Lean European Action-learning Network utilising Industry 4.0

WP 1 – Mapping Smart Technologies for Lean Manufacturing

D1.1 Assessment Tool for Smart Lean Operations

D1.2 A Taxonomy of Smart Lean Operations

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"We need operations managers able to link opportunities of Industry 4.0 with Lean techniques, methods and philosophy to improve business processes", Erlend Alfnes, project leader of the LEAN 4.0 project.

LEAN 4.0 Version Control Table

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1 Introduction

1.1 LEAN 4.0

LEAN 4.0 is a collaborative initiative between four leading Higher Education Institutions (HEI) and four industrial enterprises that aims to integrate Industry 4.0 smart technologies within the proven Lean Manufacturing paradigm in order to improve factory performances. Besides the necessity of this integration to face in an efficient and effective way the continuous market changes and needs, knowledges and experiences regarding both the continuous improvement activities associated with Lean Manufacturing and the disruptive technological innovations of Industry 4.0 are still lacking.

Together, the partners of LEAN 4.0 will address this significant gap in knowledge and practical experience, anticipating the European manufacturing industry's contemporary need for development of new skills for the operations management brought along by "Industry 4.0". By acting as a conceptual framework, LEAN 4.0 will inspire the operation managers of the future and will prepare European Manufacturing for the challenges that lie ahead.

1.2 Work Package 1 – Mapping Smart Technologies for Lean Manufacturing

Work Package 1 is devoted to the linkage between Smart Technologies and Lean Manufacturing. Based on literature research and empirical studies, a LEAN4.0 assessment tool is developed by the partner HEIs and tested at the partner companies in the LEAN 4.0 project. Subsequently, the tool is used in several other companies. Another deliverable of Work Package 1 is a taxonomy which links the focus of Industry 4.0 technologies with Lean improvement principles. The taxonomy and the assessment tool serve the operations management of companies to develop a vision and strategy for the development of LEAN4.0 in their companies' methods. Due to the complementarity of these two tools (taxonomy and assessment tool), it has been decided to report the two deliverables in only one report (not in two different reports as described in the project description) to ensure a better understanding to the reader.

1.3 Deliverable D1.1 - Assessment Tool for Smart Lean Operations

Deliverable D1.1 of Work Package 1 concerns a tested assessment tool which supports the management of industrial companies to understand the situation of their firms with respect to Lean and Industry 4.0. The assessment identifies gaps between the real and the desired use of Lean methods and Industry 4.0 tools and provides input for the development of a LEAN4.0 strategy. The assessment tool can also be seen as a learning tool for managers of a company. It helps managers to understand the value of a combined use of Lean methods and Industry 4.0 technologies. Furthermore, the assessment tool supports the internal discussion in a company about the required future development of the operations function. Chapter 2 of this report is devoted to the assessment tool. The tool itself, a PowerPoint with explanatory notes, is made available on the LEAN4.0 website.

1.4 Deliverable D1.2 - A Taxonomy of Smart Lean Operations

Deliverable D1.2 of Work Package 1 is a taxonomy which links the focus of Industry 4.0 technologies with Lean improvement principles. The taxonomy is useful for managers to develop a LEAN4.0 vision of their company. The taxonomy can be seen as a benchmarking tool: it challenges managers to think about the desired role of digitalization and Lean improvement methods in their company. Furthermore, the taxonomy supports managers in their thinking about 'LEAN4.0' organization development. The taxonomy is tested in the partner companies in the LEAN 4.0 project as well as in several other companies. Chapter 3 of this report is devoted to the taxonomy tool. The tool itself, a PowerPoint with explanatory notes, is made available on the LEAN4.0 website.

1.5 Supporting studies

The assessment tool and the taxonomy are developed based upon several studies performed in the LEAN4.0 project. In the appendix of this report, we summarize these supporting studies.

2 LEAN4.0 Self-Assessment

2.1 Introduction

The purpose of the self-assessment is to give managers input for creating a Lean4.0 strategy for their company. Managers are responsible for making decisions about the development of lean principles and methods in their company. They also need to think about the use of Industry 4.0 technologies for improving the performance of their company. During the self-assessment, managers learn about the key elements of Lean and Industry 4.0. Simultaneously, they will reflect on their own situation and they will specify the importance of the various elements. Furthermore, they will think about the critical success factors which are important for the success of improvements in the area of Lean and Industry4.0. Finally, they are challenged to define a strategy, a roadmap, for the LEAN4.0 development of their company.

The self-assessment is ideally performed with a team of managers who work in the same company and play a role in the development and execution of a manufacturing strategy. The whole assessment takes about 3 hours. The self-assessment is developed in such a way that managers may apply the methodology in their own organization without external support. However, in our experience, an external facilitator can be of great support to stimulate and organize the discussion. See Section 2.9.

Results of the assessment are input for the development of an improvement strategy and roadmap. It may be useful to organize an additional session for this purpose.

In this chapter, we will present key elements of the LEAN4.0 Self-Assessment methodology. Detailed explanation of the assessment can be found in the Self-Assessment tool itself – see the website of the LEAN4.0 project.

Section 2.2 concerns starting conditions and the required introduction at the beginning of the self-assessment. Section 2.3 gives a concise overview of the various elements within the self-assessment. In the subsequent sections (2.4 – 2.8), we will explain the content of each of the elements further. Section 2.9 summarises our experiences with the self-assessment tool and explains how it can be used by management teams, consultants, students and researchers.

2.2 Starting conditions and the introduction at the beginning of the assessment

Although the whole self-assessment just takes 3 hours, it is time consuming for the management of companies. If 5 managers need to participate, then it takes 15 expensive hours plus subsequent discussions about the development of a LEAN 4.0 strategy and roadmap. Therefore, it is important that the whole management team understands the goals and the value of the assessment:

- The goal of the assessment is to find LEAN4.0 elements for strategic choices for the coming 3-5 years. It is important that the attendees of the assessment have that in mind.
- The LEAN4.0 assessment tool focuses on the required development of the operations function of a company. Different disciplines play a role in this development: planning, operations, marketing, IT, etc. It is therefore important to have a cross-functional team of managers participating in the assessment.
- A key element of the assessment is that the participants perform the assessment together. The assessment is a self-assessment. The opinions of the participants are important. They will be asked to assess the own situation relative to the 'ideal LEAN4.0' situation and to

judge to what extent this ideal situation is desirable for the company in the near future (3-5 years). Agreement about this, is a first step towards the development of a LEAN4.0 strategy. Sometimes, managers may disagree: this is a nice opportunity for discussion. It is our experience that the discussion during a self-assessment is highly appreciated by the attendees, see section 2.9.

- Some managers may argue that they do not know much about Lean and Industry 4.0. Participation of these managers however is important. For them, the LEAN4.0 Self-Assessment is also an opportunity to learn. Also more experienced managers learn from the assessment, as is our experience.

Many companies produce more than one product. Complexity and routings of these products may be different. Also, customers may differ. It is important to agree with the participating managers which product type is central to the assessment. Companies should select an important product type, or family, on which they want to improve their competitive performance by means of Lean and/or Industry4.0 technologies. Of course, during the assessment it may be useful and important to make links to the value stream of other product types and families. In most cases, companies make use of shared resources.

The selection of product type, or family, corresponds with the selection of a Focused Target Market Segment (FTMS) within Quick Response Manufacturing (QRM), the ‘lean approach’ for companies which produce a high variety of products. More information about QRM and the selection of an FTMS can be found in Rajan Suri’s book ‘It’s about time’ (2010).

The selection of a product type, or family, can be done at the beginning of the self-assessment session or before the start of the self-assessment. It has to be noted that substantial parts of the self-assessment are independent of the product type.

A good introduction at the LEAN4.0 assessment session is essential. This introduction may consist of several parts:

- The explanation of the purpose of the self-assessment and the importance that everybody participates.
- Briefly explain the meaning of Lean and Industry 4.0. It may be valuable to give a starting example of what LEAN4.0 can do for a company. In the LEAN4.0 Self-Assessment tool an example of ‘the-garage-of-the-future’ is given. See the website of the LEAN4.0 project.
- A short introduction by each of the participants. It is good that they tell about their experiences with Lean and Industry 4.0. This may give a first impression of the importance of Lean and Industry 4.0 for the company.

Support for these elements in the introduction of the self-assessment is given in the LEAN4.0 Self-Assessment tool.

Next, the participants of the assessments have to understand how a 9-points scale works. During the assessment, the participants are asked to assess their current situation and the desired situation on various topics by means of a 9-points scale. This scale offers the possibility to answer questions in two steps. First by making a rough assessment (little, average, much) and next by nuancing this answer.

2.3 The self-assessment – stepwise towards a LEAN4.0 strategy and roadmap

Figure 1 show the key elements of the LEAN4.0 self-assessment: (i) identifying performance challenges for the next 3-5 years), (ii) identifying challenges related to achieving flow (lean challenges), (iii) identifying digital (Industry 4.0) opportunities that help with those challenges, (iv) the status of success factors in the company that determine whether you can achieve the desired development and (v) formulating a strategy and roadmap. The latter is important and provides input for periodic evaluation: are you still on track, does the roadmap need to be adjusted? The development of a strategy and roadmap is not easy. In our LEAN4.0 self-assessment methodology, we will devote limited time on the development of a LEAN4.0 strategy and roadmap. This aspect will be further explored in Work Package 5 of the LEAN4.0 project.

Figure 1. Key elements in the assessment methodology.

The various elements in the LEAN4.0 assessment methodology are illustrated by means of an industrial case. We will not explain the case in this report. The case is integrated in the LEAN4.0 assessment tool (see website LEAN4.0 project) and supports the users of the tool.

In the subsections of this section, we will explain the background of the key elements in the assessment methodology.

2.3.1 Element 1 - Performance Challenges

Investments in Lean and Industry 4.0 need to serve the performance challenges of a company. There are many examples of unsuccessful investments due to a mismatch with the operational performance challenges of a company. See section 3.2.

To gain an idea of the participating managers about the performance challenges of their company (and related to the selected key product type), we use here the five performance indicators mentioned by Slack et al. (Operations Management, 9th edition, Pearson, 2019), in table 1. These are important indicators for the operations manager, but also for other managers in the company. It is good to discuss these indicators in the management team, in the assessment. Managers should have a same idea about these indicators and how it can be measured. Measurement is not important in this assessment, but understanding 'how it can be measured' helps to give a qualitative (1..9) assessment score. See Table 1.

Table 1 Performance Indicators and the assessment form..

Performance Indicator	How important is the indicator for the customer?	How good are we compared to our main competitors?
Cost (C)		
Quality (Q)		
Delivery time (D)		
Reliability (R)		
Flexibility (F) - product, mix, volume and/or delivery flexibility		
………..		

The five performance indicators are general indicators. It is fine if managers replace these indicators by more specific indicators which better serve their situation. A good question to gain this indicators is: "What are the reasons that customers come to your company instead of the company of the main competitor?" and "What are the reasons why (desired) customers sometimes decide not to purchase at your company?".

Attendees fill in the matrix of Table 1 individually and then discuss about the chosen values. This is done in each element of the assessment methodology. Discussion is important for gaining consensus.

In our experience, the performance challenges part of the assessment often gives a lot of discussion among the managers. It is good to give managers time to discuss. Setting these figures (1..9 scores for importance and performance) provides targets for improvement by means of Lean and/or Industry 4.0 technologies.

Figure 2 is a good means to illustrate the performance position of the company. The figure is a so-called 'performance-importance diagram' and shows the importance of the indicators for the key customers and the performance of these indicators related to those of main competitors.

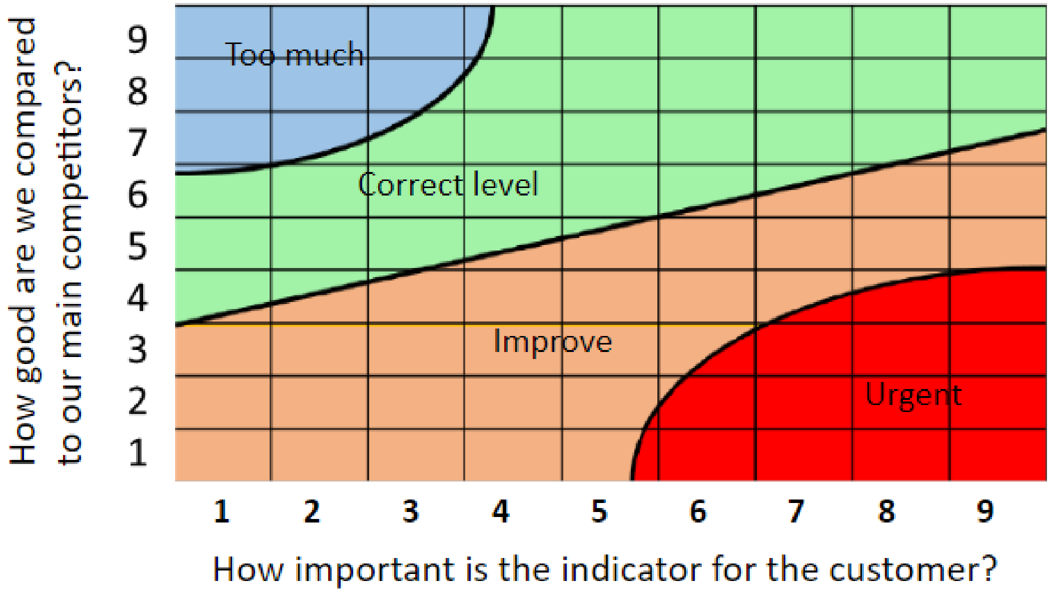


Figure 2 Performance / Importance diagram.

2.3.2 Element 2 - Lean Challenges

Element 2 of the LEAN4.0 self-assessment is devoted to the assessment of Lean principles in the company. Figure 3 illustrates important areas which require attention for getting flow in the operations function of a company.

a. A company requires a good and regular supply of goods from suppliers. If purchased components are not good, then a company will have problems in parts manufacturing or assembly. Or, worse, their customers may have problems.
b. The company also has to take care of a good balance between the availability of capacity and the customer demand. This is, in many cases, a big challenge. Good customer contact is important to align customer demand and the availability of resources.
c. Quality of processes and of the intermediate products are essential for being able to realize flow. Quality problems with respect to products and resources will disturb the flow.
d. Flow & pull, furthermore, asks for several lean measures in the operations function. Flow and pull can only be realized if changeover times (setup times) are low, if the flow is visible at the work floor (teams, cells, lines) and if the control is triggered by pull signals from the (internal) customer.
e. Finally, the ideal of flow production can only be realized in case of involved workers who are cross-trained and work in teams to reduce all the wastes in their work.

The areas mentioned here are used in the self-assessment. Table 2 shortly depicts a number of lean challenges for realizing flow. The division in four focus areas (supplier and customer aspects are combined in the SCM area) comes from Shah & Ward (2013). The descriptions are derived from Shah & Ward (2007). Answers to these challenges in Table 2 give a good impression to what extent the company embraces Lean principles. It has to be noted that not all Lean methods can be, and are, mentioned in the Table. According to Shah and Ward (2007), various Lean techniques and methods are implicitly linked to each other and do not to be measured independently. Supermarkets, for instance, may be part of the realization of pull in the company (element 5).

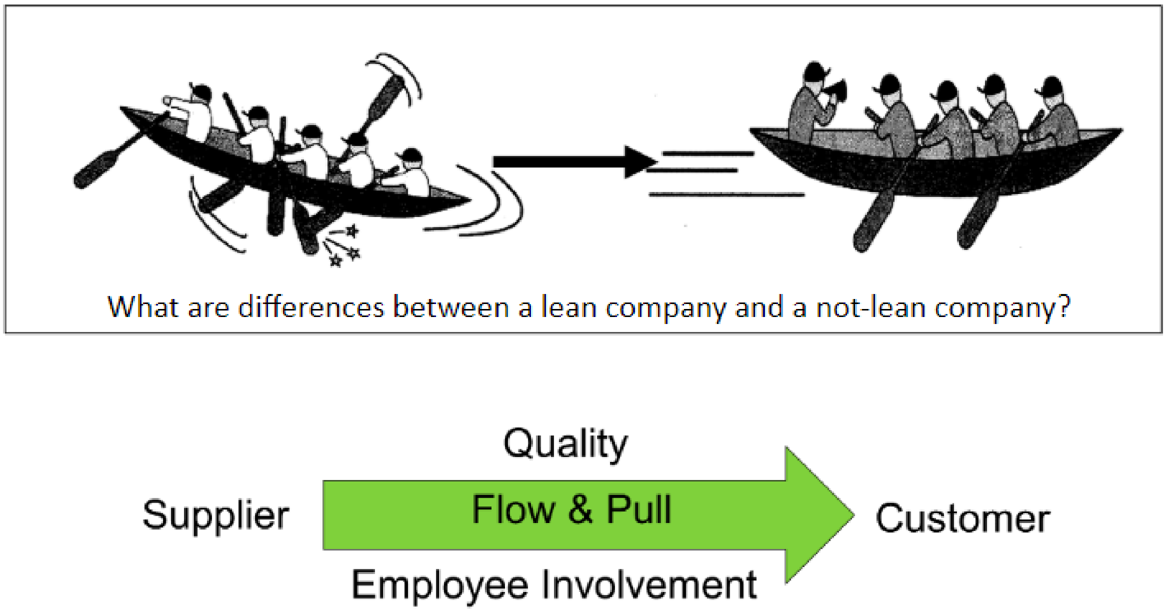


Figure 3 Main Lean areas.

Some of the terms in the table may not be completely clear. Within JIT, there is the concept of ‘Reduced Setup Time’. Setup Time is the time needed to prepare a machine, or system, for the manufacturing of other jobs. Changeover time is probably a better term: it indicates that the time needed between the manufacturing of two different product may be sequence-dependent. Reducing setup time, or changeover time, is important for reducing lot sizes and for producing a higher variety of products.

Statistical process control stresses the importance to measure and to make decisions based on valid data. Without measuring quality, it is not possible to improve.

Attendees of the LEAN4.0 assessment session have to assess the current situations and the importance of each topic. This, again, has to be done independently and forms input for a discussion. Within this discussion, it is good to link this to the performance challenges, dealt with in section 2.3.1. The discussion will, hopefully, lead to consensus which can be depicted in Figure 4. This figure is helpful to check the deviation between the current and the desired state, in relative sense. The more below the diagonal line, and the higher the importance, the more important it is to improve on this focus area.

Table 2 Lean elements (Supply Chain Management, Just In Time, Total Quality Management, Human Resource Management)

Focus area	#	Element	Description	How good are we?	How important is it?
SCM	1	Feedback to suppliers	Give regular feedback to suppliers about their performance.		
	2	JIT delivery by suppliers	Ensure that suppliers deliver the right quantity at the right time and the right place.		
	3	Supplier commitment	Ensure supplier development so they become more involved in the production process of the organization.		
	4	Customer involvement	Have customers involved in the improvement of products and production. Stimulate a regular flow of customer orders. Stay focused on their needs.		
JIT	5	Pull	Encourage JIT production, including pull signals (i.e. Kanban cards) that serve as a signal to start or stop production.		
	6	Continuous flow	Structure products and equipment in such a way to facilitate continuous flow.		
	7	Reduction setup time	Reduce process downtime between product changeovers.		
TQM	8	Total productive/preventive maintenance	Use the principles of maintenance management (visualization, organized preventive maintenance, etc.) to obtain a higher level of equipment availability.		
	9	Statistical process control	Systematically improve the quality of each part of the process for the supply of failure-free units to successive parts of the process.		
HRM	10	Employee commitment	Give employees a role in solving problems, strengthen their cross-functional perspective, work in teams.		

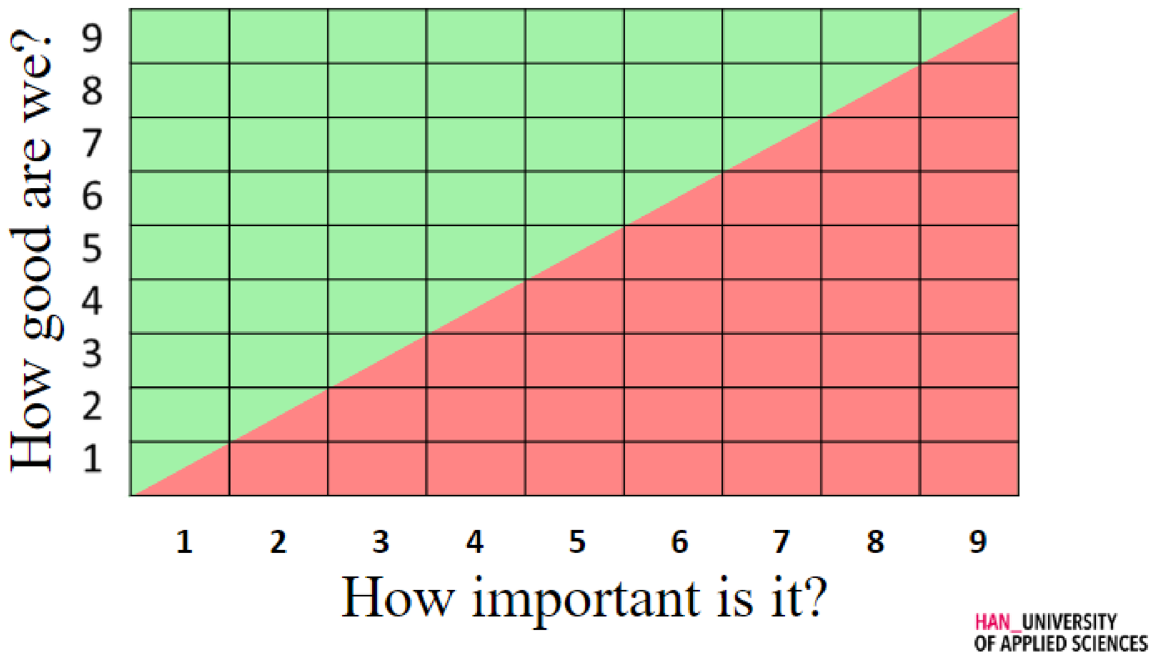


Figure 4. Matrix to be used for indicating the gap between importance and relevance.

Another aspect of importance concerns the link between product development and the production function. We added this aspect to the LEAN4.0 assessment tool on the basis of feedback of users of the tool. Table 3 presents some important elements which play a role in the communication between product development and the production function. These elements are derived from Lean Product Development literature, see Knoblinger, C. (2011).

Here, too, the deviation between the current and desired state can be visualized by using figure 4. Both the importance of an item and the size of the gap, i.e. the straight distance between the diagonal and the position of the item, can play a role in the choice of an issue to be worked on.

We noted that in many SMEs, the communication between the operations and the product development function is far from ideal. Most managers recognize the importance of a good link between product engineering, responsible for developing new products and the re-design of current products, is an essential aspect for gaining a lean production function, now and in the future.

Table 3 Lean elements to focus on in the relation between product development and the production function.

Focus area	#	Description	How good are we?	How important is it?
Variety and commonality of products	1	Achieve variety in products with modular components that have standardized interfaces.		
	2	Standardize components where possible.		
	3	Common product platforms (i.e. product parts) exist for different products.		
Alignment of product and production.	4	Design for X (manufacturing, assembly, service, sustainability) methods are explicitly used in product development.		
	5	The design of new products takes into account the possibilities of new production technologies (possible core competence technologies).		
	6	Strategic consideration is given to the choice between outsourcing and self-doing.		
Organizational coordination of product development and production.	7	The design, testing and renewal of production processes takes place in parallel with the development of new products.		
	8	Representatives of production, quality and purchasing are explicitly involved in the product development.		

2.3.3 Intermezzo – how important is Industry 4.0 for lean?

After investigating the lean elements at the company, the participating managers in the self-assessment have to understand the meaning of Industry 4.0 technologies and their possible impact on increasing the level of lean in the operations function of the company. Figure 5 lists a couple of lean terms and Industry 4.0 technologies. These terms and technologies come from a paper of Wagner et al. (2017) who try to link Industry 4.0 technologies with Lean methods.

It is fine to discuss shorty the link between Lean and Industry 4.0 methods and techniques within the LEAN 4.0 assessment. How can they strengthen each other? It is especially good to notice that Industry 4.0 technologies ask for standardization, which is also a key element in all elements of Lean. In Chapter 3 of this report, we will go deeper into the relation between Lean and Industry 4.0. In the LEAN 4.0 assessment, it is enough for the attendees to gain the feeling that Lean and Industry 4.0 may have impact on each other.

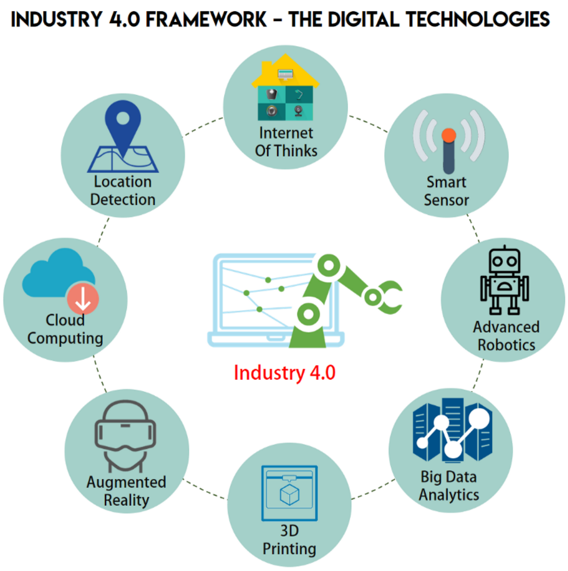
Some Industry 4.0 technologies	**Some Lean terms (link to focus area)**
Data Acquisition and Data Processing	Milkruns (SCM)
• Sensors and Actuators	Heijunka (balancing the load, JIT)
• Cloud computing	Takt time (JIT)
• Big data	Pull flow (JIT)
• Analytics	Jidoka (TQM)
Machine to Machine communication	Standardization (TQM)
• Vertical Integration	Man-machine separation (TQM)
• Horizontal Integration	Waste reduction (TQM)
Human-Machine Interaction	5 S (TQM)
• Virtual Reality	Kaizen (HRM)
• Augmented Reality	People and teamwork (HRM)

Figure 5 Lean terms and Industry 4.0 technologies.

2.3.4 Element 3 – Industry 4.0 Challenges

Industry 4.0, or the Fourth Industrial Revolution, is set to revolutionize the manufacturing and production industry by integrating the Internet of Things (IoT), cloud computing, data integration and other technological advances into the heart of production and manufacturing systems.

Important for Industry 4.0 is the idea that there is no limit on the information flow: all fixed and real-time information about customers, suppliers, products, resources and human are everywhere available and can be, or is, used to optimize and control the goods flow. Figure 6 visualises this.



(Source: https://medium.com/@winix/industry-4-0-the-digital-technology-transformation-b23ba02a7dd2)

Figure 6 Industry 4.0 technologies

We use the word 'smart' instead of Industry 4.0. This term is more known in industry and also broader than Industry 4.0. 'Smart' encompasses all digital technologies, where Industry 4.0 is merely linked to the issue of connectivity. More information about 'smart' can be found in Mora et al. (2017). An alternative for the term 'smart' is the use of the word 'ubiquitous', which indicates the omnipresence of all data needed from resources, products and humans. See, Shin and Suh (2012).

In this part of the assessment, we make use of the ubiquitous architecture, presented by Shin and Suh (2012). We use slightly different terms. The architecture which we use in the assessment is briefly described in figure 7. It distinguishes five key elements of the digital factory. First, a good information infrastructure is needed where information systems used in the design (CAD), preparation (CAPP), and planning (ERP) are connected. The involved functions have to be able to respond to serious 'disturbances' from the work floor. Second, useful product/order data + the status data of each product is needed to select actions with respect to the products/orders. Third, resources for performing the transformations of products/orders are essential. So, information about the characteristics and the status of these resources are needed to make assignment decisions and to perform timely maintenance actions. Fourth, humans are essential assets in companies. Technology may help them to avoid mistakes and may give them actual data on which they can make decisions in case of abnormalities. The control of the goods flow is, in many cases, complex. Production Activity Control systems can be used to make decisions based on real time data and an appropriate model of the behaviour of the system. A PAC system can be an automated Shop Floor Control system, but it may also be Digital Twin or Digital Shadow which supports human decision making. Some authors mention this a Manufacturing Execution System (MES). In our terminology PAC equals MES.

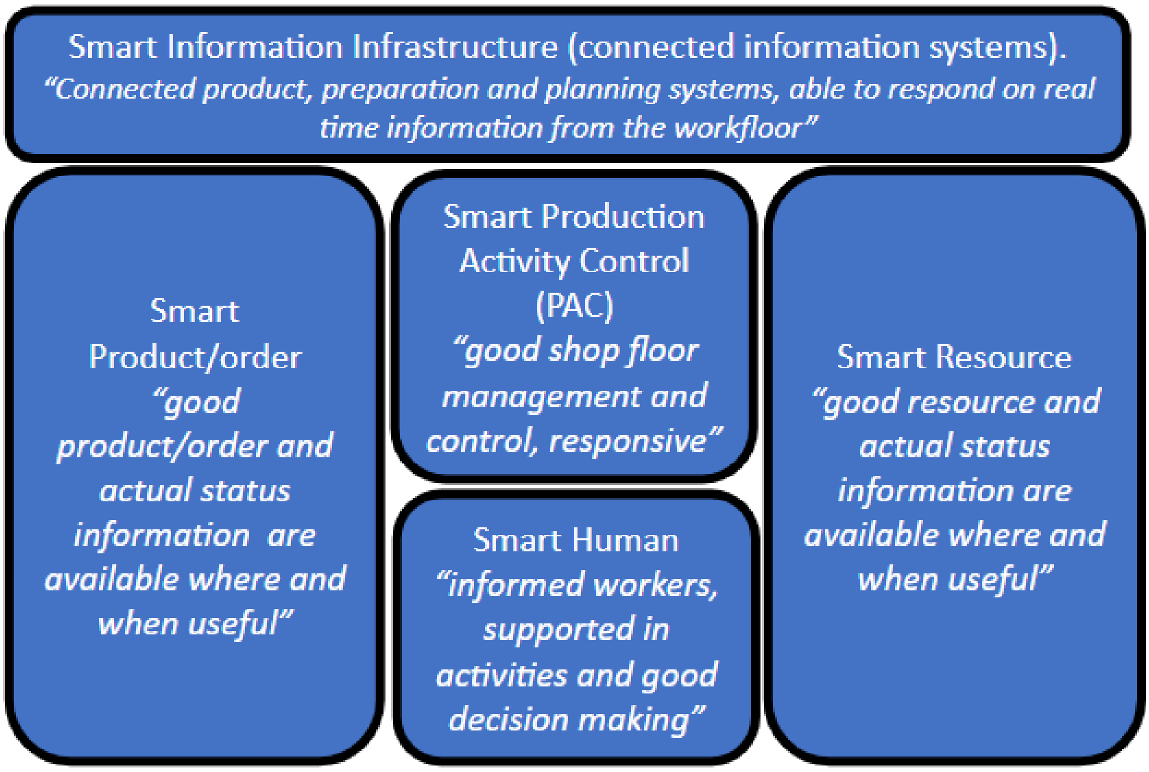


Figure 7 Architecture of the Smart Factory.

Table 4 Smart Industry elements.

Focus area	#	Element	Description	How good are we?	How important is it
Smart Info	1	Information systems	Information systems (CAD, CAPP, PLM, ERP) are up to date and connected.		
	2	Information infrastructure	Information systems are able to respond on real time information from the shop floor.		
Smart product	3	Product information	Product/order information is up to date (e.g. required processes, processing time, complexity..)		
	4	Status information	The status of each product (order) is available where and when useful"		
Smart resource	5	Resource information	Resource information is up to date (available capacity, complexities).		
	6	Status information	The status of each resource (availability, maintenance need) is available where and when useful"		
Smart PAC	7	Shop Floor Management Systems	Shop Floor Planning and Control systems are 'intelligent' and adaptive and able to exchange data with products and resources.		
	8	Integration of management systems	Product/Order, Resource, Quality, Safety, Labor, and Environmental management make use of real time data.		
Smart human	9	Digital Support	Digital systems (e.g. AR/VR, screens) support humans in doing a good job.		
	10	Information access, decision making	Operators can access manufacturing information anywhere, anytime, for good decision making		

Table 4 presents an overview of assessment questions related to elements of the Smart Industry architecture of figure 6. There are various Industry 4.0 techniques and methods related to the elements in Table 4. We will shortly give an overview of techniques. The overview is not complete: it is just meant to give examples. The listing is derived from literature and practice.

- Smart Info: CRM (Customer Relationship Management), CADCAM (Computer-Aided Design/Computer-Aided Manufacturing), WMS (Warehouse Management Software), ERP (Enterprise Resource Planning), MRPI&II (Material Requirement Planning/Manufacturing Resource Planning).

- Smart Product: RFIDs (Radio Frequency Identification), SIMs (Subscriber Identity Module), Big data.
- Smart Resource: Additive manufacturing/3D printing, Robots and cobots, AGV's (Autonomous Guided Vehicles), ASRS (Automatic Storage Retrieval Systems), Flexible manufacturing cells and systems.
- Smart PAC: MES (Manufacturing Execution Systems, sometime linked to Artificial Intelligence, SCADA/DCS (Supervisory Control and Data Acquisition/Distributed Control Systems), PCS (Process Control Systems), Shop Floor Control Systems, Digital Twin, Internet of Things, Cloud computing.
- Smart Human: Mobile (Personal Digital Assistant, Smart phone, Tablet), Augmented reality (AR glasses, such as the Google glasses or the Microsoft HoloLens), Virtual reality (VR), Pick-to-light, Digital decision support tools (intelligent devices).

In the assessment of the use of smart technologies (i.e. filling in Table 4), the participants of the LEAN 4.0 assessment, mostly members of a management teams, have to think about the quality of their digitalization and the importance to improve this. The areas are to a certain extent dependable. Without a good information infrastructure, the idea of smart products, smart resources and smart human is not realistic. Smart PAC, furthermore, asks for smart products and resources. These dependencies should be taken into account in the discussion about "what needs to be done first".

Again, figure 4 can be used to illustrate the importance to digitalize the company. It is valuable that managers discuss the outcomes by answering the following questions:

a) Is it important to make better decisions at the work floor (smart-PAC)? What are major resources to control (or bottlenecks) with respect to realizing flow? Wat are critical resources (bottlenecks) with respect to quality?
b) Is sufficient information available about products (smart products), resources and workers (smart resources) to make good and timely decisions for these bottlenecks? Who needs this information?
c) How can the information be gathered (smart info)?
d) How to support operators/workers and managers to perform their operations better and to make better decisions?

Based on the answers to these questions, a management team may get an idea about the steps to be taken in the digitalization of their company. It is also important to link their ideas to the performance challenges mentioned earlier in this assessment session.

2.3.5 Element 4 - Critical Success Factors for Lean and Industry4.0

Critical Success Factors are those limited number of factors which need to be in shape to enable, or secure, successful implementation of lean and/or Industry 4.0 technologies. It is the responsibility of managers to control these factors!

The term 'critical success factors' comes from Rochart (1982). He argues that management is not able to control everything. So, management has to focus on a limited number of factors, which are called ‘critical success factors’. These factors can be found by means of causal analysis (why-why-why does something happen) with input of various stakeholders. There are many studies about critical success factors for all types of improvements (e.g. lean, continuous improvement, kaizen, ERP, BPR, etc.).

A list of the critical success factors for Lean can be found in table 5. These factors are derived from a broad literature study on Critical Success Factors for Lean (more than 70 references), performed by researchers in the LEAN 4.0 project. See Knol et. al. (2018). This study also shows that the importance of each factors differs for various levels of lean implementation. This will be used in figures 7 and 8.

Table 5 Critical Success Factors for Lean..

Success Factor		Description	How good are we?
Vision	V	Company-wide shared long-term direction, objectives, and goals for improvement, aligned with the company vision and strategy	
Top Management Support	T	Top management take responsibility for and positively participate.	
Communication	C	Three-way communication (top down, bottom up and horizontal), honest and clear	
Improvement culture	IC	Supportive middle management, instead of ‘steering bosses’	
		Focus on people, not on methods	
		Mistakes are opportunities for improvement	
Improvement structure	IS	Sufficient time and money are made available	
		Training (everybody)	
		Performance management	
Integral focus	IF	Supplier cooperation	
		Customer cooperation	
		Activities of all departments are in line with the improvement vision	

The scores on the success areas of Table 5 can be presented by means of figure 8. This figure asks for some explanation. The small horizontal lines (green, red and black) give information about the minimal level of critical success factors needed for being able to realize a certain level of lean. These levels are derived from the research done by Knol et. al (2018). The arrows in the figure indicate the range of values coming from more than 30 companies. It provides a kind of benchmark for companies.

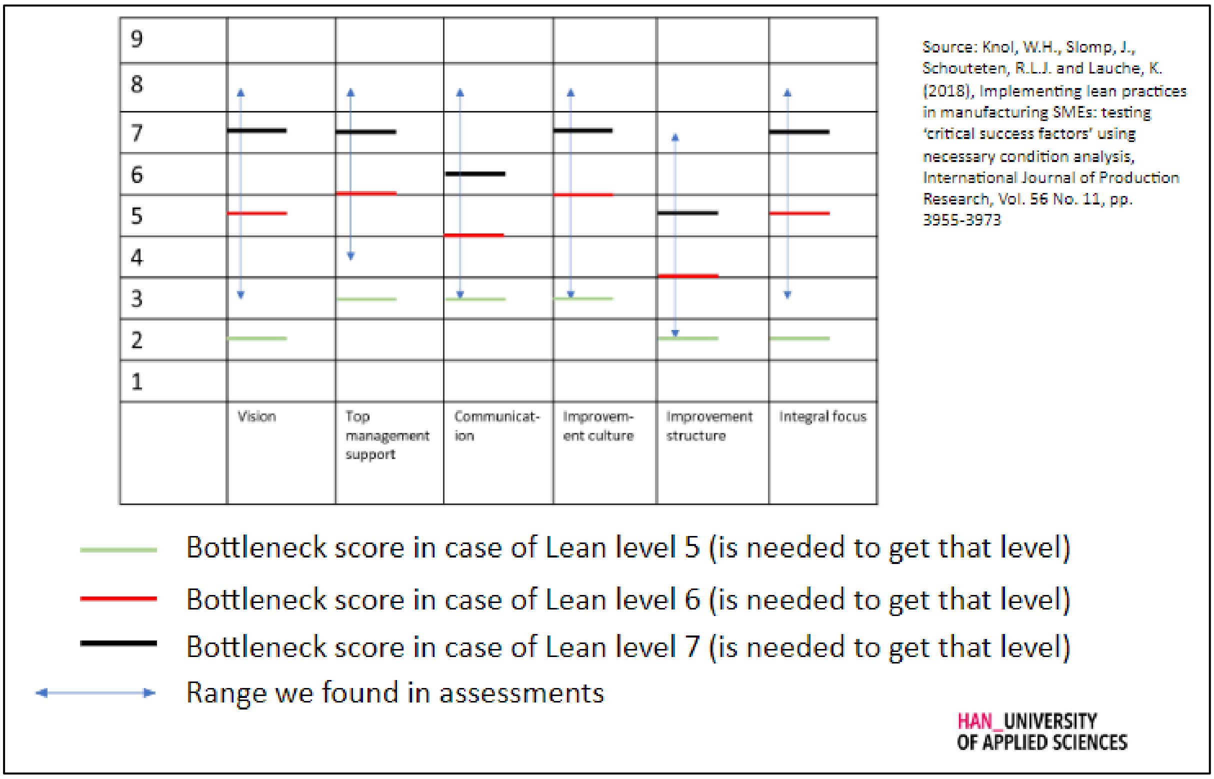


Figure 8 Depicting the scores on Lean success factors.

Figure 9 provides an example. The yellow bars indicate the current 'level' of the case company on the critical success factors. The positions of these levels within the various arrows, show that the company is doing relatively well on all success factors.

According the opinion of the attendees of the assessment session, the company has currently a 'lean level' of about 3.5. The desired lean level is substantially higher: 7. The figure on this page/sheet shows that the company can reach lean level 5 without investing in critical success factors. To realize level 6, the company first has to invest in realizing an improvement culture. For getting the high level of 7, several other success factors deserve attention (vision, top management support, improvement culture and integration (support congruence)).

Although it is difficult to indicate precisely what each lean level means, the figure helps to find the most critical success factors in the lean journey of the company.

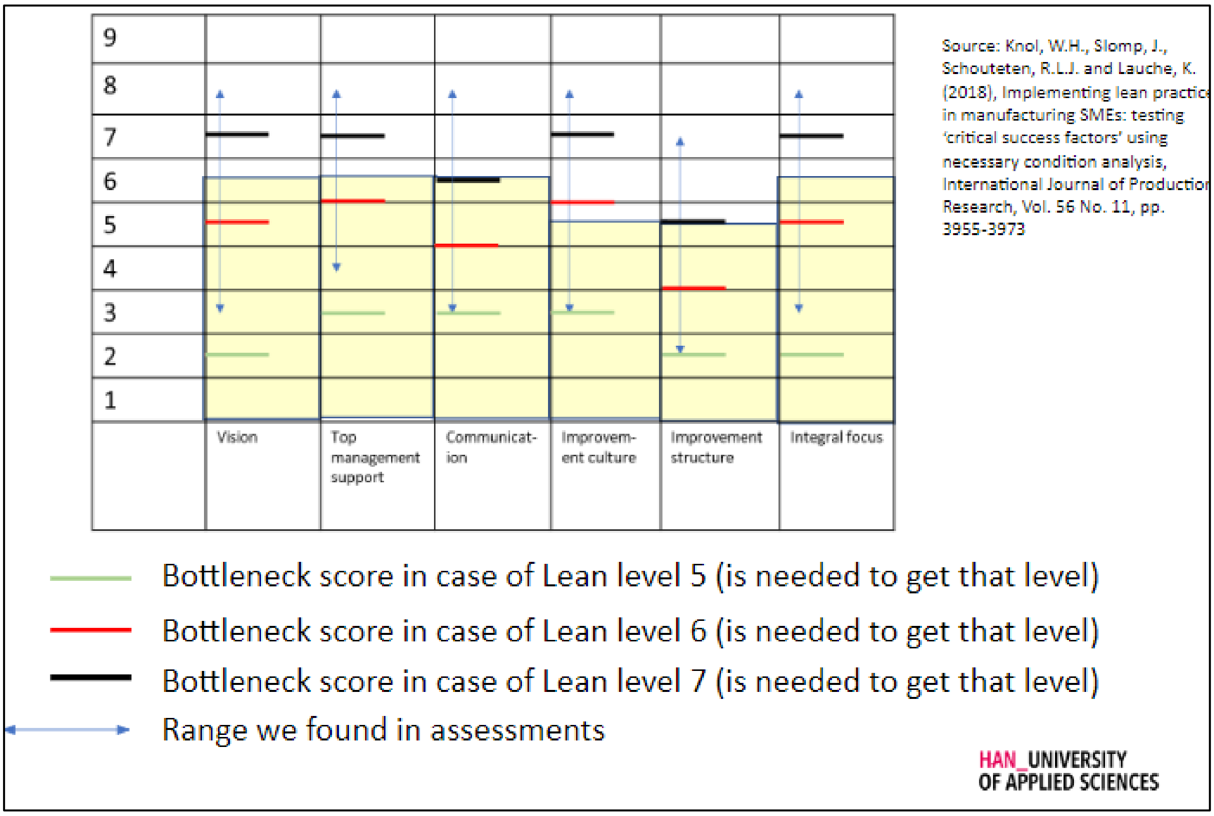


Figure 9 Depicting the scores on Lean success factors – an example

There are also critical success factors for the implementation of Industry 4.0. The heart of Industry 4.0 is, according the architecture of figure 6, Smart PAC. Invernizzi et al. (2019) performed a study on critical success factors for PAC introduction. They use the term MES instead of PAC. We think that the success factors for smart PAC are also important for other Industry 4.0 technologies. Table 6 presents the main categories of the critical success factors. We categorized them in 'human factors', 'technological factors' and 'organizational factors'.

Table 6 Critical Success Factors for Smart Industry (i.e. Industry 4.0).

Focus area for critical success factors		Description	How good are we?
Human Factors	H	Project team, communication, education and training, user involvement	
Technological Factors	T	Technology selection process, technological infrastructure, data management	
Organizational Factors	O	Top management support, project management, change management, business process re-engineering, implementation strategy and acceptance control	

The three categories, mentioned in Table 6, can be related to the need of awareness, willingness and readiness for Industry 4.0 (of Smart PAC), see figure 10. First, company-wide awareness is needed to define Industry 4.0 possibilities for the company and to gain acceptability. Human factors are most important here. We assume that a level of 8 or 9 is needed for human factors to gain a successful implementation of integrated technology. Next, there should be a broad willingness and ability in the company. This means that, next to the human factors, also the technological factors need to be in shape. We assume levels of 7, 8 and 9 are sufficient. Finally, readiness for the digital factory asks for good organizational, or managerial, factors. A clear implementation method and strategy is needed. We assume that level 6, 7, 8 or 9 is sufficient for gaining a successful implementation. Literature supports the relative importance of the various factors (see Invernizzi et al. 2019). The required levels, however, are debatable: they are here based upon the experience and opinions of the researchers in the LEAN 4.0 project.

This is a rough, not very precise, description of the importance of the various factors in the phases towards the digital factory. Understanding the ‘importance sequence’ of awareness, willingness and readiness may support management teams to take appropriate actions. Figure 10 can be used to illustrate the deviation of the current situation (i.e. the scores on the topics of table 6) and the desired situation (i.e. the colored scores in figure 10).

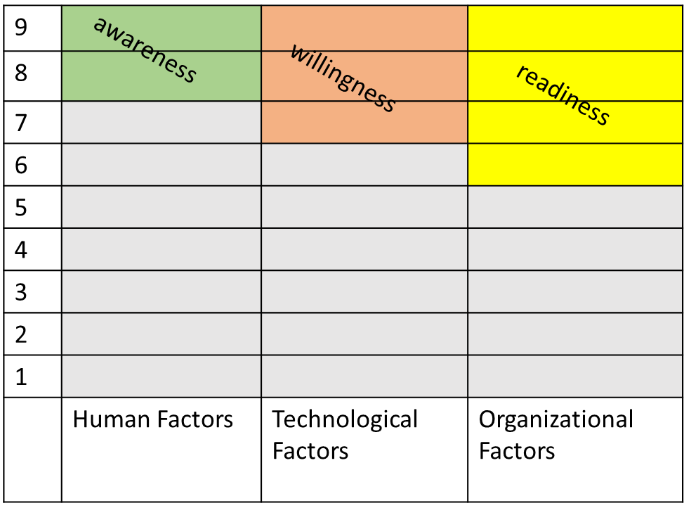


Figure 10 Depicting the level in which a company obeys critical success factors for Industry 4.0

2.3.6 Element 5 – Formulating a strategy and roadmap

In element 5 of the assessment methodology, the ‘outcomes’ of the assessment have to be summarized in order to make coherent conclusions. It is the challenge for management teams, the participants in the LEAN 4.0 assessment, to create a logical and acceptable story for the development of their company and to specify the improvements to be performed. The summary may answer the questions mentioned in Figure 11 and may, subsequently, serve the communication in the management team and the whole company.

It is our experience that a concise and precise set of conclusions, including motivation, can be best made after the assessment and be done by the facilitator of the session. These conclusions can be discussed in a short follow-up meeting. It is the task of the management team to specify a more precise roadmap for LEAN 4.0 development. An experienced facilitator can also be supportive for roadmap development.

What is the main operational target for the coming 3-5 years? What is the long term vision?

How important are lean and industry 4.0 to realize this target?

What are the key **lean** challenges for the coming period?

What are the key **Industry 4.0** challenges in the coming period?

What are the critical success factors which need special attention in the coming period?

Which concrete actions will be performed? (what, who, when, check/study time)

Figure 11 Questions that can be answered after performing the LEAN 4.0 assessment.

Figure 12 presents a simple template for a roadmap for a three-year period. It shows which activities (projects) in the field of Lean and Industry 4.0 require attention in the course of time. This global roadmap can be further specified for the various functional areas in the company (human resources, finance, production, product development, etc.). It needs to be clear which activities must be carried out in which period, by which department or functional area. By means of arrows in the roadmap, relationships between activities of the various functions can be indicated.

Strategic targets:						
	2021-1	2021-2	2022-1	2022-2	2023-1	2023-2
Lean						
Industry 4.0						
Success-factors Lean						
Success-factors Industry 4.0						
Vision of the company						

Figure 12 Simple template of a LEAN 4.0 roadmap

Creating a clear roadmap is difficult. It is not sure what will happen in the future. If it is expected that new technologies (e.g. 3D printing, AR, ...) will be available on the market in about three years, then it is good to anticipate this. Management of the company also has to anticipate expected changes in the market (e.g. increasing importance of sustainability).

2.4 Development and evaluation of the LEAN4.0 self-assessment

This LEAN4.0 self-assessment has been developed in a number of PDCA cycles in which more than 10 companies were involved.

First, a more extensive self-assessment was developed where managers, participants, had to fill in a number of questionnaires in a three-hour session. The researchers processed the answers in a PowerPoint presentation, including the differences in opinions between the participants. This was a very time-consuming task. This PowerPoint was presented about one week later to the managers. Although the discussions were good, this was not ideal. Some managers were not able to join the first or second meeting. Furthermore, we noted that differences in opinions were many times due to misunderstanding of the questions. This was a time-consuming element.

After this, we decided to 'automate' the processing of the answers of the questionnaires such that filling in the questionnaires and the PowerPoint presentations could be done on the same day. This was a great improvement. Managers filled in the questionnaires in a joint session in the morning. We urged that participants should ask the facilitator, in case of unclarities. This was not that successful. Misunderstanding of the questions remained an issue during the discussion session in the afternoon. We made an automatic link between Excel and PowerPoint for a fast creation of a presentation. This was still time consuming: the researchers had to type-over the answers on the questionnaires in Excel and subsequently had to go through the PowerPoint for adding company specific issues. We experimented with a digital questionnaire, but this was not successful. It required the need for a laptop for all participants. Furthermore, a paper version provided more overview for the attendees: when clarifications were needed, attendees could all look at the same page. Attendees told that they learned from filling in the questionnaire, but they also experienced it as time-consuming. The presentation session, which took 1.5 hour, was very much appreciated, especially the mutual discussions.

In a last development cycle, we created the current LEAN 4.0 self-assessment tool. Here the total assessment takes 'only' 3.5 hours. The questionnaires were made more concise. Based on requests from some companies, we included questions about the link between product development and the production function (see section 2.3.2). During the session, the company attendees got an introduction for each element of the assessment, then they individually filled in the questions of this part of the assessment and, after this, they started with a discussion. We applied the LEAN 4.0 self-assessment in several companies. At the end, we asked the managers for their opinion and noted an appreciation of the tool. Some comments:

"I learned a lot"

"It forces us to think about our situation"

"It is systematic and shows a scientific approach"

"it makes issues clear"

"it gives a good insight in were our company stays"

"it creates awareness, creates good discussions"

"it forces us to think about the current situation and about what is needed"

"it helps to create consensus, it aligns us"

Due to the corona crisis, we had to perform the LEAN4.0 assessment online a few times. This worked well! We applied MS Teams for this purpose. In these cases, we organized a second session (one week later) in which we (the researchers) presented the outcome of the LEAN4.0

assessment again and also suggested a rough roadmap of activities to be done by the company. This second session was introduced to 'secure' a follow-up on the LEAN 4.0 assessment. We offered some of the companies support from university by means of projects of master students, internships of bachelor students, and projects performed by applied researchers from our (applied) universities. It is our hope and expectation that companies will give a follow-up on the LEAN 4.0 assessment.

3 LEAN4.0 taxonomy

3.1 Introduction

The second deliverable in Work Package 1 concerns a LEAN 4.0 taxonomy. Another word for taxonomy is 'classification'. In the LEAN 4.0 taxonomy, presented in this chapter, companies are classified according to their maturity of using Continuous Improvement routines and using information integration technologies. This taxonomy is meant to help companies and operations managers to understand what their main challenges are with respect to the development of Lean and Industry 4.0 technologies. Major assumption is that the presence of Continuous Improvement routines is a main condition for Lean improvement, and information integration (connectivity) is a condition for making good use of Industry 4.0 technologies, such as Big Data, Augmented Reality and the Digital Twin concept. The typology can be seen as a benchmarking tool: it provides operations managers information about their relative position with respect to LEAN4.0. It serves also the development of a long-term view (>3 years) on the development of their companies.

The purpose of the LEAN 4.0 taxonomy tool, presented in this chapter, is to challenge the operations manager to think about the organizational link between Industry 4.0 and Lean in their company. We will do that through several lenses. First, in section 3.2, we will present the *lens of the tools of Industry 4.0 and Lean*. This illustrates that Industry 4.0 and Lean tools can strengthen each other. Examples from practice however, seen by the researchers in the LEAN4.0 project, show that there can also be a tension between Industry 4.0 and Lean. There are cases showing that Industry 4.0 tools may frustrate lean principles. The second lens, presented in section 3.3, concerns the *link between Lean principles and the key focus of the Industry 4.0 tools*. Based on empirical data, we will show that Lean can be developed without substantial use of Industrial 4.0 tools. On the other hand, advanced use of Industry 4.0 requires the adoption of Lean principles in a company. These two lenses brought us to the 'Lean and Industry 4.0 development maturity matrix' and the taxonomy related to it. This will be presented in section 3.4. The maturity matrix is based on *the lens of improvement*. There are two improvement axes in the matrix: (1) the extent to which Lean improvement is embedded in the organization, and (2) the extent to which Industry 4.0 technologies serve the road towards perfection. The positioning of a company on these two axes gives the manager insight in the main organizational challenges of his/her company. The two axes in the matrix brought us to a LEAN4.0 taxonomy of companies. We distinguish three basic categories of companies in the taxonomy. This is explained in section 3.5. In section 3.6, we explain, based upon cases, how companies which are growing in LEAN4.0 have to adapt their operating and improvement routines. This is a main challenge for the operations managers of the future. Finally, section 3.7 explains how the maturity taxonomy can be used, also in combination with the LEAN4.0 self-assessment methodology developed in our LEAN 4.0 project.

3.2 The link between Lean and Industry 4.0 tools

Based upon expert knowledge, Wagner et al. (2017) create a matrix to indicate which Industry 4.0 technologies are helpful for which Lean concepts. See figure 13. They claim that this matrix helps managers to select Industry 4.0 technologies if they want to improve certain Lean concepts. Stories behind the links are missing but are probably obvious. It, however, shows that Industry 4.0 technologies deserve attention in the Lean community.

	Data Acquisition and Data Processing				Machine to Machine Communication (M2M)		Human-Machine Interaction (HMI)	
	Sensors and Actuators	Cloud Computing	Big Data	Analytics	Vertical integration	Horizontal integration	Virtual Reality	Augmented Reality
5S	+	+	+	+	+	+	++	+++
Kaizen	+	++	+++	+++	+++	+++	+++	+++
Just-in-Time	++	++	+++	+++	+++	++	+	++
Jidoka	+	+++	+++	+++	++	++	+	+
Heijunka	++	++	+++	+++	+++	++	++	+
Standardisation	++	+++	+++	+++	++	++	+++	+++
Takt time	+	+	+++	+++	+++	+++	+	+
Pull flow	++	+	+	+	+++	+++	+	+
Man-machine separation	+	+	+	+	+	+	+++	+++
People and teamwork	+	+	+	+	+	+	+++	+++
Waste reduction	+	+	++	+++	+++	+++	+	+

Figure 13 Link between Lean tools and Industry 4.0 technologies (from Wagner et al. (2017)

Based on published papers, also Rosin et al. (2020) show that Industry 4.0 technologies strongly support Just-in-time and Jidoka, see figure 14. Industry 4.0 technologies however do not, or hardly, support waste reduction and People and Teamwork. This creates the following question: is there a link between Industry 4.0 and the lean focus on 'waste reduction' and 'people and teamwork'? In our LEAN4.0 project, we answer this question positively. People and teamwork are very important in Industry 4.0 companies: less people are more responsible for higher capital investments. Attention for the well-being of these workers is a key topic. Furthermore, new technologies are more complex and ask for various expertise. Teamwork is essential. Waste reduction also remains an important topic in Industry 4.0, although the removal of waste may ask more expertise because it needs to be aligned with the digitalization in the company. This will ask for well-organized improvement routines.

		Autonomous Robots	Simulation	System integration	Internet of Things	Cloud	Augmented reality	Big data and analytics	Cybersecurity		Monitoring	Control	Optimization	Autonomy
Just-in-time	Takt time planning									0				
	Continuous flow	4	10	4	9	3		1		31	10		15	6
	Pull system		2		7	1				10	6		2	2
	Quick changeover		1							1			1	
	Integrated logistics	2		1	1					4	2			2
Jidoka	Automatic stops									0				
	Andon				3					3	2	1		
	Person-machine separation	2								2				2
	Error-proofing	2			3		2			7	4	1		2
	In-station quality control	1			5	1		4		11	5		1	5
	Solve root cause of problem									0				
Waste Reduction	Genshi Genbutsu									0				
	5 Why's									0				
	Eyes for waste		4	1	6			1		12	12			
	Problem solving									0				
People and Team work	Selection									0				
	Common goals									0				
	Ringi decision making									0				
	Cross-trained		1				4			5	4		1	
Fondations	Continuous improvement		2	1			2	1		6	3		3	
	Leveled production (heijunka)							1		1			1	
	Stable and Standardized processes	2					1			3	1			2
	Visual Management		1		10	3	1	2		17	17			
	Toyota Way Philosophy			2						2	2			
		13	21	9	44	8	10	10	0	115				
	Monitoring		8	7	31	6	9	7			68			
	Control				2							2		
	Optimization		13	1	5	1	1	3					24	
	Autonomy	13		1	6	1								21

Figure 14 Link between Lean and Industry 4.0 methods (from Rosin et al., 2020)

So, Lean and Industry 4.0 deserve joint attention in a company. Figure 15 presents some examples of the application of Industry 4.0 technologies which support Lean thinking. These examples come from the experience of researchers in the LEAN4.0 project.

Case 1.
A company invested in Augmented Reality, google glasses, to instruct operators responsible for order picking. The glasses are linked to the companies information system but also to a hand-mounted device by which the operators can scan the QR-codes of the parts. The operators fill cars to be brought to assembly stations. The information system 'tells' the operator, through the glasses, where the cars precisely have to be. The information system pulls these instructions from the assembly station. Advantages: efficiency, pull and no mistakes.

Case 2.
A company invested in intelligent hand tools for assembly (screwdrivers and such). The tools are connected with an information system and a screen, for sequence instructions. The system also measures to what extent the task is done correct (torque measurement). This has improved the quality of products and processes substantially.

Case 3.
A company invested in a shop floor control system + barcoding system which provides real time information about the status of manufacturing orders. Daily, team leaders discuss a real time Value Stream Map and reallocate operators, if needed.

Figure 15 Examples where Industry 4.0 technologies support Lean.

There are however also examples of mis-investments in new technologies. See figure 16. The examples of figures 15 and 16 indicate the importance of a joint development of Lean and Industry 4.0 companies. Without a joint development, mis-investments may happen.

Case 1.
A company invested in a highly automated production system (machines, automated transport, etc.). There were no setup times anymore. The machine was also able to produce on a substantial higher speed. This was the reason why operations of different value streams were assigned to the system. This frustrated the cellular system of the company) where each value stream had its own cell..

Case 2.
A firm applies successfully a manually controlled pull system (CONWIP) in their manufacturing department. New information technology (ERP, MES) enabled a better link with the companies information system and easier information transfer between stations. However the software was not able to support the pull system. The company is puzzling about pull planning & control software.

Case 2.
A company invested in a pick-to-light system for assembly work. Workers only have limited opportunity, and capabilities, to improve their work. Automation may limit human learning.

Figure 16 Examples where Industry 4.0 investments frustrate Lean

3.3 The link between Lean principles and the key focus of the Industry 4.0 tools.

Within the LEAN4.0 project, Bokhorst, Knol and Slomp (2020) investigated the link between Lean and Industry 4.0 by means of a survey. About 100 companies participated in the survey. With respect to the concepts of Lean and Industry 4.0, Bokhorst et al. (2020) found that:

- Lean key principles (standardization, flow, continuous improvement and supplier links) cannot be served independently. Lean develops as a 'whole'.
- Industry 4.0 technologies have been developed in industry through two lines:
    - Administrative Technologies (information technologies, work on screen)
    - Process Technologies (digital automation of processes, MES systems)

Analysis of the data gained in the survey indicates that the development of process technologies in companies require a certain level of administrative technologies. Administrative technologies, on the other hand, are in many cases well developed without substantial development of process technologies.

The survey also shows that Lean as well as Industry 4.0 serves the overall performance (costs, time, quality) of the company. Combining Lean and Industry 4.0 provides the best performance.

Bokhorst et al. (2020) further investigated to what extent Industry 4.0 needs Lean, and vice versa. The results presented in figure 17 come from applying the methodology of Necessary Condition Analysis (NCA). The figure shows that a substantial use of Lean Principles goes hand in hand with the use of administrative technologies. But there are exceptions.

The results presented in figure 18 also come from applying the methodology of NCA. The figure shows that there is no company using substantial process technologies without making use of Lean Principles (the empty triangle and blue circle). The figure also shows that many 'lean' companies did not adopt advanced process technologies (the red circle).

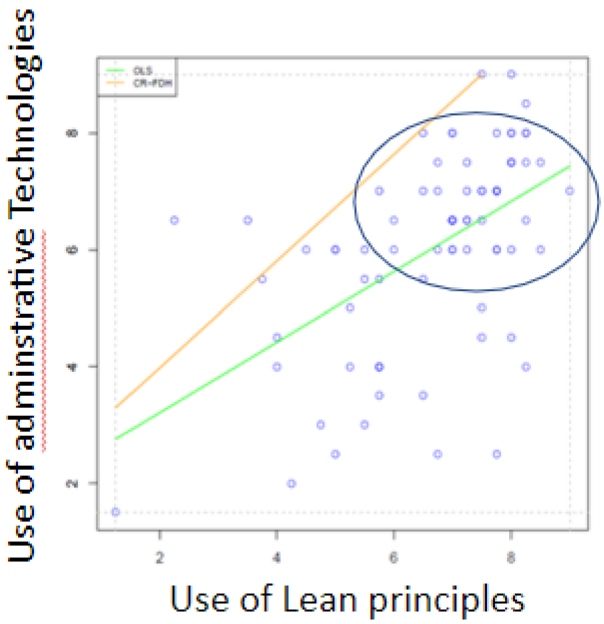


Figure 17 The use of Lean principles and administrative technologies

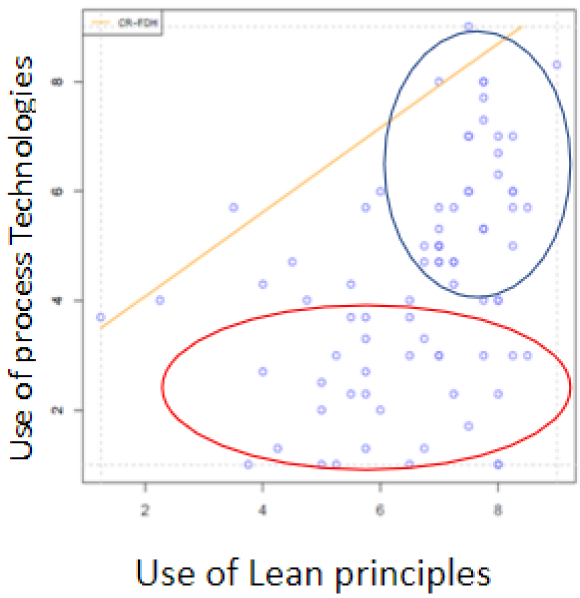


Figure 18 The use of Lean Principles and process technologies

Conclusions from the survey study, which will be used in the taxonomy, are:

- Lean and Industry 4.0 may both contribute to the performance of a company, independently or together;
- Administrative technologies are, in many cases, supportive to the lean journey of companies;
- Advanced process technologies ask for an advanced (serious) use of Lean principles;
- Applying lean principles is not strongly dependent on the use of smart technologies.

3.4 Lean and Industry 4.0 development maturity matrix – a taxonomy

Figure 19 links 'Lean Improvement Maturity' with 'Technology (or Industry 4.0) maturity. The lean improvement maturity level indicates to what extent companies have integrated improvement in the DNA of their workers and organization. The lowest level is 'ad hoc': based on what happens, new improvement projects start. In the next level, there is a certain structure and dedication in the setup of improvement projects. Probably, there are improvement boards, a suggestion box, and such. The start of these improvements, however, is not based on the strategy of the company, but more on the problems discovered in practice. In the third level, there is policy deployment. Improvements are linked to the strategy of the company. There is no sub-optimization anymore. The fourth level indicates a company where improvement is a 'dance', as a routine performed by the whole organization. Improvement initiatives are not dependent on top management but come from the communication between the several organizational levels and department. The company applies Hoshin Kanri in a structured manner, including catchball principles. It is a self-learning system. This classification of improvement maturity stages comes from Bessant et al. (2001).

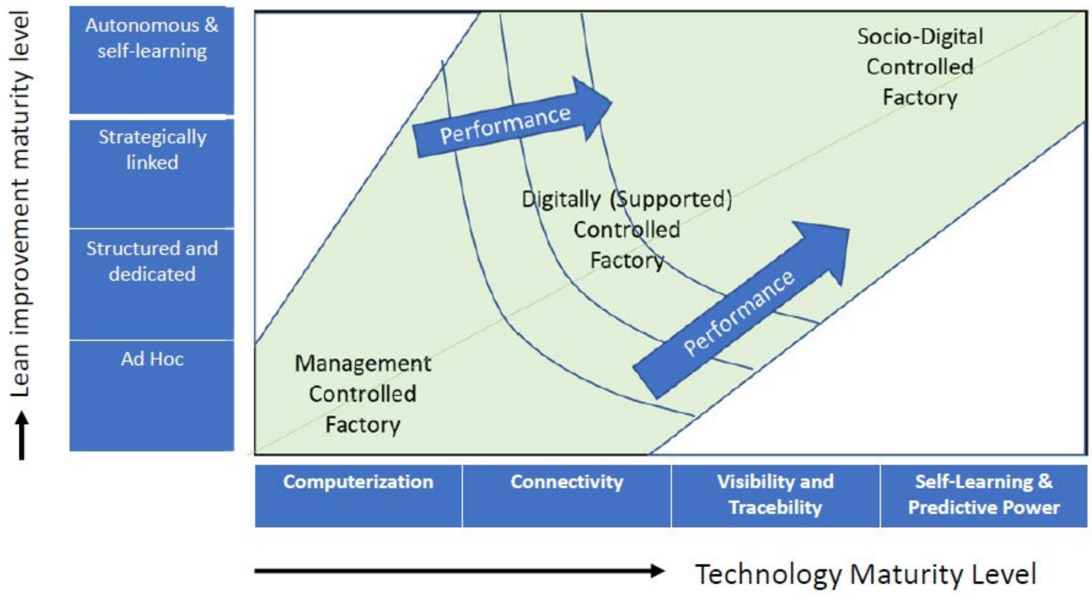


Figure 19 Lean and Industry 4.0 development maturity matrix – a taxonomy.

The technology maturity level illustrates how companies grow from (i) just using computers for main functions (e.g. CAD, CAPP, ERP), to (ii) more connectivity between the various applications, to (iii) a well-performing link of information systems with the actual status of products and resources, to (iv) a system which uses all data to continuously improve the whole system, in an automated, self-learning way. This maturity level is, to a certain extent, linked to the move from industry 2.0 to industry 4.0. The technology maturity levels are to a certain extent in line with the four stages presented in Tao and Zhang (2017), where they discuss the evolution of the interaction between physical and virtual space.

We will explain the content of the matrix further. In figure 20, there are no companies in the yellow and red part of the matrix. The sizes of the triangles are based on the survey presented in section 3.3. The yellow area, which is relatively small, shows that using Lean principles needs the support of administrative technologies (i.e. the level of computerization). Further levels in the use of lean improvement can be realized without the use of 'higher' levels of technology. Lean can be done without extensive use of digital technologies. On the other hand, using more advanced levels of technology ask for more advanced levels of the use of Lean principles. The red part of the matrix, therefore, is empty. There are no companies that use advanced technology without attention for Lean principles.

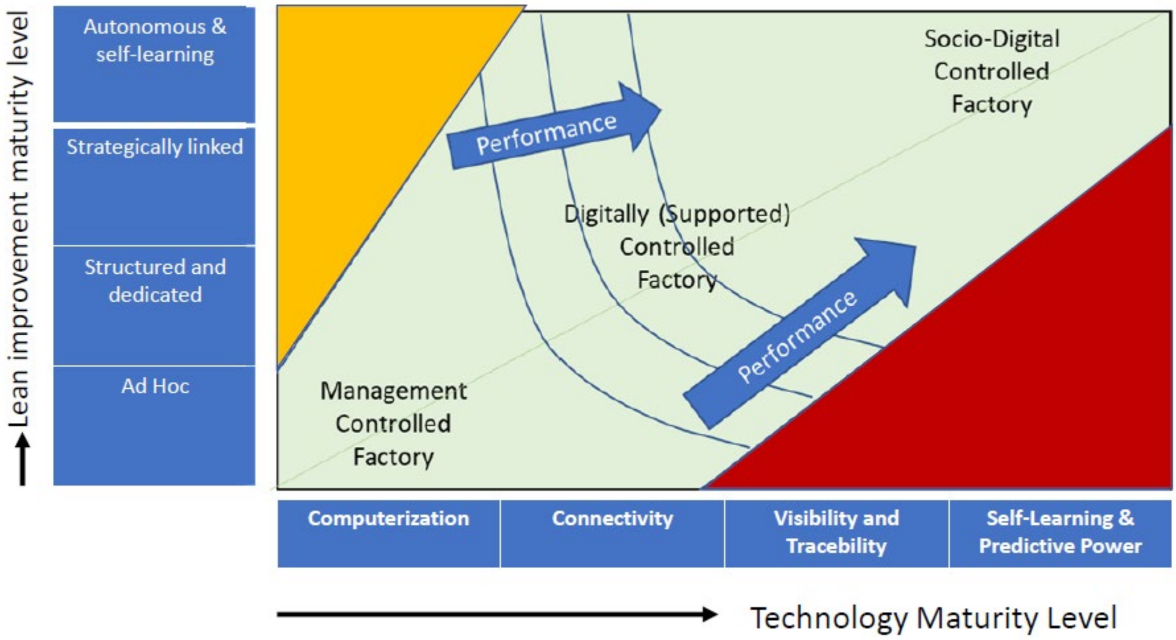


Figure 20 Lean & Industry 4.0 area in the maturity matrix

As a consequence of the previous information (the link between lean techniques and Industry 4.0 technologies and the LEAN 4.0 survey), we think that the most appropriate way to develop is given by the green arrow, presented in Figure 21. It is wise for companies to develop their Lean improvement capabilities before implementing (too) many Industry 4.0 technologies. Management has to understand that too early investments in Industry 4.0 technologies lead to fast bankruptcy, too slow investment in a slow bankruptcy. Managers have to search for a balance between lean and Industry 4.0 investments.

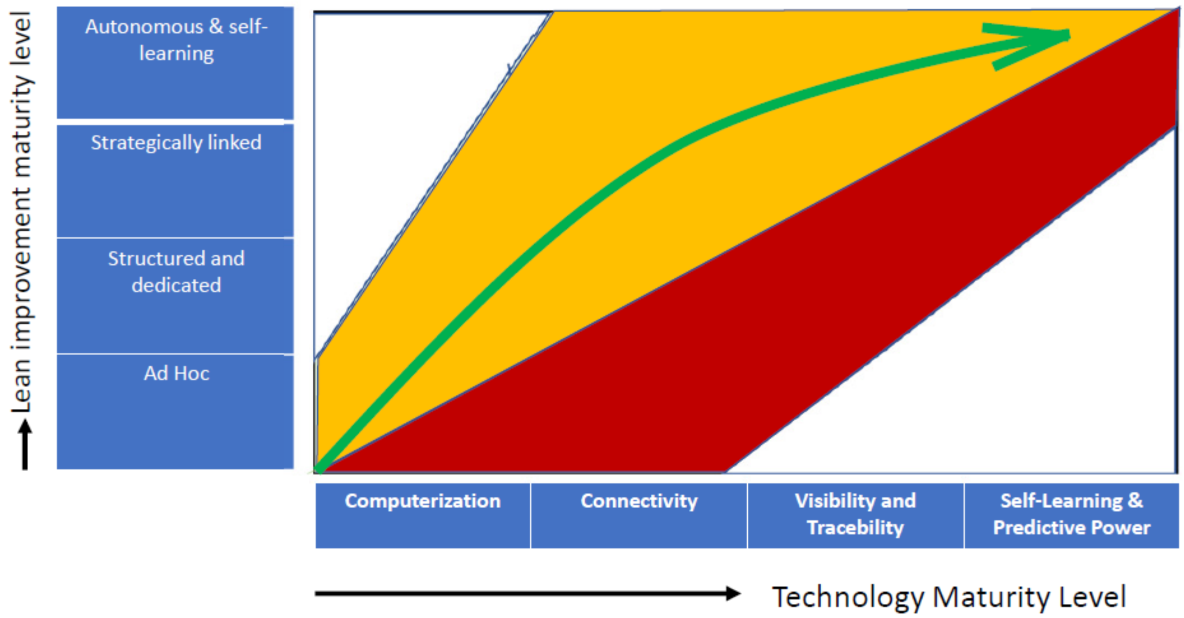


Figure 21 The ideal development curve

The curved lines in figures 19 and 22 present 'performance lines'. Each line represents a performance of the company. In order to jump from one curve to the other, investments in Lean Improvement capability and/or Industry 4.0 technologies have to be made. This figure shows that a balance is needed: a good application of Industry 4.0 technologies also needs Lean Continuous Improvement efforts. This balance created creates the shortest, most efficient way, of growing to a higher operational performance level.

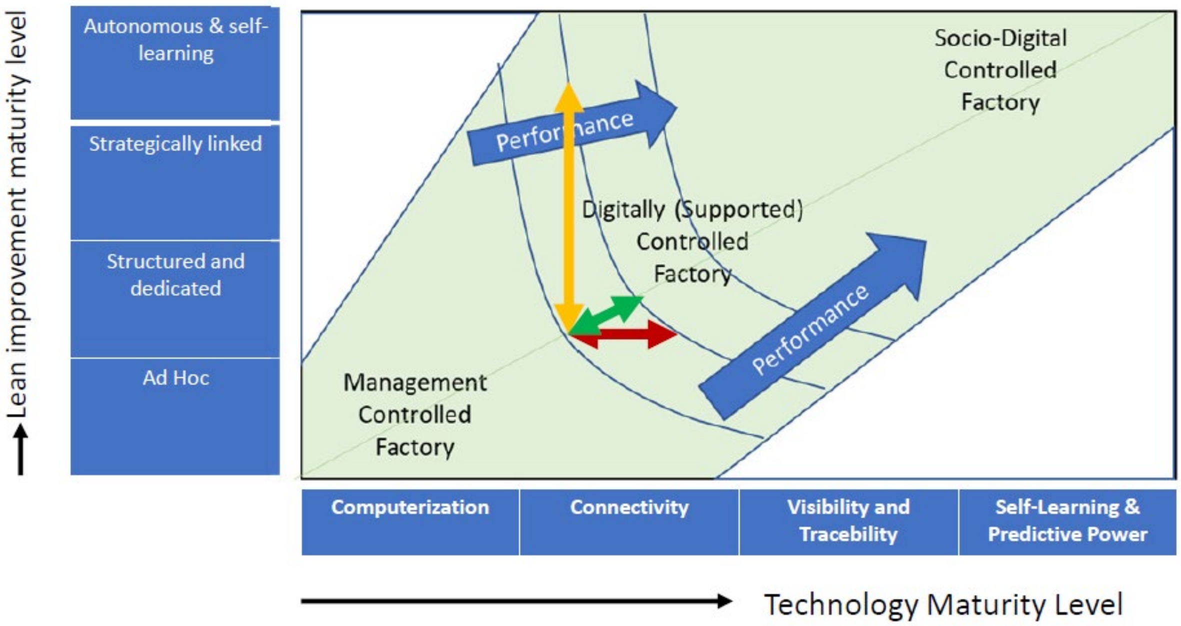


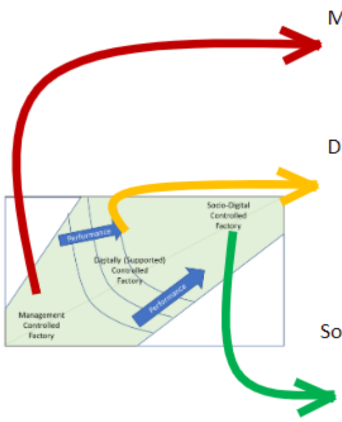
Figure 22 Towards a balanced development of Lean and Industry 4.0.

3.5 Three basic types of companies in the LEAN 4.0 maturity matrix.

There are many types of companies that can be distinguished in this framework. In fact, we made a 4x4 matrix. A number of cells are empty. The remaining cells can be seen as a classification of companies who are more or less busy with Lean and Industry 4.0. Here three types of companies are presented: the Managerial Controlled Factory, the Digitally (Supported) Controlled Factory and the Socio Digital Controlled Factory. An explanation of these types is given in figure 23.

In the taxonomy, and especially in the Socio Digital Controlled Factory, we explicitly mention the development of semi-autonomous teams in LEAN4.0 companies. Less people become responsible for expensive capital goods. Working in teams provides a pleasant environment for them and a shared responsibility.

It is our experience that companies recognize themselves in the three types mentioned in figure 23. More research is needed to specify companies in the various cells of the matrix. The ideal way of development of a company will likely depend on various contingencies, like size, product volume and variety and company culture. The variety of cells may inspire operations managers to select a development route.



Managerial Controlled Factory:

Information systems have limited functionality. They are not connected. Industry 2.0. Management spends substantial time on fire-fighting. The company is functionally organized. Improvements comes from the management.

Digitally (Supported) Controlled Factory:

Information systems have a good functionality. They are to a certain extent connected. The information exchange with the shop floor is limited: no real time data. Improvements are local. Industry 3.0. Management experiences a gap between information coming from the systems and reality. Moving towards (semi) autonomous teams.

Socio Digital Controlled Factory:

Information systems are fully connected. Information is everywhere available. There is no gap between information and reality. Improvements are local as well as cross-departmental and focused on improving value streams. Semi-autonomous teams are fully responsible for parts of the value streams. Intelligent software is used for the coordination between the teams and for their links to suppliers and (external) customers. Industry 4.0. Management focuses on realizing an agile factory.

Figure 23 Basic types of companies in the taxonomy

3.6 Adapting operating and improvement routines for LEAN 4.0.

We performed four case studies in the LEAN 4.0 project to investigate the impact of LEAN 4.0 development on organisation of the operating and improvement routines within companies. See Willems (2020). Based on a comparative study and causal reasoning, we conclude:

- *Increased use of Industry 4.0 technologies requires more formalization and centralization of operating routines. Citation of a manager of a company where a Smart PAC system is introduced: "Our planner now determines the sequence of jobs. The manufacturing teams have to obey this sequence. They don't get information about due dates anymore.".*
- *Increased use of Industry 4.0 technologies leads to sharper boundaries with respect to improvement routines. Citation of a manager of a company where information technology has played a more dominant role: "Previously, managers were heavily involved in setting-up and executing improvement projects. Now, the teams have to organize the improvement*

activities themselves. They are also fully responsible to gain the desired output. Management is more focused on improving coordinating routines."

Generally, we conclude that Industry 4.0 technologies, combined with lean methods, will have impact on the roles and responsibilities of working teams and managers. Managers become coordinators and need to facilitate the working teams. They need to be focused on improving the response time of the company. The working teams become specialists and fully responsible for improving their processes. Good Hoshin Kanri (policy deployment) is essential, where specialists (MES systems) will have an important role. Further research on the impact of LEAN4.0 on the companies' organization is needed and will serve the transition toward the Socio Digital Controlled Factory.

3.7 How to use the Taxonomy

The taxonomy provides support for operations managers to think about the future of their companies. They are responsible for developing the operations function and organizing the operating and improvement routines of the LEAN 4.0 factory.

Within the LEAN 4.0 project, the taxonomy has been developed stepwise. We first integrated a preliminary version of the taxonomy in the LEAN 4.0 assessment tool and used it as an awareness tool for the management of a company. This was relatively successful: managers recognized the logic of the taxonomy and could position themselves within the taxonomy. However, the time within the assessment tool was too limited for an extensive discussion about the LEAN4.0 future of the company. Therefore, we (the university researchers) decided to create a separate tool for the LEAN 4.0 taxonomy, consisting of a number of slides which indicate the logic of the taxonomy. The taxonomy slides, including notes, are available on the website of LEAN4.0. Each slide in the PowerPoint is meant to open a discussion between managers and/or academia.

We suggest to use the taxonomy in masterclasses for company managers. It is an awareness tool but also stimulates managers to think about the future (> 3 years) of their company. The taxonomy may stimulate managers (operations and CEOs) to perform a LEAN4.0 self-assessment with their management team. Important questions that can be asked during a masterclass where het taxonomy is explained, are:

- What is your experience with the link between Lean and Industry 4.0 technologies? Do these technologies support Lean?
- To what extent do you apply administrative technologies (IT and work-on-screen)? Are these technologies linked to process technologies in the company (MES, automated machines)? Could new technologies create more flow in your company?
- Where do you position yourself in the taxonomy scheme? To what extent is your company a socio-digital factory?
- Do you see the establishment of semi-autonomous teams as a challenge in your company?
- How will this have impact on operating and improvement routines in the company? How to realize this change?

It is important for managers to create a long-term vision of the operations function of a company, a vision by which managers and employees feel inspired and which stimulates LEAN 4.0 initiatives and experiments. The taxonomy is helpful in creating such a vision.

As mentioned earlier, the taxonomy is currently rather basic. More research is needed to identify appropriate roadmaps for companies towards the socio-digital factory. This will likely be context-dependent.

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Appendix – supportive studies

Next to the development of the LEAN 4.0 assessment tool and the LEAN 4.0 taxonomy tool, several supporting studies have been performed with support of the LEAN 4.0 project. Here, we give summaries of three important studies:

Bokhorst, J., Knol, W.H., Slomp, J. (2020). On the synergy between smart industry technologies and lean principles, paper submitted to the International Journal of Production Economics.

Summary:

Purpose – This paper examines the synergy between the use of smart manufacturing technologies and the use of principles of lean thinking. The advent of industry 4.0 and its related smart manufacturing technologies calls for a better understanding of how the upcoming smart manufacturing technologies can be put to good use within companies that often have already started their lean journey. Since there is yet little empirical evidence on synergies, this paper aims to explore the extent to which smart manufacturing technologies and lean principles (jointly) effect operational performance.

Design/methodology/approach – Primary survey data on smart manufacturing technologies and lean principles were collected from a set of Dutch manufacturers and analysed using a principal component analysis, factor analysis and Necessary Condition Analysis (NCA).

Findings – Findings show a distinction between smart process technologies and smart administrative technologies. Companies that considerably used smart process technologies and/or smart administrative technologies were also found to considerably use lean principles. Furthermore, several companies used lean principles considerably without using smart process technologies, but it was difficult to realize high levels of lean without using smart administrative technologies. Finally, companies with a considerable use of smart manufacturing technologies as well as lean principles performed relatively better than other companies.

Originality/value – The findings show interdependencies between smart manufacturing and lean thinking, which indicates the need to study both concepts in combination and should stimulate developers of new technology to recognize demands from a lean viewpoint.

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Knol, W.H., Slomp, J., Schouteten, R.L.J. and Lauche, K. (2018), Implementing lean practices in manufacturing SMEs: testing 'critical success factors' using necessary condition analysis, International Journal of Production Research, Vol. 56 No. 11, pp. 3955-3973, available at: https:// doi.org/10.1080/00207543.2017.1419583

Summary: Lean practices are considered important to increase operational performance. Previous research has identified critical success factors for implementing lean practices. This research aims to examine to which extent success factors are critical for various degrees of implementation of lean practices. Using multiple-respondent self-assessments from manufacturing companies, we conducted a Necessary Condition Analysis (NCA) (Dul 2016). Our findings indicated that the criticality of success factors is time dependent. In the initial stages of the lean journey, SMEs could improve their lean practices in a bottom up manner through local factors such as communication, a learning focus, an improvement structure, and support congruence. When lean practices were more advanced, company-wide factors had to be manifest; top management support, a shared improvement vision, and a supplier link. Our findings question the universality of success factors such as strategic involvement and indicate the need for a more dynamic model of lean implementation.

Willems, B. (2020). How information technology influence organizational structure - An explorative study to the use of information technology and its effect on the structure of small and medium sized enterprises, Master Thesis Radboud University, Nijmegen, The Netherlands.

Summary: Information Technology (IT) started as a 'nice to have' for organizations but quickly evolved to a 'need to have'. An organization without IT seems unthinkable in this era. In previous literature it has been shown that technology and organizational structure are related to each other. The purpose of this study was to gain insight into what effect IT can have on organizational structure in small and medium sized enterprises (SMEs) in order to gain new theoretical insights. This explorative study focuses on the effects IT can have on three elements of organizational structure: decentralization, formalization and specialization. This research used a qualitative approach and looked at two steel manufacturing SMEs.

The results of this research suggest that IT can influence structural characteristics. Interestingly, centralization seems to be a double-edged sword, meaning IT can both increase and decrease centralization in organizations. It seems that IT increases centralization in operating routines but can lead to decentralization in improvement routines. The increase of centralization in operating routines can be explained by the fact that information of the primary process can be easily collected and analyzed from a more central, broader perspective. The decentralization of improvement routines seems to be related to the fact that there is more time on the operational floor to work on improvement projects since IT takes over the coordination of the operational floor.

It seems that IT can increase formalization, since it makes it easier to communicate the right information to the right person. In addition, data from the operational floor can be communicated back to management, which can lead to improved work instructions and procedures. It is not clear how IT can influence the specialization of an organization.

This study shows how IT can influence the organizational structure and makes it clear that IT in an organization can lead to organizational change and therefore adds initial support to the literature.