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Transition towards an Industry 4.0 state of the LeanLab at Graz University of Technology

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Abstract

The Institute of Innovation and Industrial Management operates a learning factory (LeanLab) since 2014 to enhance academic education, company trainings and hands-on research in the fields of industrial engineering and logistics. The aim is to enable practice oriented learning in an environment close to industrial reality for facilitating effective knowledge-transfer. An extension with state of the art technologies relevant for future manufacturing sites is currently planned. Learning factories are suitable platforms for applying, testing and spreading technologies and should thus guarantee better and more targeted technology-development and transfer. Moreover, training sessions for workers will be designed to prepare them for the Industry 4.0 environment in the factory of the future. These trainings will focus on the development of the skills and qualifications necessary for workers to cope with the increasing complexity in industrial environments. This paper presents the actual state of the LeanLab and illustrates the next concrete steps towards an Industry 4.0 learning factory.

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Keywords: Learning Factory, Industry 4.0, Lean Manufacturing, Hands-On Education

1. Introduction

In the past, technology, especially automation, has been one of the key drivers to increase productivity [1]. Manufacturing industry is currently facing disruptive challenges due to a variety of factors such as ongoing demographic changes, external volatility and the increasing complexity of products and processes. In this context technological innovation, such as real time, adaptive and decentralized Cyber-Physical Production Systems (CPPS) together with a major shift in the skills and qualifications required for the industrial workforce are playing a significant role. The term “Industry 4.0” describes a vision of “intelligently” automated factories [2,3,4]. The Institute of Innovation and Industrial Management at Graz University of Technology operates a learning factory (LeanLab) to enable practice oriented learning in an environment close to industrial reality. The aim is to facilitate effective knowledge-transfer and to address future challenges faced by the manufacturing industry. Furthermore, the LeanLab is planned to serve in the near future as a platform for demonstrating relevant parts of the Industry 4.0 vision.

This research presents (1) the current state of the LeanLab, (2) upcoming challenges for industry related technological developments and changes concerning the future workforce, and (3) the applied approach and a resulting technology roadmap based on Industry 4.0 levers as the basis for concrete short-, mid- and long-term actions for achieving an Industry 4.0 status.

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2. LeanLab at Graz University of Technology

The Institute of Innovation and Industrial Management has operated the LeanLab since 2014 to enhance academic education, company trainings and hands-on research in the fields of industrial engineering and logistics. In order to gain further insights into the LeanLab operating model, the morphology of learning factories proposed by Abele et al. [3] is applied to the specific case in Appendix A.

Participants of LeanLab workshops assemble a fully functional, market available scooter (see fig. 1) in TU Graz design. The product consists of 60 pieces and is assembled in 14 working steps taking 12 minutes and 50 seconds. The curriculum aims to increase the industrial management skills and qualifications of students and industrial personnel. Topics include industrial engineering aspects such as workplace organization, logistics management, factory planning as also methodologies such as lean manufacturing or energy efficiency. The didactic and methodological approach in the LeanLab is based on two setup states: (1) the initial current state and (2) the optimized future state. When workshops start the TU Graz scooter is assembled under sub-optimal conditions in terms of workspace, material and information flows. The participants learn how to operate the process themselves and also the methods to discover improvement opportunities. These opportunities are discussed and possible solutions are worked out in the intertwined, short theory sessions. Selected solutions are implemented directly in the LeanLab and the improved setup is iterated towards the future state. The benefits of the implemented improvements are quantified through the assembly of the scooter in the new setup and the comparison of predefined key performance indicators such as throughput time, number of defects, energy consumption, etc.

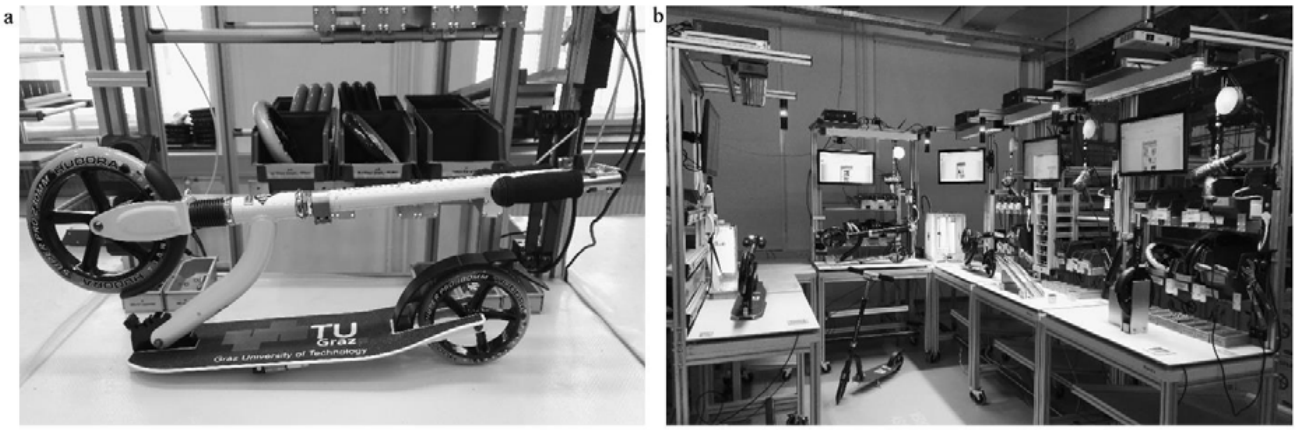


Fig. 1. (a) TU Graz scooter; (b) LeanLab “future state”.

3. Upcoming challenges in the manufacturing industry

In a volatile world, market demand for individual and specialized products with even shorter life-cycles requires changes in the industrial work system. Highly flexible and adaptable production systems are an important factor to be competitive in a globalized market with small batch sizes of frequently customized, manually assembled products. Automated mass production might become less economically viable [5,6,7]. Companies face challenges in developing skills and qualifications of their workers concerning e.g. problem-solving skills, failure analysis, the ability to deal with constant changes and completely new tasks [2]. In addition, industry and society in general must face the so called “Grand Challenges”. The European Union set up the “Horizon 2020” program to tackle the demographic change, clean and efficient energy, resource-productivity and climate actions [8]. Demographic change, with workers becoming older on average and with a background of increasing ethnic diversity, is of particular interest in this context for industrial companies [9]. This section provides information on the technology- and workforce related implications on production systems for gaining insights into upcoming challenges in manufacturing industry.

3.1. Technology

The so-called fourth industrial revolution after mechanization, electrification and automation is in frequent current discussion in industry and research. The term “Industry 4.0” describes the vision of “intelligently” automated factories, in which workers, the production system itself, products and even customers are connected. According to the vision of Industry 4.0 these interconnected systems will cooperate closely. One of the main benefits is the possibility to strive for the maximum value creation across the value chain through continuous and autonomous exchange of information and data [4].

Figure 2 shows Industry 4.0 levers according to classic value drivers derived from the literature [10].

Value drivers	Industry 4.0 levers
Asset utilization	Routing flexibility
	Machine flexibility
	Remote monitoring and control
	Predictive maintenance
	Augmented reality for maintenance and repair organization
Inventories	In situ 3-D printing
	Real-time supply chain optimization
	Batch size 1
Resource/ process	Smart energy consumption
	Intelligent lots
	Real-time yield optimization
Supply/ demand match	Data-driven design to value
	Data-driven demand prediction

Value drivers	Industry 4.0 levers
Labor	Human-robot collaboration
	Remote monitoring and control
	Digital performance management
	Automation of knowledge work
Quality	Statistical process control (SPC)
	Advanced process control (APC)
	Digital quality management
Service/ aftersales	Predictive maintenance
	Remote maintenance
	Virtually guided self-service
Time to market	Rapid experimentation and simulation
	Concurrent engineering
	Customer co-creation/ open innovation

Fig. 2. Industry 4.0 levers [10].

These Industry 4.0 levers help companies to define their strategy for deciding how to approach the fourth industrial revolution. Some specific enabler technologies are crucial, however, for realizing the full potential of Industry 4.0. Figure 3 shows technologies which might enhance the capabilities of factories to cope with the changing marked demand and to remain globally competitive in future [11,12]. The expectations are enormous from enabling technologies and the production systems derived from them, which are often referred to as Cyber-Physical Production Systems. Even a partial fulfillment of expectations such as robustness, autonomy, self-/smart maintenance, predictability, and interoperability present challenges to the fields of computer sciences, information and communication technologies as also to manufacturing science and technology [4,13]. These upcoming technologies under the umbrella term “Industry 4.0” imply changes of the production processes and consequently for future work-tasks in industry. The requirements from the workforce are thus also in a transition phase.

Area	Technology
Communi-cation	Self-organizing communication network
	Real-time wireless communication
	Wire-based high performance communication
	IT-security (data protection, information security)
	Mobile communication channel
Embedded systems	Miniaturized embedded systems
	Energy harvesting
	Intelligent embedded systems
Human machine interface	Human behavior model
	Context-based information presentation
	Semantics-visualization
	Gesture-/ voice control
	Perceptual user interface
	Remote maintenance
	Virtual / augmented reality
	Intuitive operating elements

Area	Technology
Sensor and actuator technology	Miniaturized sensors
	Intelligent and (re-)configurable sensors
	Sensor fusion
	Intelligent actuators
	Networked actuators
Standard-izations/Norms	Communications standards
	Standardization of system elements
	Identification standards
Software and systems technology	Simulation environment
	Multi-criterial situation evaluation
	Multi-agents systems
	Machine learning and pattern recognition
	Big data storing procedure and analytical methods
	Cloud computing
	Web- and cloud services
	Ontology

Fig. 3. Technologies for the industry of the future [11].

3.2. Workforce implications

Industrial history indicates that the implementation of new production systems does not necessarily increase productivity [14]. To give an example: lean manufacturing, first introduced at Toyota, and its different tools to help people become more effective could only be successfully implemented if the companies put massive effort into human-centered change processes [15]. Industry 4.0 is currently changing production processes and consequently industrial work tasks are in flux. These changes are provoking a shift in the required skills and qualifications of the human workforce [15,16]. The trend of automating highly repetitive and exhausting tasks will continue. Workers will have a much greater share of doing complex and indirect tasks such as collaborating with machines in their daily work [16,17]. This trend is leading to the following three consequences: workers will have to (1) solve

unstructured problems, (2) work with new information, and (3) carry out a number of non-routine manual tasks [17]. Dealing with continuously new information and a large quantity of data plus communication with machines are thus the basic elements of future work tasks [18].

As Industry 4.0 enforces systems with a higher complexity due to automation and the interconnectivity of all its elements, organizational and processual understanding will be, among other important skills, a basic qualification for industrial workers [5]. These comprise the ability to recognize elements of the overall production system, identification of system borders, understanding of functions and relationships within the system and thereby to be able to predict the systems behavior [18]. Figure 4 shows further qualifications and skills for future challenges in Industry 4.0 production environments. Skills are separated into personal and technical skills and structured into: “must have skills”, “should have skills” and “could have skills”.

Those skills that have arisen due to the digitalization trend show clear similarities with past development trends e.g. electrification or automation and major socioeconomic impacts are thus also implied by their appearance[14,19,20].

	Classification of required skills and qualifications		
	Must	**Should**	**Could**
Technical	IT knowledge and abilities	Knowledge management	Computer programming and coding abilities
	Data and information processing and analytics	Interdisciplinary/generic knowledge about technologies and organizations	Specialized knowledge about technologies
	Statistical knowledge	Awareness for IT-security and data protection	Awareness for ergonomics
	Organizational and processual understanding	Specialized knowledge of manufacturing activities and processes	Understanding of legal affairs
	Ability to interact with modern interfaces		
Personal	Self and time management	Trust in new technologies	
	Adaptability/ability to change	Continuous improvement and lifelong learning	
	Team work abilities		
	Social skills		
	Communication skills		

Fig. 4. Future qualifications and skills of workers [18].

3.3. Implications of upcoming challenges for industry and educational institutions

Industrial companies are able to tackle some of the upcoming challenges, such as the demographic change or increased ethnical diversity by applying Industry 4.0 technologies (e.g. CPPS). Specific Industry 4.0 technologies support labor, e.g. in the context of an expected increase in complexity by the collection, processing and visualization of manufacturing process data [2]. Examples of technical solutions for enhancing labor are:

- Reinforcing physical abilities such as strength or fine motor skills and lowering the physical work related strain by using exoskeletons, positioning devices, robots or automation of monotonous tasks [18,21]
- Lowering the required short-term memory effort by visualizing detailed and on demand information (users obtain relevant information when he/she needs it and in a form that he/she can comprehend it) [18]
- Reducing the number of errors made on the shop floor by real-time observation of the process and skill- /ability based work instructions [6,18]

The predicted shift in required skills and qualifications leads to the necessity for further training in modern technologies for the workforce of today and the future. Classic lecture based teaching methods would not appear to be suitable here, especially in the context of developing the skills required for future manufacturing environments. Learning factories, which already have an emphasis on interdisciplinarity and a close-to-practice approach, must react to innovations like Industry 4.0 to meet future teaching requirements [3].

This trend is confirmed by looking at recent research published for example in the proceedings of the 6th CIRP Conference on Learning Factories [22]. Amongst others, articles like “Implementing Cyber-physical Production Systems in Learning Factories” [23], “Using a Learning Factory Approach to Transfer Industrie 4.0 Approaches to Small- and Medium-sized Enterprises” [24] or “Learning Factory Modules for Smart Factories in Industrie 4.0” [25] provide valuable guidance for the ongoing development of the LeanLab at Graz University of Technology. Further, Schuh et al. conclude in “Promoting work-based learning through Industry 4.0” that Industry 4.0 offers technological possibilities to enhance work-based learning [2]. The LeanLab is thus in process of being upgraded to an Industry 4.0 status in order to contribute significantly to dealing with all future challenges in higher education and employee trainings.

4. The transition of the LeanLab

The external environment, the available technology, the learning needs of the participants in training workshops, the research agenda, and the expectations from industry are the drivers for development needs of the LeanLab.

The basis of the ongoing development of the LeanLab is two-fold: (a) a literature search resulting in the mapping of Industry 4.0 levers to the LeanLab case, and (b) inclusion of experiences gained from 3 years of operating the LeanLab with industry/student participants. The feedback data from students and industrial partner companies as also take-aways from field trips to similar learning facilities at other research institutions have been included. The team first established a structured process and thereafter applied it in order to derive a plan for continuous improvement and upgrades taking Industry 4.0 in consideration.

4.1. Approach

The procedure applied is structured in five steps: preparation, analysis, opportunity identification, evaluation, and implementation. This approach is based on available methodologies [26, 27] to successfully implement Industry 4.0 in working environments. As part of the analysis both the actual situation of the TU Graz LeanLab as also the future requirements (e.g. technology, workforce) are assessed. The resulting system of objectives and the available Industry 4.0 levers are subsequently brought together to identify opportunities. The evaluation is made by prioritizing all the levers across three time horizons resulting in a roadmap. Finally, the roadmap is discussed and an action plan with exact timings/responsibilities is agreed upon in the team.

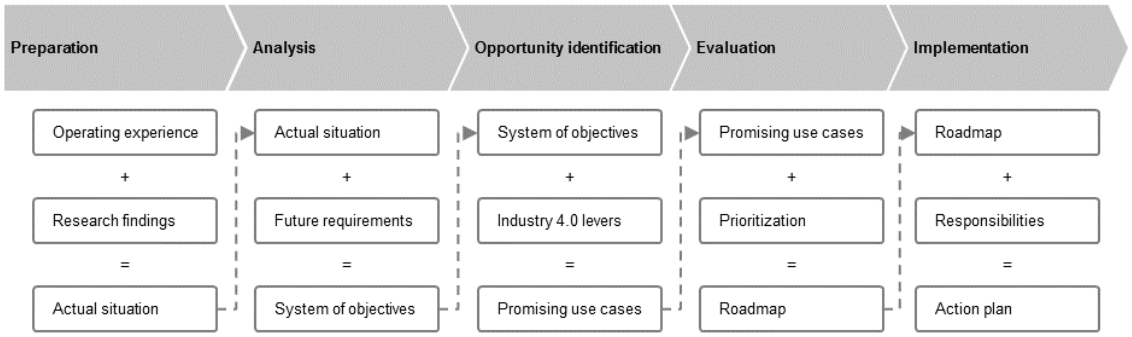


Fig. 5. Procedure to an Industry 4.0 learning factory at TU Graz.

4.2. First steps towards an Industry 4.0 learning factory

Industry 4.0 can be broken down in value drivers and a variety of assessment methodologies. In the LeanLab case, the team responsible follows the model proposed by Baur et al. [10]. The task of deriving the roadmap included the following steps: (1) reviewing the applicability of the Industry 4.0 lever, (2) prioritization along the 3 time horizons, and (3) subsequently deriving a simplified initial action plan.

The prioritization in step 2 was carried out by the LeanLab working group taking following criteria into account: applicability of technologies, promising use case; existing constraints (e.g. financial), research focus at the institute and relevance for local industry partners. The implementation roadmap (see fig. 6) includes following priorities for horizon 1:

- Implementation of a production data acquisition system (e.g. RFID) to enable the digital thread, intelligent lots, batch size 1, and quick product changeovers
- Installation of a smart shop floor board as the basis for digital performance management
- Setup of extended human-machine-interfaces (HMIs) including gesture control, smart glasses and context specific standard operating procedures (SOPs)
- Continuation of ongoing 3D printing research as part of TU Graz FabLab

The planned focus for horizon 2 will be on:

- Collaborative robotics to investigate human-robot interactions
- Big data and analytics as enablers for statistical process control (SPC), predictive maintenance, smart energy consumption, and remote monitoring and control
- Mobile workshops to experiment with machine flexibility

Longer-term, horizon 3 efforts will examine the end-to-end value stream integration, starting from product/process innovation in the TU Graz FabLab, through technology innovation in collaboration with the Institute of Production Engineering and business and methodology innovation at the Institute of Innovation and Industrial Management. The LeanLab team will also continue to develop a necessary holistic approach for educational institutions required by Industry 4.0 [28].

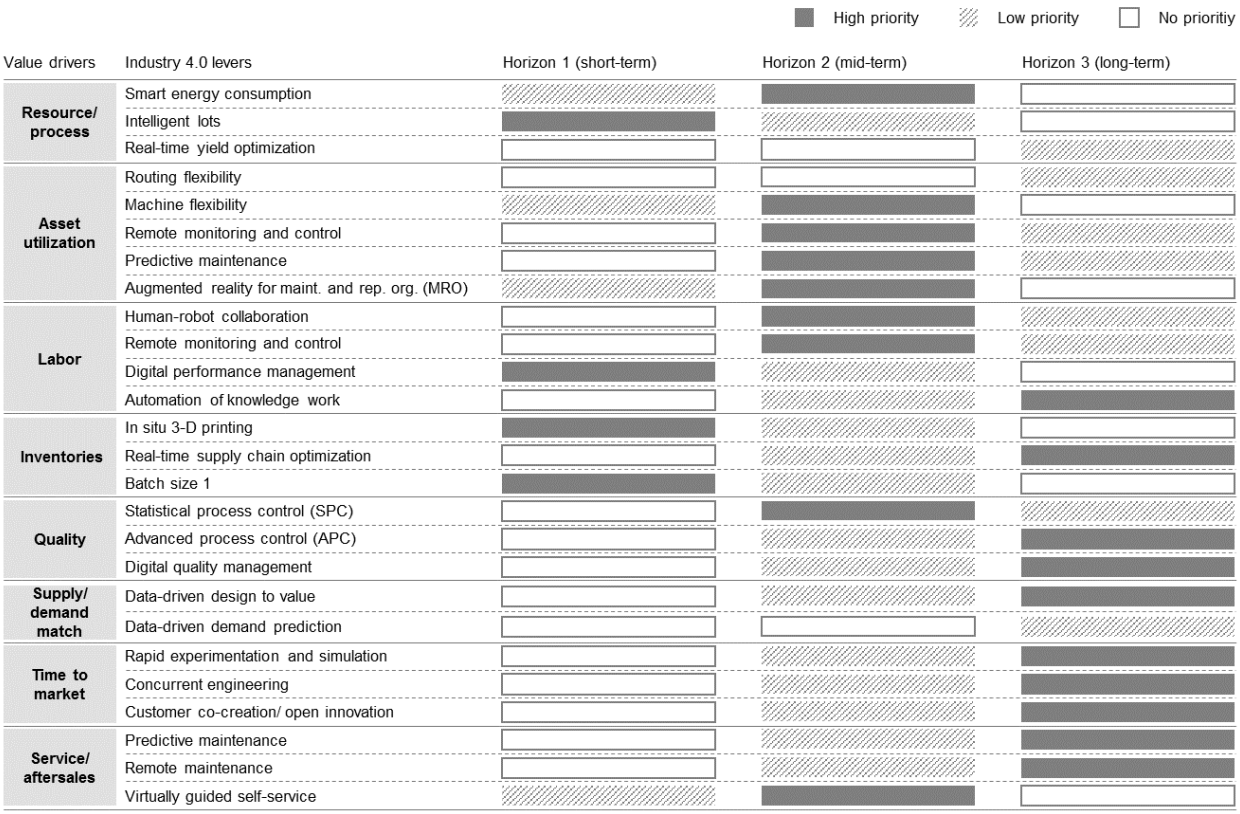


Fig. 6. Industry 4.0 roadmap along 3 horizons for TU Graz LeanLab.

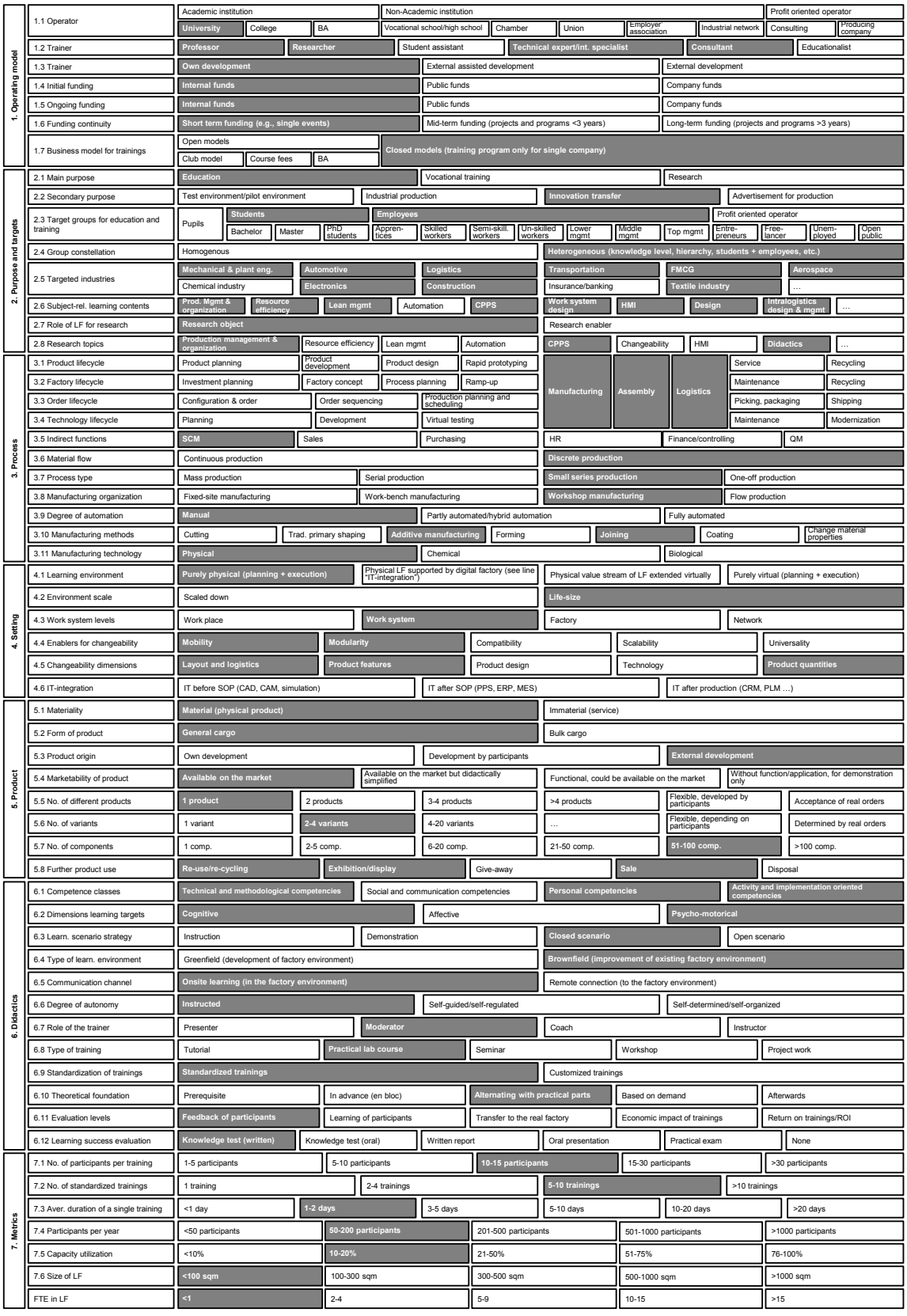
5. Summary and Outlook

The TU Graz LeanLab is a proven learning environment for students and industrial partners. In this paper the authors (a) reviewed the classification of the TU Graz LeanLab according to the morphology for learning factories, (b) summarized the upcoming challenges in manufacturing in the context of Industry 4.0, and (c) created an implementation roadmap for the specific case.

The applied approach towards an Industry 4.0 status identifies short-term priorities in the fields of intelligent lots, digital performance management, in-situ 3-D printing and batch size 1 manufacturing. The installation of RFID (intelligent lots, batch size 1) and of smart shop floor boards (digital performance management) is in progress. The mid-term horizon focuses on value drivers concerning asset utilization and human-robot collaboration. Finally, the long-term perspective includes an end-to-end value stream in cooperation with the TU Graz FabLab (open innovation, rapid experimentation and simulation) and the Institute of Production Engineering with its focus on flexible production systems.

Further research effort as part of this case study will focus on the implementation of the selected measures, their effectiveness/benefits and integration with other adjacent activities in business and academia. Ongoing efforts include the Maker Movement explored in the FabLab and technology development of a suitable gearbox for a planned TU Graz E-scooter variant.

Appendix A. TU Graz LeanLab classification according to learning factory morphology [3]



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