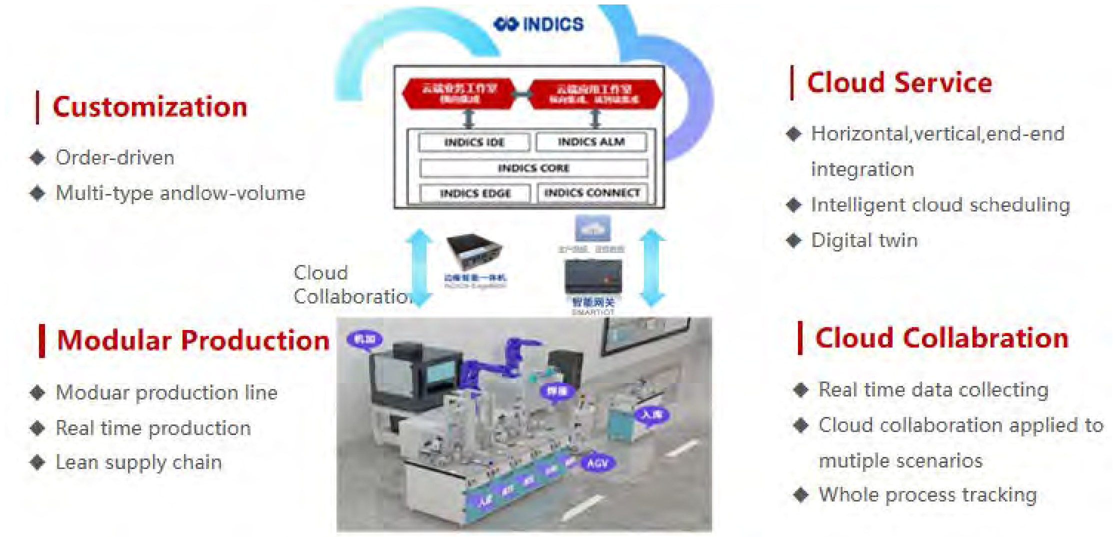


Figure 51: INDICS-based intelligent production in learning factory

The learning factory demonstrates INDICS-based cloud manufacturing mode, flexible production mode driven by personalised orders, the full life cycle business management scenario, virtual industrial software application scenario, collaborative design scenario, resource planning management scenario with the cloud ERP, production management scenario with the cloud MES, cloud-based industrial app application, and production line optimisation scenario based on cloud manufacturing software CMOM. It also tests and verifies many technologies, such as container deployment, IoT platform access and application, intelligent cloud production scheduling, production line operation optimisation based on Industrial Big Data, digital twin, collaborative design based on cloud CPDM, and intelligent gateway for edge computing.

CASICloud adopts the task-driven training mode that combines demonstration and practice, aiming to serve the development of Industrial Internet and Intelligent Manufacturing and realise the value of consultation and training. Through the miniaturised scenes and training courses for application skills, it helps trainees to deeply experience and understand the order-driven production life cycle production. The teaching content is diversified to be applied to different industrial scenarios, and can be extended to cloud manufacturing demonstration and training factory. The order-driven flexible production shown in the case has been applied and promoted in companies from the complex high-end components industry.

Neusoft Education Technology Group Neuedu has taken the key talent needs in the field of Intelligent Manufacturing into consideration and established a hierarchical IT talent training system that combines a new generation of information technology, such as AI, Big Data, software technology, intelligent IoT, automotive electronics, cyberspace security. Meanwhile, Neuedu has trained and transferred more than 200,000 talents for the industry, and taken the lead in formulating the national standard and industry standard of IT talent training and evaluation in China.

Relying on information and technology, Neuedu combines online to offline (O2O) service modes, and uses the Internet and cloud computing technology, to provide interactive and practical education services. It combines Intelligent Manufacturing engineering talent and job requirements, “transforms”, “accumulates” and “precipitates” company resources to form a new talent training system.

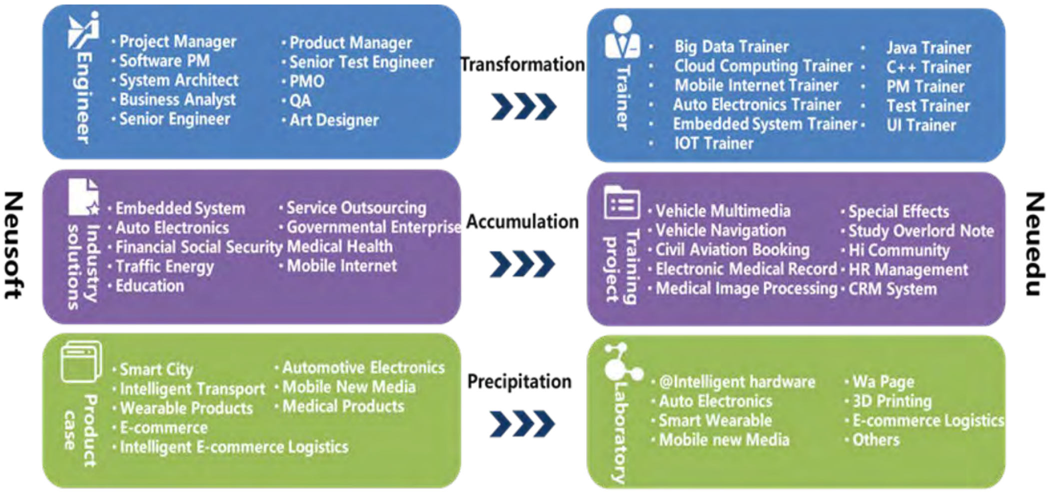


Figure 52: Structure of Neusoft and Neuedu

Based on the concept of that education creates students' value, Neuedu draws on CDIO engineering education mode, innovates the CDIO ability training program and constructs the talent training mode that covers the eight key abilities of TOPCARES CDIO system. In the training, students are trained strictly in accordance with the professional requirements and the assessment standard of the company (CMMI5 + Agile). After the training students can achieve comprehensive development in technical ability, business understanding ability, attitude, responsibility, team cooperation, communication ability and other aspects.

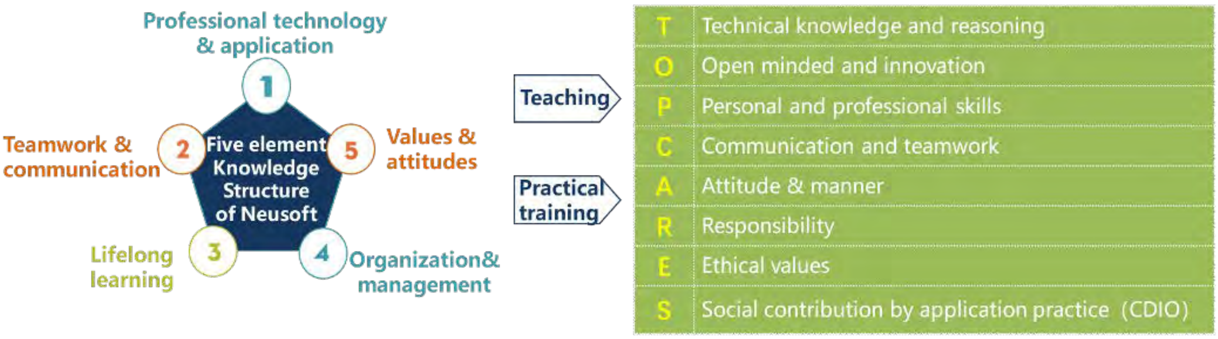


Figure 53: Knowledge structure of Neusoft

Global Advanced Manufacturing Institute (GAMI)

The Global Advanced Manufacturing Institute (GAMI) in Suzhou provides two training centres for corporate trainings regarding Industrie 4.0.

The Industrie 4.0 Demonstration and Innovation Centre serves as a high-level training facility, where theoretical knowledge of expert trainers on how to use Industrie 4.0 to increase visibility and transparency on the shop floor is enriched with hands-on experience. The core area of the Innovation Centre consists of a highly integrated small-scale production system, with a manual and a smart assembly line, a smart material replenishment system as well as integrated software and worker support systems. The smart assembly line is derived from a real production line by Bosch Rexroth, where 90 different product variants can be assembled in a one-piece flow without any change over time. With the help of RFID technology, every variant can directly communicate with each assembly station, ensuring the accuracy of tightened-up parameters. The worker is shown only the specific digital work instruction for the actual variant which guides him or her step by step through the process. Supported by the clear solutions provided, workers are able to avoid mistakes in the assembly process. Due to the derivation of the centre from a real production line, the Industrie 4.0 Demonstration and Innovation Centre can be classified as a model factory.

In the Artificial Intelligence Innovation Factory, the question is explored, how approaches and technologies in the field of AI can be applied to generate profit from the increasing volume of data. The integrated applications vary from Augmented and Virtual Reality, Cloud and Big Data Computing, Production Simulation to Human-Robot Collaboration. With the support of high-speed algorithms, incoming orders can be planned and scheduled based on the real-time status of the production. On the assembly line, the individual product requirements can be identified by RFID technology, which also accurately allocates the task to the collaborative robot in order to support the worker and enhance efficiency.

Apart from improved efficiency, safety can also be guaranteed. In the above-mentioned case, a safe human-robot collaboration is ensured by sensitive skin. Safety equipment additionally ensures that employees are within in a comfortable working distance to the robot. Smart lights indicate to which degree a planned takt time for a station is achieved, while sensors added to the material racks enable instant identification of necessary components to be provided by logistics. Augmented Reality technology at the workstations guides the operators efficiently through complex assembly processes, while a smart camera ensures the completeness of assembly task. An additional lightweight robot allows for quick teaching as well as scalable and easily adaptable support based on the current order requirements.

Furthermore, VR technology is analysed with regard to its potentials of robot remote teaching as well as equipment maintenance. The digital layout planning helps to identify improvement potentials in the production process by providing spaghetti diagrams and heat maps of the individual employees in real time.

Finally, all data generated in the production process will be collected in real time and shared with the interconnected facilities at KIT by cloud technology. An in-depth analysis of the data supports the operational decision-making worldwide. Unlike the showcasing of many advanced technologies, the Artificial Intelligence Innovation Factory can be classified as a demonstration platform for further learning and promotion.

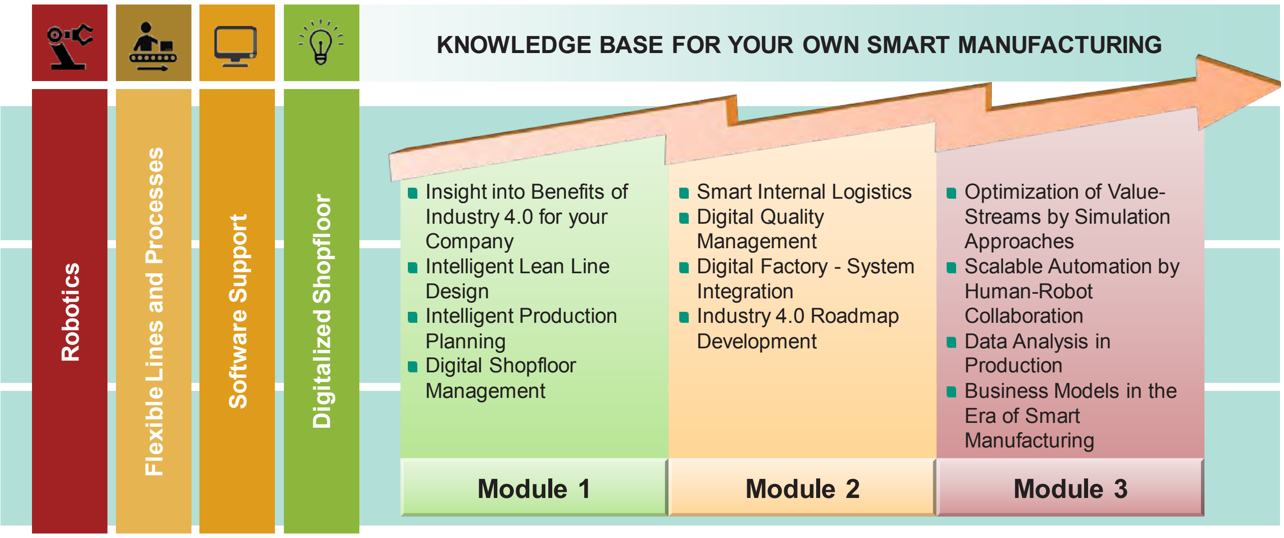


Figure 54: Training courses at GAMI

6 Conclusion and Recommendations

Based on the study elaborated in the previous chapters, the following recommendations for industry, training providers as well as policymakers can be derived. Furthermore, the outlook on potential topics in 2020 is provided.

6.1 Recommendations for Companies

- Further develop employees' qualification as it is a key success factor in the course of digital transformation.
- Make effective use of existing maturity indices to help identify and analyse existing skill gaps in a clear and systematic way.
- Make use of supporting training units and corresponding training courses once the action fields regarding workforce development are determined (in case when own training capabilities and resources are not sufficient).
- Manage the change by creating a work environment and culture, where life-long learning and agility to adapt promptly to new development are embedded.

6.2 Recommendations for Training Providers

- Shift the focus from showcasing to real learning (platforms).
- Provide practical and case-specific trainings that are closely in alignment with the Industrie 4.0 concept.
- Improve the qualification of trainers by facilitating the Train-the-Trainer concepts.

6.3 Policy Recommendations

- Facilitate the development of a maturity model that focuses on the workforce in the age of digital transformation and support companies in self-assessing their workforce's readiness and finding capacity development measures.
- Standardise such maturity levels, promote general acceptance in the industry and better enabling companies to determine the qualification of their employees and implications for future recruitments. (see EFQM Excellence model as a reference)
- Encourage Chinese and German companies / institutions to cooperate on establishing regional Intelligent Manufacturing training centres / innovation centres while facilitating the use of existing training units.
- Formulate standards for Intelligent Manufacturing training centres
- Allocate funds with a focus on establishing actual training units and Train-the-Trainer concepts instead of technological showrooms.
- Provide training subsidies to companies that support the training of their employees at Intelligent Manufacturing training centres.
- Provide financial support for training centres based on the number of trainings conducted, providing that these training centres meet the quality standards.
- Developing standards for further education curricula for the existing workforce is helpful and necessary.

6.4 Outlook

For 2020, the EG Training 4.0 will focus on the following topics:

- Propose a standardised maturity model for workforce skill assessment.
- Define the certification criteria for training centres.
- Develop a consistent course guideline coherent with the maturity model and based on the specific needs and nature of the companies.
- Define the roles of the government, industry and academia in shaping a sustainable skill development ecosystem.

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