International Journal of Engineering & Technology, 7(4.16) (2018) 60-65

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Kanban System for Industry 4.0 Environment

Laila El Abbadi [1]*, Said El Manti[1], Mariam Houti[1] and Samah Elrhanimi[1]

[1]*National School of Applied Sciences of Kenitra, Ibn Tofail University, PoBox 242, university avenue, Kenitra, Morocco.*
**Corresponding author E-mail:laila.elabbadi@uit.ac.ma*

Abstract

Kanban is a lean tool for pull production system that controls the flow of material between workstations by using kanban signal. During years, this kanban signal is taking use of new technologies given by industrial revolutions. The latest one described the industry 4.0 as the industry of the future based on cyber-physical systems. In this context, this paper discusses the functioning of new kanban system for industry 4.0 environment, called kanban 4.0. At first, the current functioning of kanban system was analyzed and object interactions were demonstrated. Afterwards, two potential functioning of kanban system within industry 4.0 environment were presented, focusing on potential object roles and interactions, in case when the product is smart and the other one considering the smart bin/container. The proposed functioning was discussed with industrial experts and can constitute a basis for further researches.

Keywords: *Industry 4.0; kanban; kanban 4.0; lean manufacturing; lean production system*.

1. Introduction

The lean production system was created after the Second World War at Toyota Company [1] to organize the production systems and its components in order to reach the shortest lead time with minimum cost and highest quality [1]. Among lean production tools the kanban system [2] that manages the flow of materials from one workstation to another [3, 4]. It means that each customer workstation communicates directly its need to its supplier workstation [5] using material kanban cards. While the information technology is evolved and informatics were integrated in the manufacturing system, a digital kanban signal, called e-kanban, replaced kanban cards [6] and works around some kanban card limitations [7, 8] such as card lost [9] and difficulties to be adapted to fluctuating demand [10].

In 2011, the industry of the future has been presented at the Hannover Fair under the name of industry 4.0 [11]. The German government initiated this project of smart factories and encouraged the industry to accelerate the procedure in using this new revolution [12] which is based on a cyber-physical system [13] that uses emerging technologies such as wireless sensor [14] and implies the inter-connection and inter-communication between objects. The production system will be then transformed to a cyber-physical production system [15] and the manufacturing/ organization tools must be adapted to the industry 4.0 environment [16] including kanban system.

The aims of this paper is to analysis the current functioning of Kanban system and describe its potential functioning within the industry 4.0 environment focusing on object interactions and roles.

2. Kanban System

2.1. Lean Production System

The lean production system was created in 1950s at Toyota Company [1]. It aims to reach shortest lead time with minimum cost and highest quality by a specific organization of production and handling processes [1] by eliminating all wastes in the processes [17, 18].

Based on a pull approach, the need to program the operations in case of request is not more relevant anymore. Decisions according order of production are taken by operator, using an information system that connects the operations through the process [19]. The kanban system is part of this production information system [20].

2.2. Kanban System

Kanban is a tool for pull production system [2] that manages the movement of materials from one operation to another [3], by using a kanban card or a digital kanban signal. Each kanban signal is a manufacturing order for a specific product [9, 21, 22]. It triggers the performing of a work only when it is necessary [22], thereby, It allows maintaining a given level of the flow of the material in the process [4]. Also, it is used to communicate effectively with internal and external operations on issues such as production schedules, delivery time and stock information [5].

2.2.1. Traditional Kanban System

The traditional kanban system is based on kanban cards. Each card is specific to a determined part of production process [9, 21]. It contains all the information and details required for each process step [9, 23].

The kanban card system remains simple to implement with low cost [22], hence there is a continuous flow control of production and stocks [9]. Although, it has some limitations due to the unproductive work caused by the manipulation of cards [24]. The movement of kanban cards always has some irregularities, since they are not moved at the exact time as the consumption of materials [24], while the pace of manufacturing operations increases and the size of the production batch, the number of card movements increases too; as result, cards are lost or misplaced sometimes, causing immediate problems in just-in-time production [9]. Decreases or increases in demand for sudden products can also

cause problems for a traditional kanban system, because it requires adjusting the number of cards used as well as updating the information contained in kanban cards [10].
In addition, kanban card system is not suitable for all enterprises, especially those with fluctuating demand, poor quality production processes, or having a relatively wide variety of products [22].

2.2.2. Electronic Kanban System or E-Kanban System

To get around the traditional kanban limits, the most optimal solution is the use of the electronic kanban system, based on a digital signal, which offers many advantages over the kanban card system [8].
The electronic kanban system (also referred as e-kanban) is a signaling system that uses a mixture of technology, such as barcodes, RFID (Radio Frequency Identification) and electronic messages [6], to trigger the movement of materials within a manufacturing or production facility [6]. By using these technologies, the kanban system can be more reliable [7], with few errors in card management and decision making [7]. This kanban system can be integrated into enterprise resource planning systems (ERP) [10], which contain all the company's information in a centralized database.
E-kanban acts as a "command panel", which allows real-time visibility of demand signals and gives an overview of the status of each workstation in the system [21]. All transaction-related information is automatically collected and analyzed at different stages of the manufacturing process to control and make decisions in relation to the size of production batches, hence the definition of the passage time of the products [7, 21].
The e-kanban supports implementing a Pull production system in a manufacturing environment where the traditional kanban system would face difficulties [7]. It can be used with a production flow that constantly evolves according to the needs of the customers, as the location and the size of each batch is known and the change of the kanban cards takes place automatically in the computer system [7], which reacts as a basis for mutual communication [21] with the enterprise stakeholders: customers and suppliers [8]. Quality problems or failures of the machine are minimized and recovery is done in a controlled manner [7]. Also, an e-kanban system can bring visibility and improvement of the production and management of materials into an arrangement where operations are dispersed [7].
In addition, there are still areas where traditional kanban may be better than e-kanban; this occurs when there is no production information in the ERP system [8].

3. The Latest Industrial Revolution: Industry 4.0

3.1. Industrial Revolutions

Until today, the industrial environment has known fourth major revolutions. The first one achieved the mechanization of production using water and steam power; the second industrial revolution introduced mass production by means of electric power; followed by the digital revolution based on the use of electronics and IT to further automate production [25]. Then, the industrial production is moving from a physical process with IT support to an integrated cyber-physical system of production [26], this characterizes the fourth industrial revolution, known also as the industry 4.0.

3.2. Industry 4.0

In 2011, the approach of industry 4.0 has been presented at the Hannover Fair [11, 12]. It was developed in the framework of a project initiated by high-tech strategy of the German government to promote the computerization of manufacturing [12].
Since it publication, the interest is remarkable of industrials and researches worldwide. However, until today, there is no agreed definition of industry 4.0 [27]. It can be considered as the fourth industrial revolution applying the principles of cyber-physical systems, internet and future oriented technologies and smart systems with enhanced human-machine interaction paradigms [28]. A cyber-physical system combines the physical world with the cyber world by embedded computer controlled feedback loops [13]. The production system is then transformed to a cyber-physical production system [15] with radical changes in the execution of operations [28]. In contrast to conventional forecast based on production planning, industry 4.0 enables real-time planning of production, along with dynamic self-optimization [28].

3.3. Industry 4.0 for Lean Production System

Researchers agreed that the industry 4.0 can be integrated in lean production system and beyond that improve lean production by increased integration of information and communication technologies (ICT) [29]. Hence, the new manufacturing environment will be characterized by the following four elements:

3.3.1 Augmented Operator

The industry 4.0 environment will enable new types of interactions between operators and machines [30] also new mission /role to be accomplished by operator. In fact, the operator will be a decisions maker and a problem solver [27] as well as in charge of supervision and control of ongoing activities [27, 29] within a reduced time of reaction [29, 31] by using innovative technology. Therefore, he will be transformed to an augmented operator who is capable to interact with intangible assets and digital contents in highly interactive as well as absorbing fruition experiences [32]. An augmented operator will address the automation of knowledge which makes it the most flexible and adaptive part in the production system [33]. He gets an intelligent personal digital assistant [32], by smart watches [29], the mobile, context-sensitive user interface and user-focused assistance systems [34].
Romero et al. [35] present the “operator of the future” or “the operator 4.0” as the smart and skilled operator who performs ‘work aided’ by machines if and as needed.

3.3.2. Smart Product

The role of a product, in the framework of industry 4.0, is changed from a passive role to an active one [27]; so that the product became smart.
However, while some definitions for smart product exist, it is not possible to find an agreed upon, generally accepted, and well recognized definition of smart products in the literature [36]. According to Rijsdijk and Hultink [37] a smart product is product that contain information technology (IT) and that is able to collect, process, and produce information. In other way, this has a memory to store operational data and requirements individually, and is able to request for the required resources and coordinates the production processes for its completion [38].

3.3.3. Smart Machine

According to Alturu et al. [39] a smart machine is defined as “a machine that knows its capabilities to come up with the most efficient way to produce a correct part the first time, every time and will check and monitor itself using the data to help close the gap between the designer, manufacturing engineer, and the shop floor”. It can imply a machine that is better connected, more flexible, more efficient and safe [40]. Also, it can participate in predictive maintenance practices while minimizing its own environmental footprint and total cost of ownership [40].

In addition, a smart machine is able to ensure four levels of intelligence [41]: Support for humans, repetitive task automation, context awareness and learning, and self-awareness [41].

3.3.4. Smart Planner

As a result of the connection between the industry 4.0 elements cited above, the information system can collect data in real time from suppliers, customers, products, operators and machines, analyses them and planes the activities by taking into consideration all requirements to be respected such as deadlines and capacities of machines. Therefore, the processes are optimized in nearly time [29, 31], the planer system is dynamic and the production system is more flexible.

4. Kanban System Evolution During the Industrial Revolution

While the second industrial revolution, the kanban system was developed with the idea to control material flow between workstations, using material cards (kanban cards).
The evolution of technology proposes bring solution to some kanban cards limitations ,such as the loss of cards and the demand that must be regular, and gives birth of a new generation of kanban; the e-kanban system based on a digital signal transferred from workstation to another trough an ERP system based on RFID technology.
The fourth industrial revolution is based on the cyber-physical systems. That means that all objects in a manufacturing environment are interconnected. The kanban system must follow this revolution and be transformed to the kanban 4.0 or smart kanban. Some industrials proposed solution to this transformation; e-kanban 4.0, which is a combination of electronic kanban, RFID and the e-ink that replaces the tag that contain the information related to a container/bin [42]. Other types of kanban was developed such as kanban bin or iBin (intelligent bin) based on smart bins (combination of bin and sensors) able to get information on inventory level, on real time and communicated it to other workstation [43]. iBin reports wireless the status to an inventory control system [44].
The following figure summarized the evolution of kanban system and its relation with industrial revolutions.

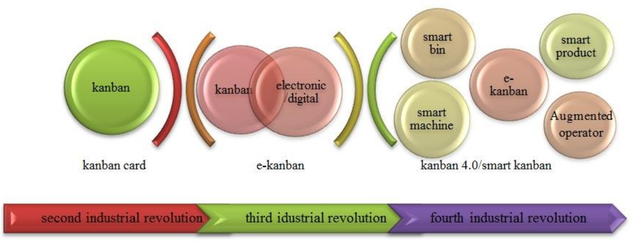

Fig. 1: Kanban evolution

5. Analysis of Kanban System Functioning in Current Manufacturing Environment

Based on the description of the kanban system given above, we can identify four primary sub-systems that constitute this kanban system which are:

- Operator: he is the main actor. He supervises the functioning of current kanban system.
- Informational system: the kanban signal can be a kanban card or a digital kanban signal. It has double roles; first it allows the customer workstation to get information on the products, and second it orders the production for the supplier workstation. A kanban board can be used to priories the production request and to get information on WIP (Work In Progress) level.
- Material flow system: the product flow has one way direction; it is transferred from the supplier workstation to the customer workstation. On the other hand, the full container/ bin has the same flow direction as the product, but the empty container circulates in the invers direction.
- Machine: the kanban signal allows the communication among the adjacent workstations which are connected via material handling equipment.

Each sub-system contains one or more components that must accomplish its defined tasks and interact with others components for the functioning of kanban system. The seven identified components are summarized in figure 2 and their interactions are presented in figure 3.

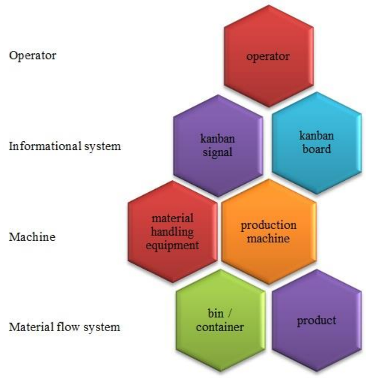

Fig. 2: Kanban system components

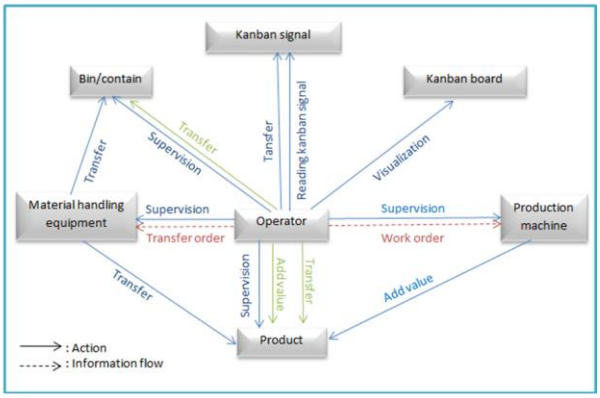

Fig. 3: Kanban functioning in current manufacturing environment

The diagram below shows that the operator is the main actor in the current functioning of kanban system. He visualizes the order priority and the WIP level on the kanban board. He is also in charge of reading the kanban signal and send the work order (idem transfer order) to the production machine (idem material handling equipment) which is responsible to add value to the product (idem transfer bin/ container or product according to the transfer order).
In case of the use of kanban card, the operator is in charge to transfer kanban card to the supplier/customer workstation. In some case, he will also add value to product as well as to transfer bin/ container or product.

6. Potential Kanban System Functioning for Industry 4.0 Environment

6.1. Role of Kanban System Components in the Industry 4.0 Environment

In the framework of industry 4.0, the kanban system will be changed and transformed to a kanban 4.0 or a smart kanban that means that all components cited in Figure 2 should be adapted to the new environment.

The following table highlights the role/ characteristics of each kanban system components in the current manufacturing environment as well as its potential role in the industry 4.0 environment.

Table 1: role/ characteristics of kanban system component in current manufacturing environment as well as in industry 4.0 environment

Kanban system components	**Role/ characteristics in current industrial environment**	**Potential role/characteristics in industry 4.0 environment**
Operator	• Workforce • Supervisor	• Decision maker • Problem solver • Supervisor and controller of activities
Kanban signal (card/ digital)	• Work/transfer order information	• Digital work/transfer order information
Kanban board	• WIP level information • Work order priority information	• Integrated in the Kanban system
Production machine	• Support for Humans, • Repetitive Task	• Autonomous and automatic add value operations
Material handling equipment	• Handling operation	• Autonomous and automatic handling operation
Product	• Passive role	• Contain operational information and Kanban information • Collect, process and produce information • Request for required resources • Coordinates the production process
Container/ bin	• Passive role	• Contain kanban information • Digital WIP level in real time

Basing on the assignment of task to each kanban system components, we will identify its equivalent in industry 4.0 environment. The following matrix shows the correlation between kanban system components and industry 4.0 environment, using as scale:

- White case: no correlation
- Gris case: high correlation

Table 2: correlation matrix between kanban system components and industry 4.0 environment

	Industry 4.0 environment		
Kanban system components	Augmented operator	Smart machine	Smart product
Operator			
Machine			
Kanban signal (card/digital)			
Kanban board			
Product			
Container/bin			
Material handling equipment			

The augmented operator can replace the operator who is considered as a workforce. He can become decision maker, problem solver, supervisor and controller of activities. The manual tasks and handling operations can be automated, and carried out by smart machines.

The smart product can be able to contain, collect, process and produce information, as well as to trigger work/transfer order. So the kanban signal and board roles can be integrated in the smart product. In some case, the product cannot be smart, so that the kanban information can be integrated in a smart bin/container.

6.2. Potential Object Interactions for the Functioning pf Kanban 4.0

There are two potential functioning of kanban system, the first one when the product is smart and the second one when the bin is smart.

6.2.1. Case 1: Kanban 4.0 Functioning based on Smart Product

In case the product is smart, it will send directly work order to the production machine which could response to this order by adding value to the product. Idem, smart product will send transfer order to material handling equipment, so that the product could be moved to next workstation. Otherwise, the product can communicate its operational information with an augmented operator. This later receives also information from smart production machine and smart material handling equipment. Also, the operator is in charge of ensuring the efficiency of the kanban system functioning.

The following figure shows the interactions between objects in this case.

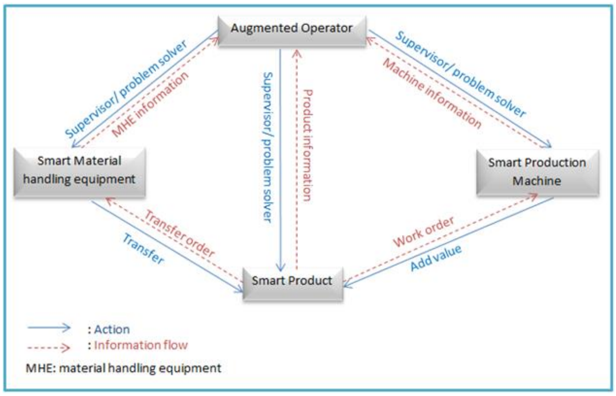

Fig. 4: Kanban 4.0 functioning based on smart product

6.2.2. Case 2: Kanban System Functioning based on Smart Bin/Container

In this case, the work order (idem transfer order) can be sent by smart bin/container/packaging to smart production machine (idem smart manufacturing handling equipment) which will then add value to product (idem transfer bin/container/packaging).

The augmented operator will receive information from smart production machine, smart MHE as well as smart bin/container/packaging, and then he will react on any object in the kanban system, to ensure the efficiency of the kanban system functioning.

The following figure shows the interactions between objects in this case.

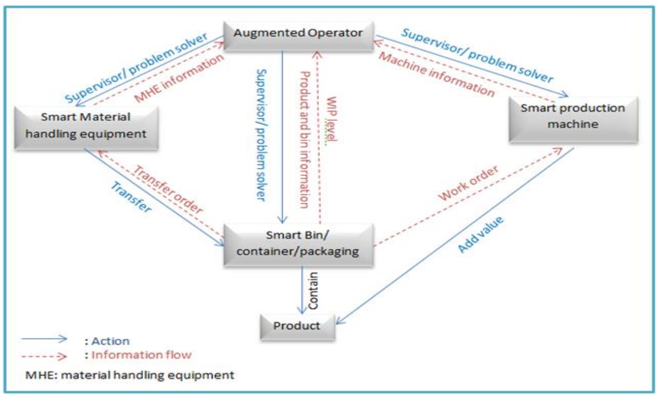

Fig. 5: Kanban 4.0 functioning based on smart bins/containers

6.2.3. Interviews

For this research expert interviews were conducted in order to validate the proposed potential functioning of kanban system in an industry 4.0 environment. The first one is an expert in supply chain management and the second one is an expert in ERP system.

Expert 1 point of view:

The introduction of the new generation kanban 4.0 will allow the reduction of the cycle time basing on the reduction of the queue, as well as the intermediate times between the different manufacturing steps will be reduced. The access to the real time information about the stock, the WIP as well as their status will be easier. In addition, the automated functioning will insure the reliability of the data (stocks, traceability, measures).

Expert 2 point of view:

A kanban 4.0 system or a smart kanban system depend mainly in these data transfers on ERP system, whose main role is to group all the information of the enterprise into a single database. This will enable industrial to solve several problems and failures caused by their suppliers or their own shop floor, as long as the products or bins are going to be smart, they will be able to keep the traceability of all the tests of reliability and quality, which will help them to go back to the cause of a given problem and solve it from the source.

7. Conclusion

This research was focusing on kanban system as the main tool for lean production system and its functioning within current and future production systems.
By analyzing first the current functioning of kanban system, this paper identifies the principal elements that constitute the kanban system which are: operator, kanban signal and board, material handling equipment, production machine, bin/container as well as product, then it demonstrates the interaction between these elements.
Using the industry 4.0 environment based on cyber-physical system which can be characterized by: augmented operator, smart machine and smart product, this paper proposed two potential functioning of kanban system for this new environment, called kanban 4.0; the first one when the product is smart and is able to send the work / transfer orders, the second one considering the smart bin/container as the transmitter of the work / transfer orders. The new interactions between kanban elements are then shown. Those two types of functioning can constitute a basis of further researches that are interested on the implementation of kanban system/ lean production system in industry 4.0 environment.

References

[1] Ohno T, Toyota production system: beyond large-scale production. *Productivity Press*, 1988, available online: https://books.google.co.ma/books?id=7_-67SshOy8C&printsec =frontcover&dq=Toyota+production+system:+beyond+large -scale+production&hl=fr&sa=X&ved=0ahUKEwjf_cLphIXcAh WBiSwKHdb9A_IQ6AEIKDAA#v=onep-ge&q=Toyota% 20 production%20system%3A%20beyond%20large-scale% 20 production&f=false, last visit: 04.07.2018.

[2] Hines P, Holweg M & Rich N, Learning to evolve, a review of contemporary lean thinking, *International Journal of Operations & Production Management*, Vol. 24, No. 10, 2004, pp: 994-1011.

[3] Ramnath BV, Elanchezhian C & Kesavan R, Inventory optimization using kanban system: a case study, *The IUP Journal of Business Strategy*, Vol. 6, No. 2, 2009, pp: 56-69.

[4] Sugimori Y, Kusunoki K, Cho F & Uchikawa S, Toyota production system and Kanban system, Materialization of just-in-time and respect-for-human system, *International Journal of Production Research*, Vol 15, No. 6, 1977, pp: 553-564.

[5] Apreutesei M, Arvinte IR, Suciu E, & Munteaunu D, Application of Kanban System for Managing Inventory, *Bulletin of the Transilvania University of Brasov*, serie I: Engineering Sciences, Vol. 3, No. 52, 2010, pp: 161-166.

[6] Surendra M, Gupta YAY & Ronald FP, Flexible kanban system, *International Journal of Operations & Production Management*, Vol. 19, No.10, 1999, pp: 1065-1093.

[7] Graves R, Konopka JM & Milne RJ, Literature review of material flow control mechanisms, *Production Planning and Control*, Vol. 6, No. 5, 1995, pp: 395-403.

[8] Houti M, El Abbadi L & Abouabdellah A, E-kanban the new generation of traditional kanban sytem, and the impact of its implementation in the entreprise, *Proceedings of the International Conference on Industrial Engineering and Operations Managament (IEOM 2017)*, 2017, pp: 1261-1270.

[9] Kumar CS & Panneerselvam R, Literature review of JIT-kanban system, *International Journal of Advanced Manufacturing Technology*, vol.32, No. 3-4, 2007, pp: 393–408.

[10] Mertins K & Lewandrowski U, Inventory safety stocks of kanban control systems, *Production Planning & Control: The Management of Operations*, Vol.10, No. 6, 1999, pp: 520-529.

[11] Dombrowski U, Richter T & Krenkel P, Interdependencies of industry 4.0 & lean production systems- a use cases analysis-, *Proceedings of the 27th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2017)*, Procedia Manufacturing 11 (2017), 2017, pp: 1061-1068.

[12] Sung TK, Industry 4.0: A Korea perspective, *Technological Forecasting & Social Change*, Vol. 132, 2017, pp: 40-45.

[13] Lee EA, Cyber physical systems: design challenges, *Proceedings of the 11th IEEE Symposium on Object Oriental Real-Time Distributed Computing (ISORC)*, 2008, pp: 363-369.

[14] Godavarthi B, Nalajala PR & Ravi Teja ML, Wireless sensors based data acquisition system using smart mobile application, *International Journal of Advanced Trends in Computer Science and Engineering*, Vol.5, No.1, 2016, pp: 25 -29.

[15] Wagner T, Herrmann C & Thiede S, Industry 4.0 impacts on lean production systems, *Proceedings of the 50th CIRP conference on Manufacturing Systems, Procedia CIRP 63 (2017)*, 2017, pp: 125-131.

[16] El Manti S, El Abbadi L & Hmina N, The integration of lean manufacturing tools in the industry 4.0, *Proceedings of the International Conference on Industrial Engineering and Operations Management (IEOM 2018)*, 2018, pp:1191-1192.

[17] Cua KO, McKone KE & Schroeder RG, Relationships between implementation of TQM, JIT, and TPM and manufacturing performance, *Journal of Operations Management*, Vol. 19, No. 6, 2001, pp: 675-694.

[18] Liker JK & Meier D, *Toyota way field book a practical guide to implementing the Toyota 4Ps*, McGraw-Hill Companies, 2006.

[19] Leal AC, Machado LF & Henriques de Miranda Costa VM, Case study of the implantation of pull production in a company of plastic packaging segment, *Proceedings of the International Conference on Industrial Enginneging and Operation Management (ICIEOM)*, 2012, pp: ID88.1-88.10

[20] Wan H & Chen FF, A web-based kanban system for job dispatching, tracking, and performance monitoring, *The International Journal of Advanced Manufacturing Technology*, Vol. 38, No. 9-10, 2008, pp: 995-1005.

[21] Muris LJ & Moacir GF, Variations of the kanban system: literature review and classification, *International journal of Production Economics*, Vol.125, No.1, 2010, pp: 13–21.

[22] Suprasith J, Andrew PC, Thaloengsak C & Chayanun K, Supply chain efficiencies through e-kanban: a case study, *International Journal of the Computer the Internet and Management*, Vol. 19, No.1, 2011, pp: 40-44.

[23] Mayilsamy T & Pawan KE, Implementation of e-kanban system design in inventory management, *International Journal of Scientific and Research Publications*, Vol. 4, No. 9, 2014, pp: 2250-3153.

[24] Drickhamer D, The kanban e-volution, *Material Handling Management*, 2005, pp: 24-26, available online: http://mhlnews.com/technology-amp-automation/kanban-e-vol ution, last visit: 15.02.2017.

[25] Schwab K, *The fourth industrial revolution- What It Means and How to Respond*, 2016, available online: http://www.vassp.org.au/webpages/Documents2016/PDevents/The %20Fourth%20Industrial%20Revolution%20by%20Klaus%20Sch wab.pdf, last visit: 04.07.2018.

[26] Kagermann H, Wahlster W & Helbig J, Recommendation for implementing the strategic initiative Industry 4.0, *Final report of the Industrie 4.0 Working Group*, 2013.
[27] Mrugalska B & Wyrwicka MK, Towards lean production in industry 4.0, *Proceedings of the 7th international conference on Engineering, Project, and Production Management. Procedia engineering 182 (2017)*, 2017, pp: 466-473.
[28] Sanders A, Elangeswaran C & Wulfsberg J, Industry 4.0 imply lean manufacturing: research activities in industry 4.0 function as enablers for lean manufacturing, *Journal of Industrial Engineering and Management*, Vol. 9, No. 3, 2016, pp: 811-833.
[29] Kolberg D & Zühlke D, Lean automation enabled by industry 4.0 technologies, *International Federation of Automatic Control (IFAC)-PapersOnLine*, Vol. 48, No. 3, 2015, pp: 1870-1875.
[30] Lorenz M, Rüßmann M, Strack R, Lueth K & Bolle M, Report on man and machine in industry 4.0, *the Boston Consulting Group publication*, 2015, available online: http://englishbulletin.adapt.it/wp-content/uploads/ 2015/10/ BCG_Man_and_Machine_in_Industry_4_0_Sep_ 2015_tcm80-197250.pdf, last visit: 20.06.2018.
[31] Singh K, Lean production in the era of industry 4.0, *Logistics engineering and technologies group*-working paper series 2017-005, 2017.
[32] Longo F, Nicoletti L & Padovano A, Smart operators in industry 4.0: a human-centered approach to enhance operators capabilities and competencies within the new smart factory context, *Computers & Industrial Engineering*, Vol. 113, 2017, pp: 144-159.
[33] Schmitt M, Meixner G, Gorecky D, Seissler M & Loskyll M, Mobile interaction technologies in the factory of the future, *Proceedings of the 12th IFAC Symposium on Analysis, Design, and Evaluation of Human-Machine Systems*, 2013, pp: 536-542.
[34] Gorecky D, Schmitt M & Loskyll M, Human-machine-interaction in the industry 4.0 era, *Proceedings of the 12th IEEE international Conference on Industrial Informatics (INDIN)*, 2014, pp: 289-294
[35] Romero D, Bernus P, Noran O, Stahre J & Fast-Berglund A, The operator 4.0: human cyber-physical systems & adaptive automation towards human-automation symbiosis work systems, *Advances in Production Management Systems. Initiatives for a Sustainable World, IFIP Advances in Information and Communication Technology*, Vol 488, Springer, Cham, 2016, pp: 677-686.
[36] Gutiérrez C, Garbajosa J, Diaz J & Yagüe A, Providing a consensus definition for the term “smart product”, *Proceedings of the 20th Annual IEEE International Conference and Workshops on the Engineering of Computer Based Systems (ECBS)*, 2013, pp: 203-211.
[37] Rijsdijk SA & Hultink EJ, How today’s consumers perceive tomorrow’s smart products, *Journal of Product Innovation Management*, Vol.26, No. 1, 2009, pp: 24–42.
[38] Loskyll M, Heck I, Schlick J & Schwarz M, Context-based orchestration for control of resource-efficient manufacturing processes, *Future internet*, Vol. 4, No. 3, 2012, pp:737-761.
[39] Atluru S, Deshpande A, Huang S & Snyder JP, Smart machine supervisory system: concept, definition and application, 2008, available online: http://homepages.uc.edu/~atlurush/MFPT 2008.pdf, last visit: 04.07.2018.
[40] Beudert R, Leif Juergensen L & Weiland J, Understanding smart machines: how they will shape the future, *Schneider Electric White Paper*, 2015.
[41] Davenport TH & Kirby J, Just how smart are smart machines?, *MIT Sloan Management Review*, vol. 57, no. 3, 2016.
[42] Kanbanbox, E-kanban 4.0: e-kanban + RFID + e-ink, 2017, available online: https://www.kanbanbox.com/fr/ekanban-rfid-industrie-40, last visit: 20.06.2018.
[43] Hofmann E & Rüsch M, Industry 4.0 and the current status as well as future prospects on logistics, *Computer in Industry*, Vol. 89, 2017, pp: 23-34.
[44] Würth, Ibin –the first intelligent bin, 2013, available online: https://www.wuerth-industrie.com/web/en/wuerthindustrie / cteile_management/kanban/ibin_intelligenterbehaelter/ibin.php, last visit: 20.06.2018.