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KAIZEN IN SMART MANUFACTURING (SM) PROJECTS: FRAMEWORK AND EXAMPLES OF IMPROVEMENT AREAS

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Purpose: The fourth industrial revolution has a strong influence on changes in enterprises towards smart manufacturing. Technological progress and digital economies created new conditions for business. Currently producers aiming at digitalization of processes and smart manufacturing based on key technologies (pillars) of Industry 4.0. In transformation process, the question arises, from what to start the changes and which path to choose to smart manufacturing (SM). Apart from big projects of SM, changes need the concept of Kaizen based on small steps of changes on workstations towards smart production. The purpose of the paper is the presentation of links between Smart Manufacturing (SM) projects and Kaizen.
Design/methodology/approach: The paper was realized based on literature review and examples of SM projects.
Findings: The study found that Kaizen is evolving with the automation and digitisation of production. IC technologies facilitate Kaizen improvements. The automation of production processes provides insight into historical data through process monitoring. Fully autonomous equipment is equipped with systems for transferring data to a central decision-making system. The machine operator's job is to collaborate with robots and control machine operation in real time using simple data visualisation and warning systems.
Research limitations/implications: The work prepared is of a high degree of generality. Kaizen is implemented at workplaces and is concerned with practical improvements. These improvements are many, following the principle of small steps. The publication focuses on presenting the idea of Kaizen in SM projects.
Practical implications: The paper can have an impact on the practical application of Kaizen in SM projects as it presents examples of Kaizen improvements.
Originality/value The topic of adapting Kaizen to SM projects is a new area of research that will be strongly built upon due to the utility of Smart Kaizen.

Keywords: Smart Manufacturing (SM), Industry 4.0, Kaizen, Lean.

Category of the paper: general review.

1. Introduction

In a strong dynamic business environment, changes in companies are needed, including changes that can be implemented in small steps according to Kaizen.

The Japanese method of the continuous improvement of organisations. Masaaki Imai has spread Kaizen in Japan and beyond (Imai, 2015). Kaizen supports the Japanese concept of Lean Manufacturing as Lean Production (processes without muda) (Abdullah, 2003; Hobbs, 2004). Kaizen is the continuous improvement of processes through the involvement of every employee on the job who thinks lean (Womack, Jones, 1996a). Realized improvements in work lead to increased safety, efficiency and productivity and quality. According to Kaizen, every process can be improved (Womack, Jones, 1996b, 1997).

The concept of Kaizen together with the tools of TPS (Toyota Production System) (Abdullah, 2003) was strongly spread at the end of the last century. Companies around the world have been inspired by lean production, which is supposed to lead them to Lean Enterprise (Womack, Jones, 1994). Lean companies can be agile. Such companies can survive and develop in highly dynamic conditions, characterised by strong business cycles and emerging difficulties in predicting market changes (Bednarek, 2007, p. 33). Quick action, which is the essence of Lean, must be based on the strong activity of companies in the process of business improvement and the strong dynamics of companies' reactions to internal and external changes. In conditions of strong competition, changes must be innovative actions. An important contribution to the science of innovation was made by P. Drucker (1992), who formulated the definition of systematic innovation as a purposeful and organised effort of a company to change the value delivered to the customer. Innovations are new or improved products and services, new technologies, new manufacturing, etc. (Schumpeter, 1960, p. 131). Innovations are built in all phases of business from design, through manufacturing, to marketing activities and customer service (Eagar, Oene, Boulton et al., 2011). During the Fourth Industrial Revolution, innovations have been given new technological capabilities called "Industry 4.0" (I4.0). The term "Industrie 4.0" was first used at the Hanover Fair in 2011. In October 2012, a working group led by Siegfried Dais of Robert Bosch GmbH presented a set of recommended industrial changes to the German government - the final report entitled 'Industrie 4.0' was prepared on 8 April 2013. (Hermann et al., 2005). Industry 4.0 focuses on building cyber-physical systems (CPS) supported by Big Data, the Internet of Things (IoT) and the cloud (Schwab, 2016). The new concept of industrial development is based on economic and social trends, e.g. Society 5.0, digitalisation of business, and customisation of products (Gajdzik et al., 2021a).

E. Toyoda and T. Ohno introduced many new production principles that formed the Toyota Production System. This system is characterised by high flexibility with continuous flow and quality assurance principles. The creation of the key principles of the system (TPS) took more than 20 years (it is assumed that the basic structure of the system was built in 1973).

The concept of Industry 4.0 is based on the digitalisation of business and the development of the Internet. The key technologies (pillars) of Industry 4.0 such as cloud computing, the Internet of Things, Big Data, 3D printing, Artificial Intelligence (AI) with intelligent robots, Virtual and Augmented Reality, and networking with blockchain, etc. have created new opportunities for company development. In technical innovations, the emphasis is on smart manufacturing technologies with learning machines and intelligent robots. Technological innovations are linked to the organisation of work. Industry 4.0 challenges employees to improve quality, to eliminate non-value-adding activities based on the technological possibilities of the fourth industrial revolution. In Industry 4.0, existing Lean methods and techniques find new applications. Examples: at the smart product level, process mapping, and value stream mapping can be applied, at the smart machine level: Kanban cards, SMED, RFID, Andon, and TPM, at the planner level: virtual Kanban (Kolberg, Zühlk, 2015). The results of changes (innovations) should be agile, flexible and intelligent and smart manufacturing. Smart Manufacturing, often abbreviated SM in reference works and referred to as “intelligent manufacturing”, refers to a new global industrial method that relies heavily on the evolution of the latest technologies in terms of connected means of production during the manufacturing process. According to Kusiak, A. (2017) “Smart manufacturing integrates manufacturing assets of today and tomorrow with sensors, computing platforms, communication technology, data-intensive modelling, control, simulation and predictive engineering. Smart manufacturing utilises the concepts of the cyber-physical systems, Internet of Things (and everything), cloud computing, service-oriented computing, artificial intelligence and data science” (p. 509). The main implementers of SM are key technologies such as CPS, big data, cloud computing, IoT, AI, and human/staff education (Wang et al., 2021). In SM, the machines are connected, but also and above all to the Internet to ensure optimal and scalable control of production processes. In SM, the aim is to create new value for the customer using new manufacturing technologies. Lean Manufacturing is useful in building Smart Manufacturing. In the ongoing Fourth Industrial Revolution, a new concept is emerging called "Lean Industry 4.0" or "Lean Digital" or "Lean 4.0" (Powell et al., 2021). According to Powell et al. (2021) "Lean manufacturing that is based on participation and standardized practices can take advantage of the collaborative environment and structured data collection and analysis offered by Industrial Internet of Things (IIoT) and Cyber-Physical System (CPS) technologies. Lean Manufacturing is based on the new technologies of Industry 4.0, which enable companies to build cyber-physical production systems that are strongly linked to IIoT - the Industrial Internet of Things. Industry 4.0 enriches the Lean Manufacturing concept through the opportunities provided by information technology, artificial intelligence and machine-to-machine (M2M) collaboration (Gajdzik, Kowal, 2020). Sum up: on the one hand, it is impossible to develop Industry 4.0 without Lean tools, and on the other hand, Industry 4.0 increases the effectiveness of the Lean concept and creates new opportunities for its development and introduction of new or improved tools in digital business. But Lean does not exist without Kaizen. New application possibilities have emerged for the Kaizen concept within the disruptive technologies or pillars of Industry 4.0. Example 1: Kaizen uses virtual space and digital twins. Simulation tools allow manufacturers to first test a project in the virtual world and then implement them in the physical world. Example 2: Computer technologies (IT) do easier Kaizen. Barcodes, Radio Frequency Identification (RFID) (Gladysz et al., 2017; Gladysz, Santarek, 2019) and mobile devices create new opportunities for the development of processes. Riezebos et al., (2009) state that IT complements Lean and improves Kaizen. Example 3: Wireless technologies are strong support for A3 cards, Andon, Heijunka, JiT, Kanban, Poka-Yoke, SPC/SQC, supermarket, TPM, TQM, VSM (Gladysz, Buczacki, 2017, 2019). At the stage of planning activities and developing projects of workstation digitalisation it is worth applying Kaizen, expecting bottom-up (employee) initiatives. Changes implemented at individual workplaces will in time create Smart Manufacturing. According to the idea of Industry 4.0 companies want to be smarter. The road to Smart Manufacturing, according to the idea of Kaizen, is implemented in small steps, from individual workstations through production lines to smart factories and entire supply chains.

This paper aims to provide a general understanding of Kaizen in Smart Manufacturing (SM) projects. The work is based on a literature study and SM projects realized step by step. The basic research question can be formulated as follows: Who Kaizen turns the processes into smart.

2. Kaizen framework for smart manufacturing (SM) projects

Smart Manufacturing (SM) projects include production technology modification projects and new machine investments, IT projects, operation visualisation projects, process monitoring projects, activity automation projects, machine data collection projects, etc. (IEC PAS 63088:2017). Modern technologies are based on the digital modelling of processes, which allows the production system to take the differing wishes of customers into account at each stage of production but smart products are determined by production costs (Aheleroff et al., 2017). The status (position) of a Lean company is achieved primarily through the comprehensive elimination of all kinds of waste (muda) (Walentynowicz, 2013). Industry 4.0 exposes smart changes that take place within companies and across entire supply chains (Kagermann et al., 2011). Both Lean Manufacturing and Smart Manufacturing aim at improving processes and work organisation. Lean focuses on lean manufacturing and smart focus on technology intelligence and process agility. According to Soder (2017), smart manufacturing is another form of manufacturing evolution. Soder outlined the evolution of manufacturing systems from conventional systems through flexible, computer-integrated systems to Lean Manufacturing and Industry 4.0 (Figure 1).

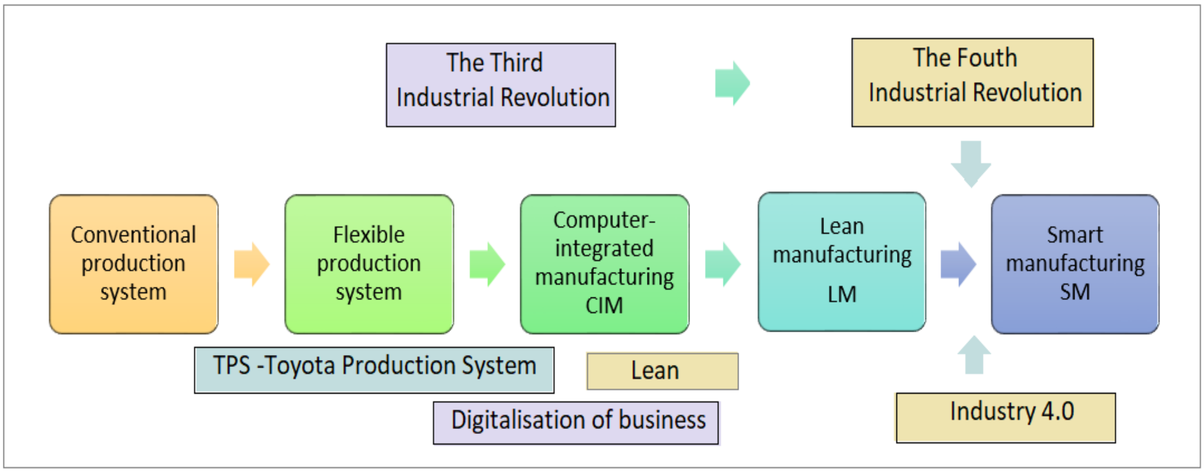

Figure 1. Evolution of production systems. Adapted from: „Von CIM über Lean Produktion zu Industrie 4.0", by J. Soder, 2017 In T. Bauernhansl, B. ten Hompel, B. Vogel-Heuser (Eds), Handbuch Industrie 4.0, Band 1: Produktion, Springer, Wiesbaden.

The source of ideas for Lean Manufacturing is Kaizen, which starts with bottom-up initiatives (employee proposals for eliminating waste). The main assumption of the Kaizen philosophy is the continuous improvement of business processes. The beginning of changes (building smart workplaces) is Kaizen workshops and Kaizen idea boxes. The vast majority of enterprises start implementing Lean Manufacturing with the 5S method. The next tools are used at the stage of improving the efficiency of machine operation as part of TPM or reducing the changeover time of equipment - SMED. Over time, the number of projects is increasing and the Lean methods and techniques used are complemented by further tools, including those belonging to quality management, and Key Performance Indicators (KPIs) (Walentynowicz, 2013). For KPIs, from an extensive list, companies select the most useful indicators for their industry and business (SLMP report).

The main assumption of the Kaizen philosophy is the continuous improvement of business processes. Tools such as PDCA, 5Why, FMEA, Ishikawa diagram or Pareto-Lorenz diagram are used to detect the sources of the problem (Imai, 20016, p. 49). Lean methods when combined with quality building methods create new technical modules for process improvement and quality management systems, e.g. 6Sigma on Lean, FMEA in Lean, Quality Kaizen, 5S and Work Quality (Bicheno, Holweg, 2016). Kaizen allows employees to organise and improve their work. Employers encourage employees to propose changes and complete Kaizen requests. Subsequent ideas from employees contribute to improving processes and eliminating unnecessary activities and operations. The following forms of Kaizen are used in enterprises: Quick Kaizen (QKaizen), Standard Kaizen, Major Kaizen and Advanced Kaizen (AKaizen) (Piasecka-Głuszak, 2017). QKaizen is used to solve problems that can very easily be eliminated "on the spot" or in a short time (less than a week). The problem is eliminated by the machine operator or the work team leader. In contrast, AKaizen involves many people and addresses a difficult problem. AKaizen uses tools such as PPA, DOE, Six Sigma, etc. Among the mentioned forms, QKaizen is the basic form because it quickly empowers workstations

(Piasecka-Głuszak, 2017). The applied continuous improvement Kaizen in Industry 4.0 is called Digital or Intelligent Kaizen because of the use of digital technologies to detect losses in processes (Mohan et al., 2022). The IT market is helping companies build Smart Kaizen Systems as intelligent systems in smart manufacturing.

The way toward SM is an individual decision for each company (Gajdzik et al., 2021b).

Companies embarking on building a smart environment very often use, especially during the preparation of the first pilot projects, the help of external IT companies. Many IT companies provide off-the-shelf digital solutions and packages of smart technologies and services. The advice of specialised companies helps manufacturers to build cyber-physical production systems (CPS). External companies advise manufacturers during the selection of key IT technologies and during the performance evaluation phase to achieve a high return on investment (ROI). In addition to large projects with the support of external companies, companies can implement smaller projects initiated by employees according to Kaizen principles, which focus on workplace improvement by using digital technologies and mobile devices and process visualization.

Small Kaizen (SKaizen) is applied at the stage of developing smart manufacturing (SM) projects for specific workstations. Smart workplaces are created in stages based on the ideas (initiative) of the employees themselves (machine operators). The SKaizen method involves achieving Smart Manufacturing step by step, station by station, machine by machine, operation by operation, etc. In Japanese companies, the Kaizen method is strongly promoted in digital enterprise projects concerning individual machines, installations and workstations, so that over time the project develops into digital production lines and digital factories or entire supply chains. The first projects can be implemented in small steps while keeping investment costs at a moderate and acceptable level. In large investments and implementation of many projects, the planned costs are high and the expected results of production optimisation are delayed. Many Smart Manufacturing projects start with the manufacturing process and, over time, include processes centred around production and even supply chains (Gajdzik, 2022).

Technologies of Industry 4.0 create new opportunities for process improvement in enterprises by connecting smart devices on the shop floor through access gateways, combining digitalised operating procedures with cloud technology, sharing real-time process data, ongoing analysis of performance indicators (KPIs), and using 3D printing and other advanced technologies to manufacture more complex products at workstations (Gajdzik et al., 2021). Digital technologies and integrated computer systems together with process simulation and visualisation, data analytics enable both product creation and the definition of manufacturing and service processes in supply chains (Szozda, 2017). Digital process integration takes place through IoT platforms that connect business applications and IT-computer process support systems (ERP, CRM, PLM) with machines, products, materials and components. Individual business web applications connect to social media and users' end devices (laptops, computers, smartphones, tablets). The combination of the real and virtual worlds improves the functioning of supply chains by equipping them with advanced technologies for production, transport, storage, and distribution (Christopher, Towill, 2000). In Industry 4.0, Kaizen acquired a new frame of reference, which is cyber-physical solutions, as coherent reference structures of the combined virtual and physical world of manufacturing, computer-aided manufacturing, communication and production control systems (Lee, 2008). The centre of the structure is formed by intelligent, networked machines independently performing repetitive tasks and exchanging information, and through learning algorithms, able to adapt to change (Castro et al., 2012). In the fourth industrial revolution, Kaizen refers to the level of influence and effectiveness of implementing Industry 4.0 solutions in companies. The concept of Kaizen is very useful to achieve process efficiency in small steps. The application of Kaizen helps many companies to implement intelligent technologies at individual workstations and individual installations (machines). By applying Kaizen, the operational team of employees outlines (suggests) the development paths of digitisation projects at workstations. Changes in small steps at workplaces are categorised as small Kaizen. The large ones use advanced computer process simulation and product prototyping systems based on digital twin models. With small Kaizen, many digital improvements in production can be implemented immediately, even at no or low cost. Large projects - huge investments (e.g. construction of a new hall fully equipped with intelligent machines) require many financial and economic analyses, as well as many very detailed analyses of optimisation of processes, the productivity of equipment, energy savings, the flexibility of supplies, availability of staff, staff reorganisation, levels of equipment cooperation, process innovations, quality of processes and products, customer expectations, as well as social and environmental analyses. In small projects, the quality of the work is assessed above all, which is continuously improved following the Kaizen concept. The bottom-up initiative of changes allows factory owners and production engineers to analyse the validity of implemented solutions at a specific work in the context of cost efficiency and directions of improvement. Employee projects take into account the ideas and suggestions of contractors (machine operators, process plant managers, facility managers) to improve their work. In modern Kaizen, it is not necessary to write down change proposals by hand, as computers and mobile devices streamline the transmission of proposals (image, video, etc.). Increased access to digital information shortens the execution of activities and provides the ability to use data (search for relevant data) to improve processes (Lee, 2015). The management of processes and, in particular, the prevention of equipment, failures is facilitated by the use of advanced analytical algorithms and machine learning techniques based on the vast amounts of data collected by individual sensors. Having the right data is not a guarantee of production improvement, data must be able to be analysed and, above all, understood. Data from multiple sensors must be filtered and processed to be useful for the content process optimisation task (Lee, 2015). Machine operators gain greater accessibility via the network to all relevant information from all processes in real-time. Production visualisation and mobile devices enable optimal data to emerge from the information flow at any time and according to different evaluation criteria: cost, resources, quantity, quality, availability, time, productivity, etc. (Kiraga, 2016). New manufacturing technologies - additive technologies - 3D printing and others make it possible to produce complex-shaped products at the workstations without additional quality improvement operations. A similar effect is obtained by using multi-tasking machine tools, e.g. machining centres. Multi-tasking technologies contribute to the reduction of transport, storage, inter-station operations, etc. (Gladysz, Santarek, 2019, p. 944). As learning machines evolve, machine operators require more and more support during process improvement from IT teams (Gajdzik, 2021). Kaizen is applied at the each of stages of CPS development. Lee et al. (2015) identified five levels of CPS architecture within the collaboration of physical processes and digital space. The different levels of CPS correspond to the functions of technology in smart factories. The first, lowest level includes data collection and interpretation - the Connection level. The second level is the application of modern technology for analysing process performance - analytics capability - the Conversion level. The next level includes monitoring of work (processes) in real-time - real-time acquisition, and comparing monitoring - the Cyber level. The fourth level is called the Cognition level.

At this level, technologies strongly support humans in optimising processes. The fifth (highest) level is services, processes, and network configurations - the Configuration level. At this level, machines have cooperative learning and adaptive and executing algorithms. The participants in Kaizen are the operators of machines and process technology with the support of staff IT (Lorenz et al., 2015). Kaizen participants are operators of smart technologies, which Romero calls 'Operators 4.0'. D. Romero used the name to describe the role of humans in cyber-physical systems (Romero et al., 2016a). The cyber-physical system with human factors, abbreviated as H-CPS, is based on the cooperation of humans and machines in more and more intelligent processes (Sun et al., 2020). In the cooperation human with machines in cyber-physical production systems, the operators can take on various roles, such as virtual operator, using VR, smarter operator, being a personal assistant of this technology, operator cooperating with robots (collaborative operator), analytical operator and many others (Sun et al., 2020; Romero et al., 2016b; Rupper et al., 2018). The cooperation is supported by computer models and simulations that provide new techniques, e.g. in predictive maintenance. Plant operators and managers are using a wider range of mathematical and statistical techniques in product design and process improvement.

Widespread employee access to wireless technologies supports suction systems, e.g. e-channeling. Employees equipped with mobile devices collect and transmit data faster, e.g. within SPC, SQC, TPM systems, etc. (Gladysz, Buczacki, 2017, 2019; Gladysh, Santarek, 2019, p. 945). Kaizen participants use process mapping and evaluating their progress is easier in CPS. Information technology facilitates the synchronisation of process maps with information and computer systems, e.g. ERP. Value stream maps (VSMs) with extended MRP (Material Requirements Planning) system components are called SyVSM (synchro-MRP VSM) (Bertolini et al., 2013). Enhanced process visualisation systems make it easier for employees to make adjustments during value creation (Rother, Shook, 1999). In cyber-physical production systems, the product takes on smart characteristics and a new framing of quality, which is called: smart quality (SmartQ). SmartQ consists of utilitarian and emotional values and most of all the degree of personalisation of the product. Kaizen is one of the promising alternative strategies for achieving continuous improvement of processes performance by identifying a company's value stream and then systematically removing all waste (Logu, 2021). Determinants of Kaizen are the following smart levels, i.e. smart product, smart machine, smart operator and smart planner. At the smart product level, operators use process mapping and value stream mapping. At the smart machine level, Kanban, SMED, RFID, Andon, and TPM with prediction are used. At the planner level, traditional and virtual Kanban are used (Mrugalska, Wyrwicka, 2017).

Wagner (2017) ranked the usability of Lean tools according to digital and smart data access and distinguished such levels: (1) data acquisition and processing, (2) machine-to-machine communication - M2M, (3) human-machine integration - HMI. The highest level of usability when it comes to the application of Lean tools in smart manufacturing is standardisation, the second position belongs to Kaizen, and the third to Just-in-time. The next positions are occupied by: Jidoka, Heijunka, teamwork, pull flow analysis, and time settings. The last place belongs to 5S (due to the replacement of manual activities by intelligent technologies). Lean Manufacturing with Kaizen is a base for Smart Manufacturing. In the evolution of production systems, the following features are exposed: importance, priority, key, flexibility, continuity, validity, agility, and personalisation. „Lean is one of the prevalent approaches in the present scenario because it uses several strategies to focus on the elimination of non-value-added activities along with resource utilization" (Beifert et al., 2018). Lean and Smart cause a considerable decrease in resources waste and increase productivity (Sanders et al., 2016). Lean and Smart principles focus on dynamic production variation and are seen as more efficient than traditional manufacturing (Beifert et al., 2018). The discussion shows that process simplification and improvement activities support the implementation of Industry 4.0 and vice versa (Figure 2). Lean production systems came before Smart Production Systems and now laid the foundation (base) for smart production.

To start smart manufacturing (SM) projects (abbreviated: smart project), the company performs a diagnosis of the technological state and the employee reflects on the quality of his work. The project team marks the current place where the company is before the implementation of the project (state diagnosis), as well as the place to which the company is aiming.

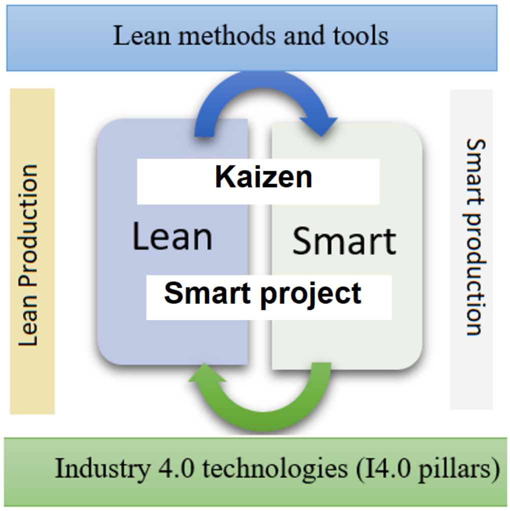

Figure 1. Kaizen in smart production.

Source: own elaboration.

The basis for many SM projects is the digitisation of workstations, therefore the company checks whether it electronically collects workstation data (data from machines, installations), if not then it begins this stage, if so, the data collected from machines must be visualised and the results from specific devices must be provided for analysis to managers and/or designers, who make decisions on the directions of process optimisation. The basis of new technological projects is the integration of information systems so that the introduced technologies do not perform many unnecessary activities, such as re-entering data. When introducing Kaizen at this stage, the employees (operators) look for problems related to the lack of data at particular stages of the process and the lack of possibility of the ongoing improvement of operations. The projects to eliminate the data gap are linked to projects to equip machines with intelligent sensors. Projects for the purchase of sensors and their installation on machines, together with the gradual modernisation of existing technology, are implemented in small steps from individual machines operated by operators. Even if it is assumed that ultimately the number of machine operators is to be reduced to a minimum or even to zero, some employees will remain. These will most likely be IT specialists and operators of intelligent equipment, who are currently lacking in the labour market. With gradual projects (implemented in stages), the company can train staff to operate the machines. It takes time for new staff to become familiar with the production profile, technologies and organisational principles. In addition, in the course of large investments, an additional social risk factor appears - in the form of employees' fear of losing their jobs when starting new investments in a fully intelligent factory, while the phasing of changes implemented during the small project of process modernization allows for reorganization of the human factor and preparation of employees to operate new functions of the equipment. Modern technologies are used at the stage of employee training, e.g. virtual reality. To assimilate Smart Kaizen principles, an employee needs to interact with virtual and augmented reality. Computer modelling and simulations help employees to implement changes. Simulations support the design and evaluation of Lean Manufacturing systems. Employees also use simulation and modelling to verify Kaizen conclusions and forecast directions for process and product improvement. Once one station is optimised, operators (participants of Kaizen) can move on to the next one until they reach the entire production line. Of course, according to project management, at each stage of the project, you need to provide adequate resources and analyse the costs of investment (ROI) (Heagney, 2012).

Smart manufacturing projects are based on Key Performance Indicators (KPIs) in the fields of productivity, quality, maintenance etc. (Kumagai et al., 2017, ISO 22400-1:2014). No decisions should be made until a sound economic and financial assessment of the project has been completed. Each enterprise establishes its way of achieving smart manufacturing, and each of the ways differs from the others in terms of the scope of activities, the time required to implement changes, costs, ROI value, and additional investment costs. The aim of SM projects is significant operational improvements and measurable process optimisation. A mistake made during process digitalisation projects is to assume that the implementation must be fast and complete - as a result of extensive activities and large investments. Managers would like to build the new factory of Industry 4.0 within a few months. This cannot be done for several reasons. The first reason: large projects are difficult to justify economically. The second reason: the period of return on investment (ROI) may be longer than planned. The third reason: there are difficulties in estimating particular risk categories e.g. natural, technological, market, etc. Example of a large-scale investment: the construction of a new facility equipped with machines that meet all the criteria of the requirements of intelligent production in terms of data collection and transmission. Example of a small project: installation of sensors on machines and data collection and step-by-step replacement of machines with intelligent ones. Planning large investments requires more time and many more analyses of the legitimacy of the planned investments than smaller projects. The path of digital transformation of companies through Kaizen starts with small changes in workstations, where the costs are small or the changes are almost completely costless. In small projects, measuring the effects and learning lessons are done almost on an ongoing basis. After one project the next step is taken, from one machine to another, from one workstation to another, and from one line to another, until a smart factory is created. The method of small steps in Smart Manufacturing projects is realized by the Japanese company Mitsubishi Electric. On the corporation's website in the news section, you can find a lot of information about the project activities undertaken using the SMKL methodology - Smart Manufacturing Kaizen Level (IAF, 2020).

3. Examples of Kaizen in smart manufacturing (SM) projects

Project 1: Step-by-step automation of work (production). Initial state: activities were previously performed by humans, without much involvement of industrial automation systems. Activities: introduction of cobots to collaborate with humans. The project requires relatively little investment. Investment tasks: (Task 1) purchase of an IC system to enable contact with software to control and optimise work operations, (Task 2) purchase and installation of equipment for automated work, including cobots and, in the long term, intelligent robots. If these activities were previously performed by humans, automation can bring tangible benefits and at the same time initiate a transformation towards smart manufacturing.

Kaizen questions about automation of work operations: (Question 1) What work operations cause losses? (Q2) What work operations can be improved? (Q3) Which work operations are repeatable on the workstations? (Q4) What work operations create value for the customer? (Q5) What work operations are dangerous for workers? (Q6) In which work operations is there a high level of human error? (Q7) Which work operations are determinants of product quality? (Q8) What work operations can be done in less time? (Q9) What work operations produce the most waste?

Traditional industrial robots are often better suited to many applications in the field of fast and precise assembly, while cobots are indispensable for increasing the flexibility of the production line. They also make it possible to specifically support people - for example, when taking goods out of crates or putting them in, whereas conventional industrial robots tend to work independently rather than together with workers. Cobots are also better able to handle tasks involving pallet handling, machine maintenance and material handling. Other applications include machine loading, order picking, packaging and testing.

Kaizen questions about reasons for changes and work organization: (Q1) Why should cobots and robots be implemented? (Q2) Considering the process conditions, are cobots or fixed-mounted robots better? (Q3) Which tasks (operations) will be allocated to robots and which to cobots? (Q4) What is expected of robots and cobots? (Q5) Where will the cobots and robots be located in processes? (Q6) What movements should the robots make? (Q7) Should the robot be controlled by external experts or the machine operator? (Q8) What kind of part production and performance is needed? (Q9) Is repeatability or precision essential? (Q10) Is an integrated robot vision system or vision inspection system required? (Q11) Is it better to choose a fixed-mounted system or rather a flexible collaborative robot?

To operate industrial robots, workers must be qualified. Completion of training is essential. The worker must take part in theoretical and practical training. It is also important to learn health and safety principles to be able to follow them later during work. This is very important for worker safety. Questions about operator knowledge and skills: (Q1) Are workers able to quickly develop the knowledge needed to operate the robots? (Q2) What training is required to operate robots? (Q3) Will the knowledge and skills of the operators be used at another stage of the production process?

Automated production systems operate on a physical product in a factory. They perform operations such as processing, assembly, quality control or material handling, in some cases carrying out more than one of these operations in the same system. Kaizen questions about the results of changes: (Q1) Does the automation of production operations increase productivity? (Q2) Do robots and cobots reduce labour costs? (Q3) By how much will the defect rate decrease? (Q4) Will production lead times to decrease? (Q5) Will stock levels fall? (Q6) Will storage costs be reduced?

Project 2: Implementation of the Poka Yoke system at the assembly station. Initial condition: the company relies on the knowledge and predisposition of its employees. Task: equip the assembly stand with electronic documentation of the process, preferably supplemented with 3D computer models, divide the production process into elementary activities, during which the worker uses individual assembly elements, subassemblies and tools, places the parts in lockable containers, sometimes additionally equipped with light signals. The course of operations: once the assembly of a new device has started, the worker is guided step by step through the system opening the containers with the elements to be used at a given moment. Similarly, manual or pneumatic (electric) tools are only unlocked at precise stages of the assembly cycle. The result: a lower risk of mistakes, an increase in the employee's efficiency, the plant receives objective information about the time of performing particular activities and the efficiency of the workplace (Adapted from: www.iautomatics.pl).

Kaizen question about work documents: (Q1) What documents are needed at the workplace? (Q2) What data is transmitted electronically? (Q3) What data is missing in the electronic documentation system? (Q4) How to simplify data transfer? (Q5) What forms of process data visualisation to use? (Q6) What kind of report to generate in the workplace?

An assembly line usually consists of a conveyor or set of conveyors, assembly stations, industrial robots and manipulators, and support equipment. An assembly line forms a transport line with a defined cycle of assembly stations (either universal or dedicated to each operation to be performed on it). The workstations are equipped with specially designed auxiliary equipment. Depending on the size of the space available to the client for setting up the line, and also taking into account the operating times of the individual workstations, assembly lines can be constructed as straight lines or L- or U-shaped lines. If there are also auxiliary operations, there may be stations or nests for component assembly in the vicinity of the line.

Kaizen questions about assembly stations: (Q1) What is the current work rate? (Q2) What are the working times at the workstations? (Q3) What is the coordination of the machines? (Q4) Is the transport line universal or dedicated? (Q5) What work movements does the worker carry out at the workplace? (Q6) What are the workstation types of equipment? (Q7) Are all work tools needed? (Q8) Are the employees able to keep the workstations tidy?

(Q9) How to improve the movement of manufactured product parts? (Q10) Are the workstations ergonomic? (Q11) How to achieve a better work sequence?

Project 3: Embedding sensors in machines. Initial state: check if the machine is collecting data. If not, plan an action: how to collect information from the machines, how to visualise and provide the results from a specific device for analysis to the managers making the decision. End state: predictive maintenance. Tasks: stage 1: production data is stored in an electrical database (production data and machine status), machine status is collected and stored in an electrical method, either automatically or by simple actions (example: scanner, code reader), status: electrical copy, daily report of machine operation, stage 2: data used to manage the production facility is indicated by an HMI device such as a monitor or PC display, but is not analysed (graphs and lists are automatically generated in real time based on the collected data from the machine), status: generation of graphs and lists using computer programs (graphs and lists contain real-time analytical data), stage 3: the system can analyze data, the system automatically warns operators when action variance correction is necessary, state: notification is automatically given to decision makers (operators), stage 4: automatic processing and application of algorithms using AI to recognise and perform improvement based on results - systems automatically perform feedback checks, state: use predictive maintenance based on digitised data to optimise production and maintenance plan (Adapted from: She et al., 2019).

Kaizen questions: (Q1) Is the machine collecting data? (Q2) How to collect data from the machine? (Q3) How to present machine data? (Q4) Where to store machine data? (Q5) What data is needed for predictive maintenance? (Q6) What data is needed to build a system to alert operators to equipment faults? (Q7) Which devices communicate with each other? (Q8) What solutions does the device's operating panel have?

4. Concussion

The general knowledge presented about the use of Kaizen in Smart Manufacturing projects can be useful at the stage of planning and developing changes that start at individual workstations or machines and in time end up in Smart Manufacturing. Each project is geared towards a specific goal. In line with Kaizen, it is worthwhile to involve employees at the stage of planning and improvement projects at workstations, and even to hand over the initiative for implementing changes to them, especially at the stage of improving the project at the control workstations. In Industry 4.0 Kaizen and Smart Production can coexist, especially at the beginning of the companies' journey towards smart factories. When the company has a high level of digitalisation, it can use smart Kaizen based on digital twins and other solutions of the Industry 4.0 technologies and pillars.

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