Lean European Action-learning Network utilising Industry 4.0

WP 4 – Process Innovations for Smart Lean Operations

D4.1 Industrial Skillset for Smart Lean Operations

D4.2 Decision Support for Smart Lean Operations

D4.3 Process Innovations within Smart Lean Operations

Version: Final

Date: 30-05-2020

Project Reference: 601227-EPP-1-2018-1-NO-EPPKA2-KA

Co-funded by the Erasmus+ Programme of the European Union

LEAN 4.0 Version Control Table

Deliverable Title	D4.1 Industrial Skillset for Smart Lean Operations D4.2 Decision Support for Smart Lean Operations D4.3 Process Innovations within Smart Lean Operations
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Version date	30.05.2020
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Revision History:

Date	**Version**	Summary of Changes	Initials
27.03.2020	First Draft (with D4.3)		EA
22.04.2020	Draft (with D4.1 and D4.3)	Modified after discussion with Jannes and Daryl	EA
05.05.2020	Draft ready for internal review	Modified after discussion with Jannes and Daryl	EA
18.05.2020	Draft ready for external review	Updated after feedback from internal evaluation	EA
30.05.2020	Approved	Updated after feedback from external evaluation	EA

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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 their necessity in order to face in an efficient 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 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 4 – Process Innovations for Smart Lean Operations

This work package will explore the potential of including Smart technologies in Lean Manufacturing abilities focusing on solving problems and developing process innovations for Smart Lean Operations. The prerequisites of this work include identifying the relevant industrial skillset for Operations managers. A skillset refers to the defined list of particular competences that are required for Operations Managers of the future to manage the complexity and effectively handle the implementation of Smart Lean Operations. In addition, a Decision Support methodology will be developed for finding specific potential technological and process innovations. These will ensure that the industrial partners have the needed competence to manage development of Smart Lean Operations, and that the industrial partners can identify specific areas of improvement in both technologies and in manufacturing processes that can be focused on.

1.3 Deliverable 4.1 – Industrial Skillset for Smart Lean Operations

This Deliverable will identify the industrial skillsets required by Operations Managers to develop Smart Lean Operations in their own companies. WP1, industrial surveys and focus groups will be used as input to map the documented knowledges required for future Smart Lean Operations development.

1.4 Deliverable 4.2 – Decision Support for Smart Lean Operations

The output of this Deliverable will be a Decision Support Methodology that will support Smart Lean Operations by developing future scenarios. In particular, a Formative Scenario Analysis will be applied to develop a methodology for creating realistic Smart Lean Operation Roadmaps.

1.5 Deliverable 4.3 – Process Innovations within Smart Lean Operations

Thanks to this Deliverable, the knowledge and research to combine the Lean and Industry 4.0 paradigms to enable Smart Lean Operations will jointly be explored, developed and improved. This will provide foundational theory related to the implementation, adaptation and usage of Industry 4.0 technologies, thus lifting the current level of practical knowledge and research within Smart Lean Operations.

2 Work Package structure

This work package will be divided into three main parts, one per each deliverable. The first part to be treated will be Deliverable 4.3 - Process Innovations within Smart Lean Operations, that will be treated in the next Section (Section 3). Understanding the state of the art with respect to the combination of Lean and Industry 4.0, in fact, was considered as a fundamental starting point to then develop the Decision Support Methodology of D4.2 and the industrial surveys and focus groups of D4.1. Therefore, a literature analysis was carried out to assess the combination of Lean practices and Industry 4.0 (I4.0) technologies. In particular, the effects of specific I4.0 technologies on given Lean practices were analysed. Based on the WP1 (that, in turn, was based on the works of Shah and Ward [1], [2]), ten main Lean principles were identified, i.e. *Continuous flow*, *Pull*, *Single Minute Exchange of Die*, *Total Productive Maintenance*, *Jidoka*, *Six Sigma*, *Customer Involvement*, *Supplier Integration*, *Kaizen* and *People & Teamwork*. Dealing with I4.0 technologies, instead, nine technologies were chosen (i.e., *Sensors & Actuators*, *Cloud computing*, *Big Data & Data Analytics*, *Integrative Technologies*, *Assistive Technologies*, *Decision Support Systems*, *Advanced Algorithm*, *Additive Manufacturing* and *Advances Vehicles*), starting from the classification done in WP1 and improving such classification based on the results from the literature analysis. In such a way it was possible to understand which I4.0 technology can impact on a specific lean practice.

The outputs of this deliverable were then used for Deliverable 4.1 – Industrial Skillset for Smart Lean Operations, which will be treated in Section 4. The initial aim of this deliverable was that to identify the industrial skillsets required by Operation Managers to develop Smart Lean Operations based on the results of WP1, industrial surveys and focus groups. However, from WP1 and from industrial workshops and meetings carried out during the project, it has emerged that the main necessity for a Smart Lean Operations development is the understanding of the impact of I4.0 technologies on increasing the level of lean. Therefore, in this deliverable we focused on the identification and evaluation of the I4.0 technologies that can help lean practices. To do so, as mentioned, we started from the outputs of D4.3, providing a concise summary of the I4.0 technologies that impact the ten main Lean principles above listed and evaluating their impact in the form of a three level classification as proposed by Wagner et al. [3].

Finally, Section 5 reports the last main part of this work package, i.e. Deliverable 4.2 – Decision Support for Smart Lean Operations. Here, a Decision Support System to assist Operations Managers in the achievement of a Lean4.0 strategy is reported. Starting from the identification of the performance challenges of a certain Focused Target Market Segment (FTMS), Operations Managers will first identify the lean practices of help to achieve such performance challenges and then they will assist in the detection of the I4.0 technologies that can be of help. Moreover, they will be guided to choose correctly among the different possible I4.0 technologies based on their effect on the performance challenges and based on some evaluations internal to the company (costs perspective, sustainability perspective, …). To do so, the outputs of the other two deliverables (D4.1 and D4.3) and of the two deliverables of WP1 have been used.

3 D4.3 - Process Innovations within Smart Lean Operations

3.1 The digital transformation of Lean manufacturing

Implementation of Lean manufacturing concept has given rise to significant positive impacts on various industries during the past couple of decades. The concept of Lean production was first introduced by Womack et al. [4] inspired by the Toyota Production Systems (TPS). TPS provided tools and methodologies to eliminate waste in an effective, but mostly problem-specific way. Hence, Womack and Jones [5] systematized the Lean Thinking and put together five critical elements of Lean implementation, i.e., value, value stream, continuous flow, pull, and the continuous improvement. Although Lean tools and techniques have already proven their efficacy in various sectors, it seems as if Lean production, on its own, is not capable of coping with the current market dynamics anymore [6]. Strong market demand fluctuations do not go in line with the capacity levelling concept. In addition, the lack of change-ability in production lines and the fact that laborious adjustments are required for changes in production processes, buffer stocks and cycle times, are all indicating that Lean tools and techniques are of limited suitability when it comes to shorter product life cycles and highly customized products [6], [7]. To keep up with the aforementioned high demand for customized products, tighter competition and increased emphasis on immediate and responsive service, companies are being directed towards digital transformation and service-oriented paradigms. This transformation has been accelerated recently thanks to the increasingly affordable hardware and software solutions realized by cheaper and more effective sensors and actuators, more powerful networking equipment and platforms such as wireless technology and cloud computing and also Big data analytics and artificial intelligence related developments. These components form the recently introduced "Industry 4.0" concept targeting the digitization and automatization of production. However, the thirst for adoption of I4.0 technologies can pose ever greater challenges in terms of cost-benefit justification, implementation considerations and frameworks, and its influence on already established production practices such as Lean manufacturing [8], [9]. Recently researchers have thus focused on covering this new area by exploring the integration of Lean tools and Industry 4.0 technologies. In the following, we aim to summarize the main outputs of these works, providing to the Operations Managers a summary of the existing correlations between Industry 4.0 technologies and Lean tools. In particular, since from the literature analysis it was found that lean manufacturing has to be used as a foundation to build an Industry 4.0 implementation on [8], [10], we focused on the impact of different I4.0 technologies on specific lean practices, understanding how these advanced technologies can improve lean practices. In such a way, we were thusd able to provide foundational theory related to the implementation, adaptation and usage of I4.0 technologies for each lean practice.

3.2 Existing integrations of Industry 4.0 technologies and Lean practices

Based on the results from the literature analysis, the effects of the main I4.0 technologies on each main Lean principle have been summarized here. The main Lean principles used were derived from the WP1 (that, in turn, was based on the works of Shah and Ward [1], [2]), and they were ten: *Continuous flow*, *Pull*, *Single Minute Exchange of Die*, *Total Productive Maintenance*, *Jidoka*, *Six Sigma*, *Customer Involvement*, *Supplier Integration*, *Kaizen* and

People & Teamwork. Concerning instead I4.0 technologies, the classification done in WP1 was used as starting point and then improved based on the results from the literature analysis, resulting in nine different I4.0 technologies, i.e. *Sensors & Actuators*, *Cloud computing*, *Big Data & Data Analytics*, *Integrative Technologies*, *Assistive Technologies*, *Decision Support Systems*, *Advanced Algorithm*, *Additive Manufacturing* and *Advances Vehicles*. A brief description of these technologies can be found in Table 1. As mentioned earlier, we focused on the impact of the different I4.0 technologies on the specific lean practices since lean adoption is a prerequisite for a positive effect of I4.0 technologies [8], [10].

3.2.1 Continuous flow

The continuous flow is part of the wider Lean method Just-in-Time that aims to deliver the right product, at the right time, place and quality in the right quantity for the right costs. Particularly, continuous flow aims to move in the shortest time a single product through every step of the process instead of grouping work items into batches. In such a way it is possible to continuously send goods to market, delivering value more often to the customers. Several I4.0 tools can contribute to this objective.

Advanced Vehicles (AV), such as Automated guided vehicles (AGV) and Autonomous Mobile Robots (AMR), for instance, can transport single units through a flexible material flow, without the need for building continuous material handling devices like belt or roll conveyors [11], [12]. In addition, they can guarantee to supply material to workstations in accordance to the requirements by transporting objects within the material flow automatically, avoiding the human mistakes that might happen with forklifts for examples. In addition, in case of obstacles the transportation system will reroute the vehicle to an alternative path, thus further guaranteeing an efficient delivery of materials by reducing the congestion [11]. Furthermore, in a perspective of *Integrated Technologies* that allows the connection of *AV* with other advanced I4.0 technologies such as Indoor Positioning Technologies (*Sensors*), *Big Data* and *Cloud Computing*, it is possible to further increase the responsiveness of the system, besides the flexibility and productivity of the overall manufacturing system, by optimizing the scheduling of the material handling systems thanks to the use of *Advanced Algorithm* [13]. Moreover, in this perspective of an integration between machines on the same level, in the case of a capacity constraint in production, the production processes can autonomously change according to an auto-adaptive production plan thanks to the possibility provided by the advanced algorithms to find and automatically redirect to available capacities [3], [14], [15].

The combination of *Advanced Algorithm* and *Integrative Technologies* has been described as fundamental to create a proper flow without any interruption, bottlenecks or delays not only within the organization but also within the whole supply chain [16], [17]. For example, an intelligent routing system that analyzes traffic information in real-time have been designed in Ref. [18] to manage JIT deliveries and provide a general improvement to deliveries with reduced waiting times and higher customer satisfaction. Furthermore, Wittenstein Company adopts a flexible system of supply chain where, instead of fixed transport intervals, an integrated system with production and automated guided vehicles (AGVs) determine the milk-run system-based transport interval through real-time demand. According to the study, the system registered gains of 25% with the new implementation [19]. Linking different actors of the supply chain through *Integrative Technologies* has in fact been reported to eliminate waste in raw material management, work in process and finished product inventory, thus enabling the supply chain to be more efficient [20].

In many cases a disruption in flow arises due to errors in inventory counting, capacity shortages and centralised controlling systems leading to delays in decision making [21]. In Ref. [22] it was stated that inventory could be improved by 70.2% thanks to the use of appropriate Industry 4.0 tools. In this perspective, particularly interest is the development of dynamic value stream maps. Value stream mapping (VSM) is a fundamental lean tool that aims to identify improvement areas in the value stream [23]. Traditional VSM is a manual ‘pen-and-paper’ process, and the data collection for it can often be challenging and tedious. In addition, it only offers a ‘snapshot’ of the process, and small changes could change this picture dramatically [24]–[26]. A dynamic VSM is an innovative approach that overcome all the limitations of the traditional VSM and it can be obtained through the use of Industry 4.0 technologies, particularly *Sensors* and *Big Data and Data Analytics*. It represents a real-time VSM and, hence, it offers excellent possibilities for waste reduction and immediate feedback on decisions. Interesting is the possibility to eliminate the errors associated with inventory by real-time exact tracking of inventory [27]. An error-free inventory status aids maintaining a low inventory level and timely ordering of goods [28]. Particularly, *Sensors* such as RFID or other indoor positioning techniques allow to acquire real-time data about the materials and equipment that can be analysed through *Data Analytics* helping to eliminate inventory errors and maintain a low level of stock and a timely order of products [29], [30]. Furthermore, the combination of this dynamic VSM with *Cloud Computing* provides real-time KPIs [31], enabling a decision making process that is based on facts and more reactive to incidences [32]. Finally, such a combination of I4.0 technologies can further support a continuous material flow by reducing machine downtimes through predictive maintenance actions [33], but this will be better explained in Section 2.2.4.

By combining the real-time data provided by the cyber network (combination of *Sensors*, *Big Data & Data Analytics* and *Cloud Computing*) with a simulation tool (*Decision Support* System) to obtain a simulation-based real-time solution, it is possible to ensure the continuous flow by detecting bottlenecks and by drastically reducing inventory levels [34]–[36]. In addition, simulation-based real-time solution can be used for production planning, resulting in a drastic reduction of the inventory levels and ensuring production flow [36]–[38].

Assistive Technologies, such as Augmented Reality (AR), can provide information to operators about cycle time and tasks to perform, in order to support JIT production [17][30]. Virtual Reality (VR) can instead be used to assembly training, providing a platform for “learning by doing” instead of learning by seeing, listening, or observing, resulting in fewer errors and lesser time in actual product assembly when compared against the participant from traditional training group [39]. Collaborative robots (cobots), by assisting employees in their work and benefiting from a certain level of autonomy to react to the employee's actions, can collaborate to respond in real time and ensure that production runs smoothly [40], [41]. In addition, Mayr et al. proposed the use of autonomous robots to adjust production planning in real time [33]. Wagner et al. extended this concept proposing system integration (*Integrative Technologies*) to ensure a continuous flow by allowing systems to adjust autonomously production planning [3]. Finally, autonomous robots are able to identify and avoid production errors and can adjust themselves to possible irregularities [17], [27], [33].

Additive Manufacturing has been reported to facilitate the achievement of the Lean principle of the *Continuous flow*. In fact, since this technology allows a print-on-demand production system, a one-piece flow production can be achieved. In such a way it is possible to eliminate inventory and to decrease the lead times and enhancing logistics efficiency, since 3D printers can be installed near customer's location [42].

Integrative Technologies allows an enhanced interconnection and communication between cells and workstations that are reported to facilitate a flexible, fast and high-quality material flow, and, in turn, the feasibility of continuous flow implementation [43], [44].

3.2.2 Pull

Pull is the technique of planning the production according to the customer's request. The idea behind is that an operation in an industry should be performed only when it is demanded for, i.e. when the customer arises a demand [45]. It means that every subsequent operation has to initiate the operation of its predecessor. A normal push production would lead to extra inventory, unsold goods in the factory and in turn leads to extra costs of manufacture, maintenance etc. [46]. Improper track of quantity of materials supplied to the production line and alterations in schedule after material supply severely affect the pull production system [27]. Kanban is one of the best methods of implementing pull production, in which a successive station generates Kanban cards to initiate operation for a particular station. However, traditional Kanban cards are usually undermined due to card losses during their loops between workstations or facilities, leading to mistakes in production control or scheduling and, hence, reduced operational performance [47], [48]. For example, due to such errors, an over-production of fasteners was reported in Ref. [49]. The incorporation of Industry 4.0 technologies into Kanban systems (denoted as e-Kanban [50]) can overcome these limitations and enhance pull systems in terms of both product/service-related information and manufacturing processes [14].

The use of *Sensors* allows to provide the exact status and location of production batches and to recognize missing and empty bins automatically and to trigger replenishment (via *Integrative Technologies*) [17], [27], thus ensuring that the right product arrives at the right destination at the right time [34].

In addition, in partnership with *Sensors* and *Cloud Computing*, *Big Data analytics* can constantly monitor production flow and holistically integrates all sectors of the intelligent plant (*Integrative Technologies*), thus allowing the system to become self-organized through decentralized decisions (by means of *Advanced Algorithm)*, adjusting e-Kanban to changes in batch sizes, market demands, work plans or cycle times [33], [51]. In such a way, real-time scheduling can be achieved, allowing manufacturing priorities to be established to afford suppliers flexibility and reaction capability [52], and the e-Kanban parameters can be continuously updated accordingly [53]. In addition, it is also possible to achieve what Wagner et al. called Just-in-Time delivery system [3], where orders are automatically sent to the suppliers, but this will be better described in Section 2.2.8. An example of such an application is the optical order system "iBin" introduced by Würth Industrie Services GmbH & Co. in 2013: a camera in the module detects the charging level of the bin and iBin reports wireless the status to an inventory control system. Besides, iBin is also able to send orders automatically to suppliers. As a result, buffer stock can be reduced and spare parts can be scheduled order-oriented [17].

Simulations and/or digital twins, as part of *Digital Support Systems,* can be used to test different parameters of Kanban, allowing the identification of ideal Kanban parameters like lot size, stock or delivery frequency [17], [33], [54]. To further improve the results obtainable through simulations, it is important to relate them to the real-time capacity of *Advanced Vehicles* so that virtual maps are constantly updated and the Kanban parameters can be continuously adapted to the current situation [17], [27], [55].

Finally, *Additive Manufacturing* has been reported to eliminate inventory and thus promote pull systems since they allow a print-on-demand production system [42].

3.2.3 SMED

As customers' needs diversify, the product assortment also increases, with a consequent reduction in batch sizes. Hence, high changeover times (and, thus, process downtime) become an obstacle to high performance [56]. Toyota overcame this by adopting the "single-minute exchange of die" (SMED) concept which enables smaller batches and shorter lead times by drastically reducing changeover times [57]. The full adoption of "low setup practices" improves the flexibility and agility in production delivery, since shorter setup times may lead to reductions in batch sizes [58]. Inventory levels are also likely to be reduced, which directly affects the organisation's cash flow [59]. Industry 4.0 technologies can enhance the impact of low setup practices on operational performance.

Additive Manufacturing (AM) is expected to have an high impact on setup times. The basic principle of AM is in fact that a part can be manufactured layer by layer directly from a computer-aided design (CAD) model using a combination of energy delivery and material deposition, therefore with no setup time and no requirement for tooling, even for complex parts [60]. Therefore, times for selection, search and adjustment of tools and workpieces are omitted. Nevertheless, small adaptions, temperature adjustments and cleaning operations will still incur [33].

Recently, it has become very common among the factories to use the so called "Plug'n'Play" or "Plug'n'Produce" to reduce the setup times. Usually, setups and process adaptation in general are done by humans based on previous knowledge. This however leads to long setup times and also to errors. This can be overcome through "Plug'n'Play" or "Plug'n'Produce", that is nothing but connected systems equipped with self-optimising and machine learning behaviours [61]. This can be achieved thanks to *Integrative Technologies* (combining *Cloud computing*, *Big Data & Data Analytics* and *Sensors*, that allows the identification of the right moments for machine changeovers) and *Advanced Algorithm*. In particular, the operations to be performed on a part are initially loaded into the part through RFID tags. As the part reaches its respective machine, it directly communicates with the machine through RFID receivers. This results in quicker changeover of machine parameters according to the instructions read from the part [61]. Consequently, setup time in organisations is substantially reduced through self-optimisation of machines and workpiece-machine communication. An example of such an application is the automatic mold-change system proposed by Stäubli Corp. (Duncan, SC), that demonstrated a complete hands-off mold changing in less than 2 min in an injection press.

Specifically, a mold table on rails carried a preheated mold into position beside the press. A sensor in the cart read the mold setup parameters from a chip in the mold. For the mold already in the press, all power and data connections were disconnected automatically within 3 s [62]. In addition, Plug'n'Play/Plug'n'Produce could furthermore support lean production's requirement for a flexible and modular production. Modular workstations, based on standardized physical interfaces, can in fact be flexibly reconfigured to new production lines via Plug'n'Produce [6].

Moreover, the more complicated elements of the manual changeover can also be simpler using digital work instructions (*Assistive Technologies*). Employees can easily understand and visualize each step of the changeover process using augmented reality, further boosting productivity and worker safety [63].

Finally, Rüßmann et al. (2015) suggested the use of simulation (*Decision Support Systems*) to optimise machine setups by testing various methods [64].

3.2.4 TPM

In order to guarantee the highest possible plant performance Lean Manufacturing has considered Total productive/preventive maintenance, aiming to avoid failure of machines and equipment through periodical maintenance procedures and to maintain low rectification time in case of failure [27]. However, despite the high efforts taken by companies through preventive and periodical maintenance, failure of machines are not always under control, resulting in production disruption and considerable time spent to find the root cause and solve the problems [27]. According to [65], TPM will execute its functions more effectively in the future smart factory with assistance from Industry 4.0 techniques. Through *Sensors* for example, error notifications are sent to respective shop-floor and maintenance personnel when a machine breaks down [27], [66], [67]. In addition, combining *Sensors* with *Big Data & Data analytics* and *Cloud Computing*, it is possible to detect abnormal situations based on data history, standard system behaviour and expected performance, thus allowing failure patterns to be predicted in advance utilising data from other machines [68]–[71]. In such a way, either concerned personnel can be notified or *Advanced Algorithm* respond to specific changes in their environment by carrying an action, which in turn makes the maintenance planning, forecasting, spare parts logistics easier and more efficient [65], [72]. Particularly, considering *Integrative Technologies*, to mitigate the impact of breakdown, other machines can be contacted to find their availability for taking over the workload [73]. After rectification, the solution is stored into the *Cloud*. This along with failure pattern can be communicated with other machines which can then learn the mistake and prevent it from happening again [65].

In addition, *Assistive Technologies*, such as Augmented Reality, Virtual Reality and Haptic technologies, can facilitate the learning and training of the human operator as well as maintenance instructions [74]–[77]. Particularly, dealing with maintenance instructions, interaction with maintenance experts are possible, and thus, by displaying virtual elements, operators can be guided remotely [78], [79].

Finally, if a failure demands a part to be replaced, the new spare part can be printed using *Additive Manufacturing* [65].

3.2.5 Jidoka

Jidoka represents one of the pillars of the Toyota Production System [45], whose aim is to ensure that anomalies are detected during processes and not sent to the next station [80]. Jidoka relies on 4 simple principles to ensure that a company would deliver defect-free products:

1. Discover an abnormality
2. Stop the process
3. Fix the immediate problem
4. Investigate and solve the root cause

To follow these principles, different Jidoka systems have been developed in the past years [81]. The so-called first Generation Jidoka Systems, or "Jidoka 1.0 Systems", were characterised by mechanical gadgets, known as "Poka-Yokes" in the lean manufacturing jargon, that allow to perform a task in a way that the right choice was the only possible. Later on, Second Generation Jidoka Systems, or "Jidoka 2.0 Systems", were upgraded and characterised by the addition of an "Andon" visual and/or audio alarm features in order to effectively notify human operators about a quality or a process problem in a manufacturing process. With the advancement of operational technologies, a Third Generation Jidoka Systems, or "Jidoka 3.0 Systems", emerged. These systems are characterised by new hardware- and software-enabled features capable of not only detecting, but supporting human operators in the fault diagnosis of the problem at hand by means of analog and digital sensor signals processing and error code lists, also known – "Jidoka rules". Currently, with the emergence of the Industry 4.0 technologies, a Fourth Generation Jidoka Systems, or "Jidoka 4.0 Systems", has started to take the lead, introducing a culture of adapted systems that automatically early-detect and diagnose a problem, and in some cases correct it before it actually occurs [66], [81]. I4.0 technologies have an impact in fact on both the traditional "Andon" and "Poka-Yoke" concepts.

Dealing with the former, nowadays, failure recognitions are obtained through signal lamps. With the adoption of I4.0 technologies such as *Sensors* and *Assistive Technologies* (tablets, smartphones, head-mounted displays, smart watches, …), recognizing failures does not depend on location of employees anymore since the employees receive error messages on their *Assistive Technologies* [17], [26], [66] In addition, as already mentioned in the previous section (Section 2.2.4.), when failures are recognised, it is possible to automatically trigger fault-repair actions.

Dealing with Poka-Yoke, instead, I4.0 technologies can help operators to avoid mistakes in different ways. For example, *Sensors* allow part recognition, identifying any incorrect component and thus parts can then be removed, contributing to the idea of poka-yoke. In addition, as mentioned in the previous section (Section 2.2.4.), failure patterns can be predicted in advance (please refer to the previous section for more details). Furthermore, AR and other *Assistive Technologies* can be used to achieve an error-free picking and assembly [82]–[87].

Although not directly related to Jidoka, *Decision Support Systems* have a certain complementarity since the utilization of simulations for example can anticipate potential difficulties and mitigate failures in the productive process [88].

3.2.6 Six Sigma

Six Sigma seeks to improve the quality of the output of a process by identifying and removing the causes of defects and minimizing impact variability in manufacturing and business processes. This is accomplished through the use of two Six Sigma sub-methodologies: DMAIC (Define, Measure, Analyse, Improve and Control) and DMADV (Design, Measure, Analyse, Design and Validate). The former is used for projects aiming at improving an existing business process, while the latter for projects aiming at creating new product or process designs. Focusing on DMAIC, it has five phases:

1. ***Define*** the system, the voice of the customer and their requirements, and the project goals, specifically.
2. ***Measure*** key aspects of the current process and collect relevant data; calculate the 'as-is' Process Capability.
3. ***Analyse*** the data to investigate and verify cause-and-effect relationships. Determine what the relationships are and attempt to ensure that all factors have been considered. Seek out root cause of the defect under investigation.
4. ***Improve*** or optimize the current process based upon data analysis using techniques such as design of experiments, poka yoke or mistake proofing, and standard work to create a new, future state process. Set up pilot runs to establish process capability.
5. ***Control*** the future state process to ensure that any deviations from the target are corrected before they result in defects. Implement control systems such as statistical process control, production boards, visual workplaces, and continuously monitor the process. This process is repeated until the desired quality level is obtained.

It can be seen that DMAIC (and Six Sigma in general) is a statistical-based and data-driven approach, therefore it is very dependent on accurate data. In such a perspective, Industry 4.0 technologies can have a high impact on Six Sigma. Davies et al. [67], for example, described how I4.0 technologies could impact on each of the five phases:

1. The desires of the customers can be monitored in a much easier way through Electronic Kanbans (please refer to Section 2.2.2. for more details).
2. Key production metrics (production rates, downtime, set up time) can be automatically captured through the use of *Sensors*, *Big Data & Data Analytics* and *Cloud Computing*. *Advanced Algorithms* anticipate production problems (machine failures, performance deterioration) and communicate the information to key production personnel via *Assistive Technologies* (smart watches, tablets, …).
3. Combining *Sensors* with *Big Data & Data analytics* and *Cloud Computing*, it is possible to detect the reason behind failures, based also on data history. In addition, it is possible to prevent failures (please refer to Section 2.2.4.).
4. The data captured in real time can be stored for later analysis thanks to *Big Data & Data Analytics* and *Cloud Computing*. Conventional statistical methods could be applied to the data for continuous improvement activities thanks to *Advanced Algorithms*.
5. Through the use of *Sensors* and *Big Data and Data Analytics*, it is possible to have a real-time Value Stream Mapping (please see Section 2.2.1) that allows to control and

evaluate the current state. In addition, the integration of *Cloud Computing* provides real-time KPIs.

The importance of *Sensors*, *Big Data & Data analytics* and *Cloud Computing* for an efficient discovery of real-time defects in the process and their root-cause analysis was highlighted also by other authors [89]–[91]. By applying such I4.0 technologies, KKCO was capable to instantly evaluate control charts based on the real-time data and provide quality management personnel with the real-time clear stop/go instructions (thanks to *Advanced Algorithms* and *Assistive Technologies*), reducing the defect rates of some machines from more than 10% to less than 6% [49].

3.2.7 Customer involvement

Customers are the prime drivers of all the businesses, and they are the crux for a business to survive. Therefore, customer involvement represents a milestone if a company wants to thrive, especially in an environment where customers are increasingly more demanding (they require greater product quality and variety,) and challenging traditional methods of engaging and buying from providers. Maintaining the connectedness to the customer base and predicting changes in market trends are thus fundamental [92], and I4.0 technologies can have a great impact, although poorly investigated [93]. Davies et al., in fact, reported that "*the real time heterogeneous nature of Industry 4.0 and the capability to harvest a vast amount of customer and market related data provides the capability to remain dynamically linked to the customer base and market trends. With the appropriate analytical methods applied to the data, the intelligence necessary to maintain customer and market alignment can be obtained*" [67].

From the statement just reported, it emerges clearly the importance of *Big Data & Data analytics*, which can, for example, enhance the forecast quality [33], [94]: traditional analysis tools for customer analysis and market research areas (such as quality function deployment for example) have in fact limitations on the quantity of customers' requirements and their relationship with product design requirements, besides the problem of acquiring exact needs of customers, and *Big Data & Data analytics* can facilitate extreme complex calculations and processing of relationship between needs and functions for large volume of data [95].

In addition, combining *Big Data & Data analytics* with *Sensors*, Astola et al. developed a management system able to share real-time information directly in customer's information system, reducing communication times and costs and increasing efficiency and value added for costumer [96]. In addition, integrating *Sensors* in the products gives the possibility to track usage data and send to the manufacturer, which can then collect and analyse these data (through *Big Data & Data analytics*), enabling in turn a better identification of customers' needs and behaviours in order to provide more sustainable products and solutions [15].

Furthermore, Sanders et al. stressed even more how the customers' involvement has to be established right from product development stages: "*No more can the old 'sell and forget' mentality be found in the minds of manufacturers*" [27]. However, nowadays, once the specifications are set for manufacturing, customers are provided with very little flexibility to alter them at a later stage. Through *Integrative technologies*, the start of freeze period, i.e. the period at which manufacturing parameters are frozen and cannot be changed, can be elongated until the point where unchangeable parameters are incorporated into the product. This is achieved quite effortlessly by the integration of different systems such as manufacturing execution system, B2C applications, etc. This provides a system for customers to be kept informed about the actual production stage (the customer will be directly connected to the various elements in the supply chain due to the horizontal integrating digitized mechanism) and expected completion of the order [97]–[100].

Finally, the combination of *Sensors*, *Cloud Computing* and *Big Data and Data Analytics* gives the possibility to obtain customer-oriented real-time key performance indicators (KPI) for quality, delivery time and costs [101].

3.2.8 Supplier integration

Inappropriate transfer of information between manufacturers and suppliers is a significant source of waste, with respect to the process as well as the product. Suppliers need to be regularly informed about the status and condition of the products and services provided by them. This paves the way for immediate response and adequate action in case of any discrepancies. But difference in business models, operation, and data maintenance practices between the manufacturers and suppliers do not allow manufacturers to easily communicate information with other business partners. Every industry cannot have expertise and resources in all the required fields. Industry 4.0, although its effects on supplier integration are very little investigated [93], can provide the necessary tools to achieve immediate and automatic feedback to suppliers, to overcome bureaucracies and inadequate communication channels [27].

Thanks to *Integrative technologies*, the combined expertise of collaborated firms expands the horizons of business, along with beneficial risk mitigation in case of catastrophes. Data of products and production processes is shared beyond the boundaries of individual industries, enabling them to be highly synchronised [61]. This is for example the case of e-Kanbans, where parts are automatically ordered when Kanban bins are empty or below their reorder point [102].

Moreover, the traditional communication mechanisms between the partners in a business are renovated through *Cloud Computing* and mobile computing services. Just through smartphones and tablets connected to the internet and common cloud, easy integration and better relationship could be maintained between the business partners (*Integrative Technologies*) [103]. Thus collaboration, synchronisation and better communication mechanisms serve as enablers to maintain effective supplier feedback. For example, Satoglu et al. reported that the use of tablets to interact with employees within the transport system allowed for more efficient delivery of materials and shortening of the paths (by about 25%), with the same level of supplier reliability [62], [104]. Another example of such combination of *Cloud Computing* and *Integrative Technologies* has been reported in Ref. [49] describing the case study of KKCO, where, for example, the time of receiving raw materials and spare-parts/dies reduced significantly.

Finally, by using *Sensors*, every item would be tracked wirelessly about its origin, destination as well as the current status. Tagging every item ensures sending the right products to the correct destinations and reduction of lead times of distribution. This ensures not only timely delivery of the items, but also optimisation of the travel routes and reliability in logistics. A supplier is empowered to comment when exactly his goods would reach the customer, thereby enhancing credibility and adding value to customers [105], [106]. In case a timely delivery is not possible due to some unforeseen traffic jam or any other constraint, a smart task allocator (*Advanced algorithms*) would initiate a simulated trading process (*Decision Support Systems*), where an order is reallocated to satisfy the demanding time constraints [27]. Therefore, tagging every item, wireless tracking and smart reallocation of orders are observed to significantly promote supplier integration.

3.2.9 Kaizen

As widely known, the basic idea of lean production is a continuous improvement concept, also known as Kaizen in Japanese, that aims to improve the production and produce profits through cost reduction by eliminating waste [107], [108]. Although Poung and Guidat reported that I4.0 technologies can bring numerous advantages to the continuous improvement process [32], Buer et al. stated that there have been few studies investigating how the introduction of Industry 4.0 impacts Kaizen [8].

The main advantage of I4.0 technologies on the continuous improvement concept reported by Poung and Guidat was the possibility to have real-time data tracking [32], that can be used to give instant visual feedback regarding performance (KPI) and provide transparency and better communication between production stakeholders [29], [109]. To do so, the combination of *Sensors*, *Big Data* and *Data analytics* and *Cloud computing* is necessary. *Sensors* can in fact provide constantly updated data on production flow, equipment condition and failure notifications, that, once shared with *Cloud computing*, can be collected and analyzed thanks to *Big Data* and *Data analytics* in order to identify improvement points [3], [110]–[112]. As reported in Section 2.2.1., an example of this approach is the dynamic value stream mapping, that can increase the identification of potential improvements and waste reduction compared to the labor-intense and time-consuming manual data acquisition of the traditional value stream mapping [66], [113].

In addition, Kolberg and Zühlke [17] proposed the use of *Assistive Technologies*, such as Augmented Reality, to visualize value stream mapping, similarly to what suggested in Ref. [67], [114]. Moreover, *Assistive Technologies* can be used by production workers to provide immediate feedback of production conditions: every operator is equipped with a smart handheld device (smart phones and tablets), which is integrated with the company's network, providing an extremely comfortable environment for employees to record their concerns and feedback right at the workplace [115]. Furthermore, *Assistive Technologies*, together with *Sensors*, can assist in carrying out 5S (a systematic approach to organize the workplace) more efficiently [33]. *Sensors* in fact ensure the identification and the localization of objects, which reduces the searching time, while *Assistive Technologies* can guide operators where to place tools by replacing physical shadow boards [116].

Finally, *Digital Support Systems* in combination with *Big Data* and *Data analytics* can help the continuous improvement process optimizing the production system in terms of stocks, movements, overproduction and waiting through data-based simulation [117], [118]. [117], [118].

3.2.10 People & teamwork

It is widely known that it is the intangibles like teamwork that supports the foundation of Lean philosophy. Any company, in fact, is a combination of many people in small groups working together, and it is fundamental that each of these groups work collaboratively to ensure the expected outcomes of a company. However, despite the importance of teamwork to make sure that small groups work effectively, there have been few studies investigating how the introduction of Industry 4.0 will impact teamwork [8].

Schuh et al., for example, suggested how the combination of *Sensors*, *Cloud computing* and *Big Data* and *Data analytics* can lead to new forms of collaboration, facilitating information sharing and fostering cross-functional activities in organizations for a dynamic collaborative process, thus playing a pivotal role in increasing productivity [119].

In addition, *Assistive technologies,* such as smart devices, provide interconnectivities among workers, facilitating their collaborations and their involvement in the company [91]. The positive impact of *Assistive technologies* was pointed out also by Rosin et al., who stated that "linked to the People and Teamwork category, only Cross-Training principle appears to be improved by Industry 4.0" [34]. Augmented Reality has in fact been reported to facilitate employee training providing additional information to the employee on the tasks to be performed and providing real-time feedback on errors made in a training context [120]–[122]. Moreover, Virtual Reality allows employees to train in a simulated environment [35].

4 D4.1 - Industrial Skillset for Smart Lean Operations

As mentioned before, the initial aim of this deliverable was that of identifying the industrial skillsets required by Operations Managers to develop Smart Lean Operations. However, based on interviews with managers, industrial workshops and meetings carried out during the project and based on the results of WP1, it has emerged that one of the biggest concerns of Operations Managers is that to understand the impact of I4.0 technologies on increasing the level of lean practices. In particular, ascertained that lean has already been established by many companies and that its implementation is fundamental for fully exploiting the potentialities of I4.0 technologies [8], [10], Operations Managers want to understand which are the right I4.0 technologies that can be implemented to enhance a certain lean practice that needs to be improved. In addition, not only the understanding of which I4.0 technology can help a specific lean practice is deemed, but also an evaluation of their impact is highly claimed. It is thus clear that the previous section (D4.3 - Process Innovations within Smart Lean Operations) represents the point of departure from where determining which of the nine I4.0 technologies reported above (i.e., Sensors & Actuators, Cloud computing, Big Data & Data Analytics, Integrative Technologies, Assistive Technologies, Decision Support Systems, Advanced Algorithm, Additive Manufacturing and Advances Vehicles) can improve the ten Lean practices above mentioned (i.e., Continuous flow, Pull, Single Minute Exchange of Die, Total Productive Maintenance, Jidoka, Six Sigma, Customer Involvement, Supplier Integration, Kaizen and People & Teamwork) and the impact of these technologies on such lean practices. In particular, to express the impact of the technologies on the lean practices, the approach used by Wagner et al. [3] has been used as clue and partially extended. Wagner et al. evaluated the impact of the technologies based on a three-level classification, valuating as "+" the I4.0 technologies with a low positive impact on a certain lean principle, while with "++" and "+++" the technologies with a medium and a high impact, respectively. For example, they rated the impact of "Sensors and actuators" on "Pull" with "++". However, as it was reported in the previous Section, "Sensors and actuators" can be used to improve "Pull" in different ways, not just in one way, and thus providing just a single and general evaluation is somehow limiting. Therefore, we decided to improve their work providing a more specific evaluation: we rated each specific way of combining a certain I4.0 technology with a given lean practice. In such a way, Operations Managers can understand in which way they can maximize the impact of a specific I4.0 technology on a certain lean practice. In what follows, we summarized how a certain I4.0 technology can impact a specific lean practice and we provided an evaluation for each specific way of combining such I4.0 technology and lean practice. For the sake of clarity of presentation, we provided three different tables, one focusing on the lean practices that can be grouped under Just-in-Time (i.e., Continuous flow, Pull, Single Minute Exchange of Die), one focusing on the lean practices that can be grouped under Total Quality Management (i.e., Total Productive Maintenance, Jidoka, Six Sigma) and one focusing on the lean practices that can be grouped under Supply Chain Management and Human Resource Management (i.e., Customer Involvement, Supplier Integration, Kaizen and People & Teamwork).

Table 1 – Integration of I4.0 technologies on Just-in-Time (JIT) lean practices

I4.0 technologies \ **Lean practices**		**JIT**		
		Flow	**Pull**	**SMED**
Sensors & Actuators	Devices (Sensors) whose purpose is to detect events or changes (RFID, accelerometer, …) and send the information to other electronics that can interact with Actuators (component of a machine that is responsible for moving and controlling a mechanism or a system)	● +++ Optimization (through Advanced Algorithm) of the scheduling of the material handling systems by integrating (through Integrative Technologies) AV with Sensors Big Data and Cloud Computing ● ++ Avoidance of flow disruption as a consequence of errors in inventory by achieving real-time exact tracking of inventory by combining Sensors and Big Data ●++ Reactive decisions to incidences thanks to real-time KPIs obtainable through the combination of dynamic VSM (achievable through Sensors and Big Data and Data Analytics) and Cloud Computing ● +++ Improvement of the continuous flow by detecting bottlenecks and by reducing inventory levels through the combination of the real-time data (provided by the combination of Sensors & Actuators, Cloud Computing and Big Data & Data Analytics) and a simulation tool to obtain a simulation-based real-time solution	● +++ Recognize missing and empty bins automatically and trigger replenishment (through Integrative Technologies) ● ++ Automatic adjustment of e-Kanban parameters to changes in batch sizes, market demands, work plans or cycle times through Advance Algorithms and Integrated Technologies (thanks to Sensors, Cloud Computing and Big Data analytics)	● +++ Substantial setup time reduction through self-optimisation of machines and workpiece-machine communication (Plug'n'Play/Plug'n'Produce)

		● ++ Reduction of the inventory levels and assurance of production flow by means of simulation-based real-time solution (combination of Sensors, Big Data, Cloud computing and Simulation)		
Cloud Computing	Serve to store the high amount of data generated that can be accessed from anywhere	● +++ Optimization (through Advanced Algorithm) of the scheduling of the material handling systems by integrating (through Integrative Technologies) AV with Sensors Big Data and Cloud Computing ● ++ Reactive decisions to incidences thanks to real-time KPIs obtainable through the combination of dynamic VSM (achievable through Sensors and Big Data and Data Analytics) and Cloud Computing ● +++ Improvement of the continuous flow by detecting bottlenecks and by reducing inventory levels through the combination of the real-time data (provided by the combination of Sensors & Actuators, Cloud Computing and Big Data & Data Analytics) and a simulation tool to obtain a simulation-based real-time solution ● ++ Reduction of the inventory levels and assurance of production flow by means of simulation-based real-time solution (combination of	● ++ Automatic adjustment of e-Kanban parameters to changes in batch sizes, market demands, work plans or cycle times through Advance Algorithms and Integrated Technologies (thanks to Sensors, Cloud Computing and Big Data analytics)	● +++ Substantial setup time reduction through self-optimisation of machines and workpiece-machine communication (Plug’n’Play/Plug’n’Produce)

		Sensors, Big Data, Cloud computing and Simulation)		
Big Data & Data Analytics	Fast analysis through Data Analytics of the huge amount of data generated by sensors and control systems (Big Data) to take fast decision	● +++ Optimization (through Advanced Algorithm) of the scheduling of the material handling systems by integrating (through Integrative Technologies) AV with Sensors Big Data and Cloud Computing ● ++ Avoidance of flow disruption as a consequence of errors in inventory by achieving real-time exact tracking of inventory by combining Sensors and Big Data ● ++ Reactive decisions to incidences thanks to real-time KPIs obtainable through the combination of dynamic VSM (achievable through Sensors and Big Data and Data Analytics) and Cloud Computing ● +++ Improvement of the continuous flow by detecting bottlenecks and by reducing inventory levels through the combination of the real-time data (provided by the combination of Sensors & Actuators, Cloud Computing and Big Data & Data Analytics) and a simulation tool to obtain a simulation-based real-time solution ● ++	● ++ Automatic adjustment of e-Kanban parameters to changes in batch sizes, market demands, work plans or cycle times through Advance Algorithms and Integrated Technologies (thanks to Sensors, Cloud Computing and Big Data analytics)	● +++ Substantial setup time reduction through self-optimisation of machines and workpiece-machine communication (Plug’n’Play/Plug’n’Produce)

		Reduction of the inventory levels and assurance of production flow by means of simulation-based real-time solution (combination of Sensors, Big Data, Cloud computing and Simulation)		
Integrative technologies	Technologies that allow to integrate the information systems of the whole value chain	● +++ Auto-adaptive production planning in the case of a capacity constraint in production thanks to the combination of Integrative Technologies and Advanced Algorithm ● +++ Optimization (through Advanced Algorithm) of the scheduling of the material handling systems by integrating (through Integrative Technologies) AV with Sensors Big Data and Cloud Computing ● + Creation of a proper flow within the supply chain, without any interruption, bottlenecks or delays, when combined with Advanced Algorithm ● +++ Assurance of continuous flow by allowing systems to adjust autonomously production planning ● + Flexible, fast and high-quality material flow thanks to an enhanced interconnection and communication between cells and workstations	● +++ Recognize missing and empty bins automatically and trigger replenishment (through Integrative Technologies) ● ++ Automatic adjustment of e-Kanban parameters to changes in batch sizes, market demands, work plans or cycle times through Advance Algorithms and Integrated Technologies (thanks to Sensors, Cloud Computing and Big Data analytics)	● +++ Substantial setup time reduction through self-optimisation of machines and workpiece-machine communication (Plug'n'Play/Plug'n'Produce)
Assistive technologies	Any technology assisting the operator in operational/decision making activities (AR, VR, cobot, …)	● +++ Support of JIT production since AR can provide information to		● ++

		operators about cycle time and tasks to perform ● + VR can be used to assembly training, resulting in fewer errors and lesser time in actual product assembly when compared against the participant from traditional training group ● ++ Cobots can collaborate with employees to respond in real time and ensure that production runs smoothly		Visualization of each step of the changeover process using augmented reality
Decision support systems	Technologies that intends to improve the creation and planning of working procedures (simulation, digital twin, …)	● +++ Improvement of the continuous flow by detecting bottlenecks and by reducing inventory levels through the combination of the real-time data (provided by the combination of Sensors & Actuators, Cloud Computing and Big Data & Data Analytics) and a simulation tool to obtain a simulation-based real-time solution ● ++ Reduction of the inventory levels and assurance of production flow by means of simulation-based real-time solution (combination of Sensors, Big Data, Cloud computing and Simulation)	● ++ Optimization of Kanban parameters through simulations and/or digital twins ● ++ Continuous update of Kanban parameters by connecting simulations with the real-time capacity of Advanced vehicles (AGV, AMR, …)	● + Optimization of machine setups by testing various methods through simulations
Advanced algorithm	Algorithms that improve automatically through experience aiming to maximize the chances of successfully achieving a certain goal	● +++ Auto-adaptive production planning in the case of a capacity constraint in production thanks to the combination of Integrative	● ++ Automatic adjustment of e-Kanban parameters to changes in batch sizes, market	● +++ Substantial setup time reduction through self-optimisation of machines and workpiece-machine

		Technologies and Advanced Algorithm ● +++ Optimization (through Advanced Algorithm) of the scheduling of the material handling systems by integrating (through Integrative Technologies) AV with Sensors Big Data and Cloud Computing ● + Creation of a proper flow within the supply chain, without any interruption, bottlenecks or delays, when combined with Integrative Technologies	demands, work plans or cycle times through Advance Algorithms and Integrated Technologies (thanks to Sensors, Cloud Computing and Big Data analytics)	communication (Plug'n'Play/Plug'n'Produce)
Additive manufacturing	It is an additive process of forming objects, layer upon layer from data and 3D models	● + Possibility to achieve a one-piece flow production thanks to the print-on-demand production system	● ++ Promotion of pull through the elimination of inventory due to the print-on-demand production system achievable	● ++ Times for selection, search and adjustment of tools and workpieces are omitted (no setup time and no requirement for tooling due to the layer-by-layer manufacturing technique)
Advanced Vehicles	Vehicles that do not require a human operator to be driving (AGV, AMR) and/or that can follow innovative pathways (drones)	● + AGV and AMR can transport single units through a flexible material flow ● +++ Continuous flow guaranteed avoiding/reducing congestion thanks to the possibility to reroute the vehicle to an alternative path in case of obstacles ● +++ Optimization (through Advanced Algorithm) of the scheduling of the material handling systems by integrating (through Integrative	● ++ Continuous update of Kanban parameters by connecting simulations with the real-time capacity of Advanced vehicles (AGV, AMR, …)	

		Technologies) AV with Sensors Big Data and Cloud Computing		

Table 2 – Integration of I4.0 technologies on Total Quality Management (TQM) lean practices

Lean practices / I4.0 technologies		TQM		
		TPM	**Jidoka**	**Six Sigma**
Sensors & Actuators	Devices (Sensors) whose purpose is to detect events or changes (RFID, accelerometer, …) and send the information to other electronics that can interact with Actuators (component of a machine that is responsible for moving and controlling a mechanism or a system)	● +++ Error notifications are sent when a machine breaks down ● ++ Prediction of failures by detecting abnormal situations based on data from the past and/or other machines combining Sensors with Big Data & Data Analytics and Cloud Computing	● +++ Fast failure recognition (employees receive error messages on their Assistive Technologies) ● +++ Automatic trigger of fault-repair action (check TPM) ● +++ Contribute to the Poka-Yoke concept by avoiding incorrect components to be used thanks to part recognition	● ++ Key production metrics can be automatically captured through the use of Sensors, Big Data & Data Analytics and Cloud Computing ● +++ Advanced Algorithms anticipate production problem through the collection of data (Sensors), their analysis (Data Analytics) and the comparison with previous data (Cloud Computing)
Cloud Computing	Serve to store the high amount of data generated that can be accessed from anywhere	● +++ Prediction of failures by detecting abnormal situations based on data from the past and/or other machines combining Sensors with Big Data & Data Analytics and Cloud Computing		● ++ Key production metrics can be automatically captured through the use of Sensors, Big Data & Data Analytics and Cloud Computing ● +++ Advanced Algorithms anticipate production problem through the collection of data (Sensors), their analysis (Data Analytics) and the comparison with previous data (Cloud Computing)

Big Data & Data Analytics	Fast analysis through Data Analytics of the huge amount of data generated by sensors and control systems (Big Data) to take fast decision	● +++ Prediction of failures by detecting abnormal situations based on data from the past and/or other machines combining Sensors with Big Data & Data Analytics and Cloud Computing		● ++ Key production metrics can be automatically captured through the use of Sensors, Big Data & Data Analytics and Cloud Computing ● +++ Advanced Algorithms anticipate production problem through the collection of data (Sensors), their analysis (Data Analytics) and the comparison with previous data (Cloud Computing)
Integrative technologies	Technologies that allow to integrate the information systems of the whole value chain	● +++ To mitigate the impact of breakdown, other machines can be contacted to find their availability for taking over the workload		
Assistive technologies	Any technology assisting the operator in operational/decision making activities (AR, VR, cobot, …)	● ++ Facilitate the learning and training of the human operator as well as maintenance instructions	● +++ Fast failure recognition (employees receive error messages on their Assistive Technologies) ● +++ Allow error-free picking and assembly providing instructions to the operators	● +++ Failure recognition (refer to Jidoka)
Decision support systems	Technologies that intends to improve the creation and planning of working procedures (simulation, digital twin, …)		● + Can anticipate potential difficulties and mitigate failures in the productive process	

Advanced algorithm	Algorithms that improve automatically through experience aiming to maximize the chances of successfully achieving a certain goal	● ++ After predicting failures, Advanced Algorithm takes action that makes the maintenance planning, forecasting, spare parts logistics easier and more efficient		● +++ Advanced Algorithms anticipate production problem through the collection of data (Sensors), their analysis (Data Analytics) and the comparison with previous data (Cloud Computing) ● ++ Continuous improvement activities thanks to conventional statistical methods applied to the data
Additive manufacturing	It is an additive process of forming objects, layer upon layer from data and 3D models	● +++ If a failure demands a part to be replaced, the new spare part can be printed using Additive Manufacturing		
Advanced Vehicles	Vehicles that do not require a human operator to be driving (AGV, AMR) and/or that can follow innovative pathways (drones)			

Table 3 – Integration of I4.0 technologies on Supply Chain Management (SCM) and Human Resource Management (HRM) lean practices

Lean practices / I4.0 technologies		SCM		HRM	
		Customer involvement	**Supplier integration**	**Kaizen**	**People & teamwork**
Sensors & Actuators	Devices (Sensors) whose purpose is to detect events or changes (RFID, accelerometer, …) and send the information to other electronics that can interact with Actuators (component of a machine that is responsible for moving and controlling a mechanism or a system)	● +++ Reduce communication times and costs and increase efficiency and value added for costumer providing real-time information directly in customer's information system (thanks to Big Data and Data analytics) ● ++ Better identification of customers' needs and behaviours thanks to the possibility to track usage data (by integrating Sensors on products) and analyse them (through Big Data & Data analytics) ● ++ Customer-oriented real-time key performance indicators for quality, delivery time and costs (combining Sensors, Big Data & Data analytics and Cloud computing)	● + Enhanced supplier credibility by tagging every item: it ensures to send the right products to the correct destinations, the reduction of lead times of distribution (by optimizing the travel routes) and a supplier is empowered to comment when exactly his goods would reach the customer	● +++ Possibility to have real-time data tracking (dynamic value stream mapping) that can be used to give instant visual feedback regarding performance (KPI) and provide transparency and better communication between production stakeholders ● ++ Can assist 5S (Sensors can ensure the identification and the localization of objects, which reduces the searching time)	● ++ Facilitation of information sharing and foster of cross-functional activities in organizations for a dynamic collaborative process combining sensors, cloud computing and big data and data analytics
Cloud Computing	Serve to store the high amount of data generated that can be accessed from anywhere	● ++ Customer-oriented real-time key performance indicators	● ++ Effective supplier feedback thanks to an	● +++ Possibility to have real-time	● ++ Facilitation of information sharing

		for quality, delivery time and costs (combining Sensors, Big Data & Data analytics and Cloud computing)	easy integration and relationship between business partners through the use of Cloud computing and mobile computing services (smartphones and tablets connected to the internet and common cloud for example)	data tracking (dynamic value stream mapping) that can be used to give instant visual feedback regarding performance (KPI) and provide transparency and better communication between production stakeholders	and foster of cross-functional activities in organizations for a dynamic collaborative process combining sensors, cloud computing and big data and data analytics
Big Data & Data Analytics	Fast analysis through Data Analytics of the huge amount of data generated by sensors and control systems (Big Data) to take fast decision	● + Can enhance the forecast quality by facilitating extreme complex calculations and processing of relationship between needs and functions for large volume of data ● +++ Reduce communication times and costs and increase efficiency and value added for costumer providing real-time information directly in customer's information system (thanks to Sensors) ● ++ Better identification of customers' needs and behaviours thanks to the possibility to track usage data (by integrating Sensors on products) and analyse		● +++ Possibility to have real-time data tracking (dynamic value stream mapping) that can be used to give instant visual feedback regarding performance (KPI) and provide transparency and better communication between production stakeholders ● ++ Data-based simulation can optimize the	● ++ Facilitation of information sharing and foster of cross-functional activities in organizations for a dynamic collaborative process combining sensors, cloud computing and big data and data analytics

		them (through Big Data & Data analytics) ● ++ Customer-oriented real-time key performance indicators for quality, delivery time and costs (combining Sensors, Big Data & Data analytics and Cloud computing)		production system in terms of stocks, movements, overproduction and waiting	
Integrative technologies	Technologies that allow to integrate the information systems of the whole value chain	● ++ Postponement of the start of the freeze period by keeping customers informed about the actual production connecting elements in the supply chain thanks to horizontal integrating digitized mechanisms	● + Synchronization of data of products and production processes by sharing them beyond the boundaries of individual industries ● ++ Effective supplier feedback thanks to an easy integration and relationship between business partners through the use of Cloud computing and mobile computing services (smartphones and tablets connected to the internet and common cloud for example)		
Assistive technologies	Any technology assisting the operator in operational/decision making activities (AR, VR, cobot, …)			● + Visualization of dynamic value stream mapping ● +++ Immediate feedback of production conditions from	● + Facilitate workers collaborations and involvement in the company by providing interconnectivities among workers ● ++

				production worker ● ++ Assist 5S (assistive Technologies can guide operators where to place tools by replacing physical shadow boards)	Facilitate employee training providing additional information to the employee on the tasks to be performed and providing real-time feedback on errors
Decision support systems	Technologies that intends to improve the creation and planning of working procedures (simulation, digital twin, …)			● ++ Data-based simulation can optimize the production system in terms of stocks, movements, overproduction and waiting	
Advanced algorithm	Algorithms that improve automatically through experience aiming to maximize the chances of successfully achieving a certain goal				
Additive manufacturing	It is an additive process of forming objects, layer upon layer from data and 3D models				
Advanced Vehicles	Vehicles that do not require a human operator to be driving (AGV, AMR) and/or that can follow innovative pathways (drones)				

5 D4.2 - Decision Support for Smart Lean Operations

The aim of this deliverable is that of developing a Decision Support methodology that can assist Operations Managers in the establishment of Smart Lean Operations in their companies by providing them the needed competences and by helping them in identifying specific areas of improvements based on their goals. For the development of such a Decision Support System the combination of the previous two deliverables (D4.3 – Process Innovations for Smart Lean Operations and D4.1 – Industrial Skillset for Smart Lean Operations) with the two deliverables of WP1 is thus fundamental. In fact, by combining these four elements, Operations Managers possess the inputs for creating a Lean4.0 strategy for their companies (from D1.1 – Assessment tool for Smart Lean Operations), based on the understanding of which Industry 4.0 technologies can strengthen specific lean practices (from D4.1 and D4.3) and of which are the main challenges to develop such a Lean4.0 strategy (from D1.2 – A Taxonomy of Smart Lean Operations).

In the light of these considerations, the Decision Support System represented in Figure 1 has been developed. Each step of the Decision Support System will be specifically described in the following sub-sections. Following these steps, Operations Managers, starting from the performance challenges of their company (Step 1), can understand which are the possible Lean practices that can help them in achieving their goals and the relevance that these lean practices plays within their company (Step 2). As already mentioned, the implementation of I4.0 technologies requires a serious use of Lean practices [8], [10], and thus in our Decision Support System we consider that the relevance of the identified Lean practices in Step 2 is high. However, if it results that their relevance is low, typical lean tool such as A3, Plan-Do-Check-Act cycle and Toyota Business Practices can be used before moving to the next step in order to increase the relevance of these Lean practices. In Step 3 the Operations Managers will identify the I4.0 technologies that, in combination with lean practices, can boost the achievement of the performance challenge. At the end of this Step, some Pilots will be identified and they will be evaluated and tested in Step 4. The term "Pilot" is used to indicate a specific application of I4.0 technology that has passed Step 3.

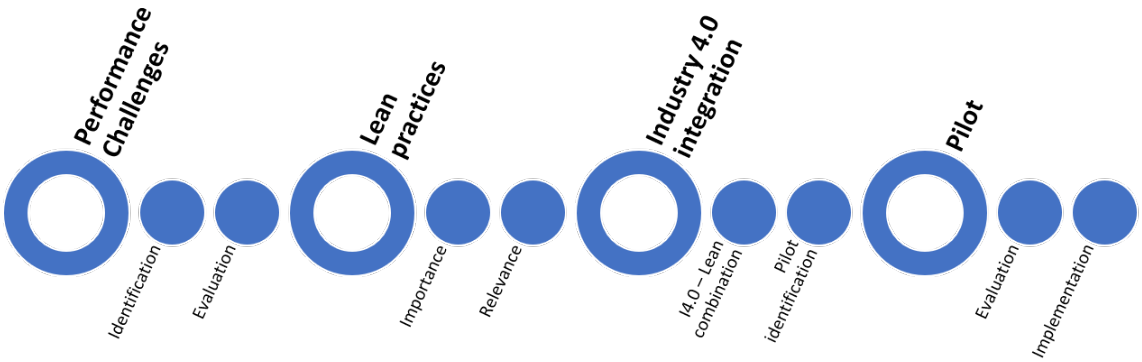

Figure 1 – Decision Support System

5.1 Step 1 – Performance challenges

Once selected the Focused Target Market Segment (FTMS) of interest, the related performance challenges need to be identified and evaluated. In D1.1 five different performance indicators were identified based on the work of Slack and Brandon-Jones [123]: Cost, Quality, Delivery time, Reliability and Flexibility. These are general indicators, that Operations Managers can replace with more specific indicators that better serve their situation. For the sake of clarity, in the following, we will refer to the five performance indicators just stated. To evaluate these performance indicators, Operations Managers can rate them from 0 (not important) to 5 (very important), and they can use a radar chart to visualize the results (Figure 2).

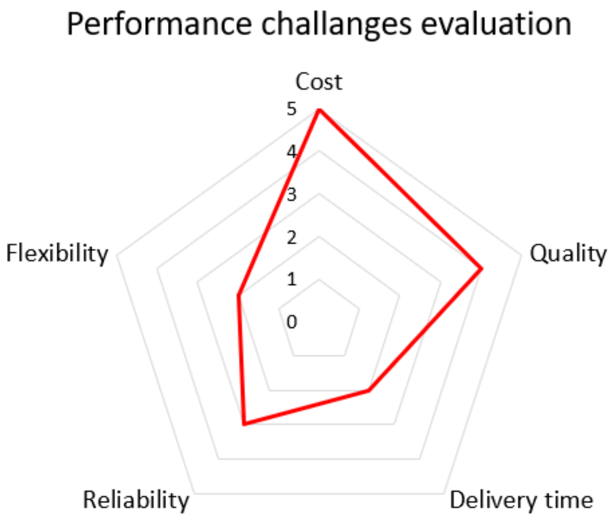

Figure 2 – Example of radar chart for the evaluation of performance challenges

5.2 Step 2 – Lean practices

After the definition of the performance challenges, Operations Managers have to understand which are the lean practices that contribute to achieve the performance challenges identified in the previous step. Moreover, they need to evaluate the relevance played by these practices in their company. To do so, they can start from the list of the main Lean practices identified in the D4.3 – Process Innovations for Smart Lean Operations and evaluate one by one the impact of these Lean practices on the achievement of the performance challenges (a scale from 1 to 9 or similar can be used). A threshold level above which a lean practice is considered worthy to be adopted needs to be defined at the beginning (a value of 5 or 6 can be used). Then, the lean practices that exceed the threshold level need to be evaluated in terms of their relevance for the company (the same scale as before can be used). To facilitate these operations, especially in the visualization, the matrix taken from the D1.1 - Assessment tool for Smart Lean Operations (see Figure 3) can be used. In particular, the x-axis “How important is it?” can be used to evaluate the impact of a certain lean practice on the achievement of the performance challenges, while the y-axis “How good are we?” can be used to assess the relevance that such a lean practice has in the company.

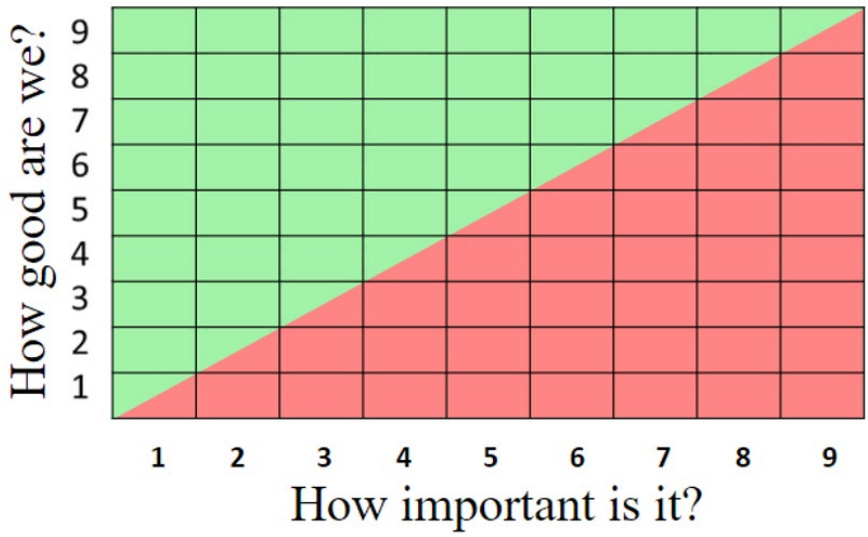

Figure 3 – Matrix to be used for indicating the importance and the relevance of a lean practice

In the development of the Decision Support System we considered that the lean practices considered impactful in the achievement of the performance challenges were all relevant for the company, i.e. they are above the diagonal of Figure 2. We decided so based on the results of the D1.2 – A Taxonomy of Smart Lean Operations and on the literature ([8], [10]) reporting that the implementation of I4.0 technologies requires a serious use of Lean practices. However, if it results that their relevance is low, typical lean tool such as A3, Plan-Do-Check-Act cycle and Toyota Business Practices can be used to increase the relevance of these Lean practices before moving to the next step.

5.3 Step 3 – Industry 4.0 integration

Once the lean practices that can contribute to achieve the performance challenges have been identified, Operations Managers have to understand which are the I4.0 technologies that can improve such lean practices and, also, which are the combinations of lean practice and I4.0 technology that have the highest impact on the performance challenges. To do so, they can leverage on the results of D4.3 – Process Innovations for Smart Lean Operations and of D4.1 – Industrial Skillset for Smart Lean Operations. For the sake of clarity, to better describe this step, we will now proceed by referring to an example. Let's assume that from the previous step of the Decision Support System three lean practices (i.e., Lean_1, Lean_2 and Lean_3) were found impactful in the achievement of the performance challenges, and that these three practices were rated with an "importance" of 8, 6 and 7 for Lean_1, Lean_2 and Lean_3, respectively. Based on D4.3, Operations Managers found that three different applications of I4.0 technologies can improve Lean_1 (i.e., I4.0_1, I4.0_2 and I4.0_3), one can improve Lean_2 (I4.0_2) and two Lean_3 (I4.0_4 and I4.0_5). We used here the term "application of I4.0 technology" because, as emerged from D4.1 and D4.3, a certain I4.0 technology can be used in different ways to improve a specific lean practice, and the impact of such I4.0 technology on the lean practice depends on the way it has been used (please refer to Tables 1, 2 and 3 to have a better understanding). It is worth mentioning that some I4.0 technologies can impact on more than one lean practice: for example, the use of Sensors to create a dynamic value stream mapping impacts both on the lean practice of Continuous flow and of Kaizen. To take this into account in our example, we considered I4.0_2 to improve both Lean_1 and Lean_2. From D4.1, then, the evaluation of the impact of these technologies can be found. At this state, Operations Managers can summarize the information at their disposal using the following Table:

		Lean practices		
		Lean_1	**Lean_2**	**Lean_3**
I4.0 technologies	**I4.0_1**	+++		
	I4.0_2	+	+++	
	I4.0_3	++		
	I4.0_4			+
	I4.0_5			++

Table 4 – List of the I4.0 technologies impacting on the Lean practices obtained from step 2 and their impact

At this stage, it is important that Operations Managers have clear in mind that their final aim is that to achieve the performance challenges identified in step 1. Therefore, the impact of I4.0 technologies on these performance challenges needs to be evaluated, and to do so the evaluation of the "importance" of the lean practices done in the previous step needs to be considered. In fact, by multiplying the impact of a specific I4.0 technology on a certain lean practice with the "importance" of this lean practice, and summing the cells of the row related to the considered I4.0 technology, the impact of this I4.0 technology on the performance challenge can be obtained. Let's consider again the example we are referring to in order to better understand. If we consider that "+" corresponds to a rate of 1, "++" to 2 and "+++" to 3, Table 4 become now Table 5:

		Lean practices		
		Lean_1	**Lean_2**	**Lean_3**
I4.0 technologies	**I4.0_1**	3		
	I4.0_2	1	3	
	I4.0_3	2		
	I4.0_4			1
	I4.0_5			2

Table 5 – List of the I4.0 technologies impacting on the Lean practices obtained from step 2 and their impact (in numbers)

Recalling that Lean_1, Lean_2 and Lean_3 were rated with an "importance" of 8, 6 and 7, respectively (step 2), the impact of the five I4.0 technologies on the performance challenges is reported in Table 6.

Industry 4.0 technologies	Impact on performance challenges
I4.0_1	24
I4.0_2	26
I4.0_3	16
I4.0_4	7
I4.0_5	14

Table 6 – Impact of I4.0 technologies on the performance challenges

The impact of I4.0_1 on the performance challenge is equal to 24 and it is the result of the following calculation: *3 (impact of I4.0_1 on Lean_1) x 8 ("importance" of Lean_1) + 0 (impact of I4.0_1 on Lean_2) x 6 ("importance" of Lean_2) + 0 (impact of I4.0_1 on Lean_3) x 7 ("importance" of Lean_3).*

The impact of I4.0_2 on the performance challenge is equal to 26 and it is the result of the following calculation: *1 (impact of I4.0_2 on Lean_1) x 8 ("importance" of Lean_1) + 3 (impact of I4.0_2 on Lean_2) x 6 ("importance" of Lean_2) + 0 (impact of I4.0_3 on Lean_3) x 7 ("importance" of Lean_3).*

Same for all the other I4.0 technologies.

Again, a selection criterion has to be adopted to decide which I4.0 technologies further consider in the further course of the Decision Support System. A valid selection criterion could be again the use of a threshold value, or the choice to pick the best X solution. Once this criterion has been chosen and applied, Operations Managers can move to the last step of the Decision Support System. In the following, we will refer as "Pilot" to indicate a specific application of I4.0 technology that has passed Step 3.

5.4 Step 4 – Pilot

As mentioned above, with the term "Pilot" we indicate a specific application of I4.0 technology that has passed Step 3. Based on the selection criterion adopted in Step 3, more than one Pilot can arrive at this Step. However, not all of them are applicable. In fact, although their implementation would result in great benefits for the company with respect to the achievement of the performance challenges, their implementation costs might be too high for the company to be supported by the company. Therefore, Operations Managers have to evaluate all the Pilots (outputs of Step 3) according to cost requirements, sustainability requirements and so on. The final stage of this part is then that to implement and test the Pilot(s) arrived till the end of this Decision Support System. It is important that at the beginning of the implementation phase, Operations Managers need to define a roadmap to assure that they stick to the right path and that they are aware of the main challenges to develop such a Lean4.0 strategy (D1.2 – A Taxonomy of Smart Lean Operations can be used for this).

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