Acta logistica - International Scientific Journal about Logistics
Volume: 7 2020 Issue: 2 Pages: 95-101 ISSN 1339-5629

doi:10.22306/al.v7i2.162
Received: 01 Mar. 2020
Accepted: 07 June 2020

TRACEABILITY IN INDUSTRY 4.0: A CASE STUDY IN THE METAL-MECHANICAL SECTOR

Rafael Granillo-Macías
Autonomous University of Hidalgo, Campus Sahagun, Department of Industrial Engineering, Cd. Sahagun, Hidalgo, Mexico, rafaelgm@uaeh.edu.mx (corresponding author)
Isaias Simón-Marmolejo
Autonomous University of Hidalgo, Campus Sahagun, Department of Industrial Engineering, Cd. Sahagun, Hidalgo, Mexico, isaiasm@uaeh.edu.mx
Isidro J. González-Hernández
Autonomous University of Hidalgo, Campus Sahagun, Department of Industrial Engineering, Cd. Sahagun, Hidalgo, Mexico, igonzalez@uaeh.edu.mx
Jorge Zuno-Silva
Autonomous University of Hidalgo, Campus Sahagun, Department of Mechanical Engineering, Cd. Sahagun, Hidalgo, Mexico, jorge_zuno@uaeh.edu.mx

Keywords: smart assets, GPS, technologies, logistics, supply chain
Abstract: With the emergence of production systems characterized by Industry 4.0 technologies, asset traceability problems have become more relevant at different echelons of the supply chain. The management of intelligent assets promoted by Industry 4.0 is considered as a process that, in addition to collecting information, allows tracking and ensuring the security of assets. This article shows various technologies for traceability and asset monitoring, from the perspective of Industry 4.0. Through a case study in the metal mechanical industry, the solutions and benefits offered by the implementation of technologies based on RFID and GPS were analysed. With this proposal, it was possible to respond to the problem of the control and monitoring of welding equipment inside and outside the company. An automatic update of the locations was also achieved, through the use of GPS. The company estimates that with this implementation levels of reliability in the inventory close to 99% can be obtained, which would lead to guarantee the traceability of the assets.

1 Introduction

The incorporation of new information and communication technologies to transform aspects related to the design of production systems, manufacturing, storage, and logistics are some of the current trends in Industry 4.0 and intelligent manufacturing. To achieve an advantage in the market and ensure an adequate level of customer service, companies have used a set of technological tools to optimize different processes such as production, human resources, finance, information management, research and development, sales and logistics, maintenance, environment, security, design, project management, and asset management [1]. In the manufacturing sector, it is where technology-based applications mainly allow companies to stay and position themselves in increasingly competitive markets, providing innovative solutions to the different challenges they face throughout the supply chain.

Obtaining real-time information generated systematically through technologies for traceability has been one of the key factors for the digital transformation of the industry, boosting global competition and innovation of supply chains [2,3]. Due to the emergence of highly automated production processes and cyber-physical production systems in manufacturing operations in Industry 4.0, asset traceability problems have become more relevant at different stages of the supply chain, impacting not only in companies that traditionally perform highly regulated operations such as the pharmaceutical, aerospace and automotive sector.

Asset management has become a critical activity in organizations that share assets between their own companies or facilities, that is, a company that has several facilities within a region can share equipment or tools to perform different production processes in different locations. Mismanagement of assets, such as raw material and/or equipment, can hamper the quality of the product or cause the loss or theft of equipment. However, with the use of new technologies in Industry 4.0, these problems can be solved, to manage assets efficiently and advanced, as well as provide real-time data [4].

Technologies in Industry 4.0 play an important character in handling the flow of products and assets throughout the supply chain. Big data, the Internet of Things, and tag-based technologies for Radio Frequency Identification (RFID) allow us to share information on inventory levels, order policies, and forecasts of future demands, thus effectively communicating requirements throughout the supply chain. These internet-based technologies, connected with physical environments (machinery, equipment, mechanisms, among others), generate the so-called cyber-physical systems (CPS) which are the main foundation of Industry 4.0. Fernandez-Carames et al. [5] also mention that these technologies promote horizontal integration of the supply chain, dynamically determining supply needs efficiently and in real-time, mainly between suppliers and manufacturers. The objective of this article is to show some technologies for asset traceability, from the perspective of Industry 4.0. Through a case study in the metal mechanical industry, the solutions and benefits offered by the implementation of technologies based on RFID and GPS were analysed. The hypothesis for this study was that with the implementation of technologies for traceability it is possible to significantly improve the levels of inventory reliability.

1.1 Asset Administration

Pittman and Atwater [6] through the APICS dictionary defines an asset as: “any resource owned by a company, whether tangible (cash, machinery, equipment, and inventories) or intangible (patents, software or licenses)”. The ISO 55000 standard generalizes an asset as “an element, a thing or entity that has potential or real value for an organization”. On the other hand, the British Standard Institute defines in BSI PAS 55-1, the term "active" as "machinery, property, buildings, vehicles and other items, and related systems that have a different and quantifiable commercial function or service" [7].

Asset management is described as a set of activities to achieve a specific business or organizational objective, which includes the identification, maintenance, and renewal of assets [8]. The British Standards Institute defines asset management as “the systematic and coordinated activities and practices through which an organization optimally and sustainably manages its assets, its performance, risks, and associated expenses throughout its life cycle with to achieve its strategic organizational plan” [7]. Maletič et. al [9] points out that asset management is also essential, especially for companies where their assets are the basis of their success. According to Hastings [10], asset management also involves the use of information technology-based systems to offer efficient visibility and control for the identification of equipment, locations, and monitoring of activities throughout the organization. Inventory management, sourcing and purchasing, cost estimation, maintenance routines, financial reports, and work processes are some of the main applications of information systems for asset management.

Lima and Costa [11] mentions that asset management is based on four fundamentals or principles that translate into continuous actions such as 1) focus on the value that the asset can deliver to the organization (value); 2) transform strategic decisions into technical, economic and financial decisions (alignment); 3) strengthen the implementation, operation and improvement of asset management within the organization (leadership); and 4) be confident that the assets will achieve their essential objective (assurance). In the environment of Industry 4.0, the transformation has been promoted towards the so-called “intelligent asset management”, with the purpose of monitoring and tracking physical assets anywhere, by including technologies such as RFID or GPS tags to transform assets physicists in "intelligent assets". Nel and Jooste [12] indicate that intelligent asset management emphasizes the notion of technological processes to improve the collection and processing of information, in support of strategic decision making. The digitalization of the assets allows, in turn, the increase of the value of these for the organization. In the research carried out by Nel and Jooste [12], they point out that intelligent asset management is the integration between physical and virtual media that organizations use innovatively, to improve the management of their assets.

1.2 Traceability in Industry 4.0

The growing demand for highly customized products is a factor present in the fourth industrial revolution, directly impacting the different stages of the supply chain, which implies more flexible production systems and shorter product life cycles. To meet these requirements, CPS is applied to interconnect and self-manage production processes in an “intelligent factory” environment that incorporates external and internal conditions for autonomous adaptation for the benefit of optimizing these processes [13]. In the intelligent factory, the flow of bidirectional information between all components such as machines, products, control programs, and assets is understood through traceability.

Technology and systems for traceability are the main support for monitoring products within Industry 4.0. The concept of traceability according to ISO 8402 and ISO 9000 refers to the ability to track the history, application or location of an entity through registered identifications. Bougdira et al. [14] also mentions that due to the properties and characteristics of Industry 4.0, traceability should be considered as an intelligent process to register, identify and collect data in the different processes throughout the supply chain to recover the information, not only to track but also to ensure the security of the (active) objects within their environment. The information provided by the technology for traceability may include location, speed, acceleration, temperature, humidity, product information (price, dimensional information, physical characteristics, among others), as well as physical and physical condition. characteristics of the means of transport used for logistics [3].

Bar codes and global positioning systems (GPS) are some of the first technologies used for traceability and tracking. According to Halawa et. at [15], other technologies that are commonly used for tracking and location are Ultra Wide Band, radio frequency identification systems, and Wi-Fi vision and technology systems.

With the development of information systems and new concepts on CPS combined with the Internet of Things (IoT) and cloud computing, innovative technologies have been promoted for traceability among which are: wireless networks, identification by radiofrequency and smart tags. In general, these technologies aim to provide real-time information for traceability and product tracking [4].

Table 1 shows some technologies for traceability and applications of these in different sectors such as construction, medical equipment, and the education sector [16-19]. RFID, GPS, IoT, Cloud Computing, and Big Data are common technologies for asset management and identification.

Table 1 Traceability technologies

Source	Technology for traceability	Application / Tracked Object
[16]	RFID	Construction sector
[14]	Cloud computing Big data GPS	Not specified
[4]	Internet of things	Health sector
[17]	RFID Internet of things	Educational sector
[15]	RFID	Not specified
[18]	RFID	Health sector
[19]	GPS sensors	Construction sector

In the review of concepts and trends in Industry 4.0 by the authors Ben-Daya et al. [20], also indicate as technologies related to traceability to RFID, IoT and Big Data tags. The IoT applied to traceability in the supply chain, arose from the evolution of information and communication technologies that have been used for object tracking.

IoT refers to global networks in which several objects are integrated with electronic sensors, actuators, or other digital devices to collect and exchange data [21]. Ben-Daya et al. [20] also mention that IoT is a network of physical objects that are digitally connected to identify, track, and interact within a company and its supply chain, allowing visibility, monitoring, and information exchange. The main characteristics of the IoT that favour traceability in the supply chain are: (1) intelligent manufacturing systems, (2) real-time data acquisition, and (3) real-time visibility of production processes. Lee and Lee [22] identify IoT, wireless sensor networks (WSN), cloud computing, and RFID, as key technologies for IoT.

Besides, RFID tags are also considered as one of the most advanced technologies for supply chain traceability, influencing most of the industry, specifically impacting manufacturing sectors. Unlike barcode scanners, RFID generated data can be read at a distance of up to several meters [18]. RFID technology is widely used in the intelligent identification of assets so that they can connect and interact with each other through specific forms of interconnectivity [21]. RFID identification devices are labels or bar codes that are increasingly associated with systems for asset management. Systems for asset management based on architectures such as IoT are developed to track the products attached with the labels, which contain all the necessary information for traceability [15, 23].

Other technologies used by logistics companies, with information and data flow processes, are Real-Time Location Systems (RTLS). RTLS has properties for object identification, like those offered by RFID systems. Unlike RFID, RTLS enables continuous label localization in a space with an accuracy of up to 15 cm in supervised areas [24].

In this context, RFID technology is a key element for asset management due to its ability to integrate CPS, connecting objects in the physical world with their representations in information systems [12]. For example, among the applications of this technology for traceability, Bisio et al. [16] propose an original architecture designed to manage and track assets within construction sites, where they integrate a classic radio frequency (RFID) tracking solution, Bluetooth low energy tags and smartphones.

Finally, the preponderant technologies for traceability is Big data. Big data is a term that refers to a large amount of data, which exceeds the capacity of conventional software. In the context of Industry 4.0, data collection is the first step towards a comprehensive analysis of smart asset management. For example, in the manufacturing sector, Big data is used to obtain information to understand customer requirements and improve the user experience [25]. In asset management, Big Data in conjunction with IoT offer great opportunities, but also great challenges, for example, in terms of data exchange [8, 26].

2 Methodology

The company in which this case study was conducted is a company in the mechanical metal sector focused on the manufacture of mass cargo transportation for the railway industry, which has manufacturing centres located in Mexico and different countries. At the international level, the railway industry is characterized by technical, organizational, and operational complexity. Technological progress for rolling stock, as well as infrastructure and increased capacity utilization, are some of the challenges facing the railway industry [27].

In Mexico, the supply chain of this company consists of national and international suppliers that deliver different inputs and materials (steels, welding, and special parts) for production. Some of the assemblies that are required within their production process, due to capacity and manufacturing times, are made outside the company.

One of the improvement issues that this manufacturing company has is the proper management of its assets. The reliability and traceability of assets are determining factors for the company's performance indicators. Because this company is under a projected organization, that is, production plans and programs are executed based on projects; Asset reliability levels are a vital element to ensure the proper administration and planning of inventories and assets that are required for the execution of a specific project. Particularly, welding equipment used in most production processes is one of the assets with the highest economic and strategic value for the business. The welding processes that are carried out with these assets represent 90% of the total production operations in the company, being the most relevant processes executed with MIG (Metal Inert Gas) welding.

A welding equipment consists of two basic elements: (1) a source, which has the function of generating energy, and (2) a feeder, which is used to initiate and maintain the arc between the wire and the base metal. The company owns about 1,000 welding equipment, with an average cost per team of USD 6,000, which presents a considerable investment in this type of assets. Welding equipment is distributed in two types of locations depending on the manufacturing processes, (1) internal locations, corresponding to the work positions along the different production lines, and (2) external locations corresponding to warehouses both own and suppliers, where special manufacturing processes are performed.

Due to outsourcing operations and in compliance with the quality requirements in the processes, the company has 31% of its welding equipment outside its facilities, that is, in external locations. Thus, the fact that the assets are in different internal and external locations, has caused problems for the traceability of inventories in this company. As shown in Figure 1, the process in which the welding equipment interacts starts at the request of the manufacturing department, which makes a requisition for the movement of the welding equipment to the previously planned external or internal locations.

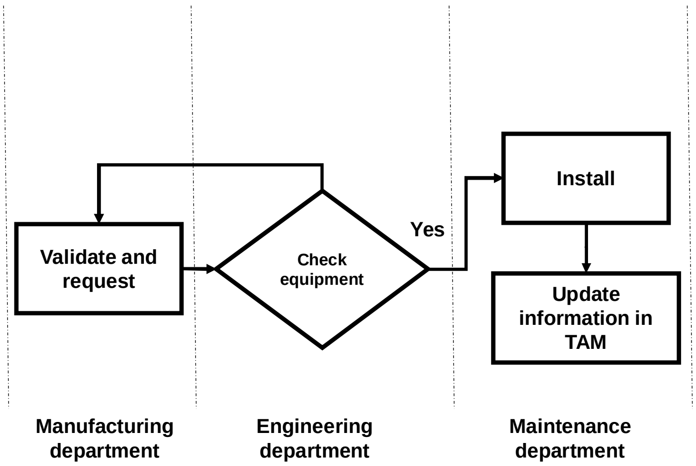

Figure 1 Welding equipment application process

Subsequently, the welding engineering department validates that said equipment has the necessary technical characteristics for the assigned process and simultaneously generates the service request with which the maintenance department performs the corresponding installation. Once the installation of the equipment is completed, the same maintenance area updates the location of said asset through the Tool & Asset Manager (TAM) application. The TAM is an asset management tool, which allows the use of barcode readers and RFID tags, to identify and traceability of company assets [28].

The main function of the TAM in the company is the control of assets, such as tools, hydraulic equipment, communication equipment, power tools, and welding equipment. This application allows to manage and know the traceability, as well as the amount of tools and equipment that the company has, in addition to helping to determine the status of the same (new, in use, with failures, in repair, obsolete, with report of theft, in calibration, among others). The information collected by the TAM serves as a support in the decision-making process for the acquisition of equipment and tools for future projects, optimizing current resources. One of the restrictions of the TAM, is that the information mainly obtained from external locations, involves manually updating the databases by company personnel. In addition to the above, the continuous change of location of the assets and the lack of traceability in the external locations caused that in some projects there were more welding equipment than necessary, while in other projects they would be unable to comply with the production due to the lack of such equipment.

As a sequence of this problem, the loss and loss of welding equipment, positioned the company at a 77% level of reliability in its inventories. Also, the economic impact was estimated, contrasting the theoretical inventories declared in the TAM system and the physical inventories, obtaining losses calculated for about 1.4 million dollars.

3 Result and discussion

The company evaluated different solutions for asset control based on strategies for identifying procedures and software applied to inventory traceability. However, these strategies proved to be ineffective, mainly due to the uncertainty in updating databases in external locations.

Subsequently, the company evaluated alternatives with Industry 4.0 technologies. RFID was the initial proposal because this technology is one of the most prolific for traceability in the supply chain. However, due to the movements of assets in locations outside the company, GPS technology was also evaluated, which is suitable in external environments.

The alternatives with RFID and GPS were evaluated, considering in each case the positive and negative attributes, as shown in Table 2.

Table 2 Attributes of the technologies analysed

	RFID		GPS
	Passive	Active	
Indoor operation	Yes	Yes	No
Visibility in areas outside the company	No	No	Yes
Two-way communication	No	Yes	No
Tag size	3 mm - 50 mm	50 mm - 150 mm	50mm - 150 mm
Reading range	0 m - 3 m	0 - 30 m	0 m - 20,500 km
Battery life	-	Long	Long
Infrastructure cost	Medium	High	Medium
Maintenance cost	Low	Medium	Medium
Operating cost	Low	Medium	Low
Operating frequency	50 Khz - 2.5 GHz		1.5 Ghz - 2.7 Ghz

Specifically, in the configuration of the traceability information system, the organization followed a procedure based on (1) selection of network technology according to the needs of the company, (2) the development of engineering for its operation, which included aspects such as the placement of devices and sensors in welding equipment subject to traceability and (3) the evaluation of the development necessary for the data management system, including aspects such as communication infrastructure and interface of users. This study considered factors such as accuracy, accessibility, line of sight, wireless communication, data storage, and power supply.

Finally, after an agreed analysis and considering the need for visibility of assets in external locations as preponderant, the company selected GPS technology as a solution proposal. The proposal included a GPS model with the company's operating requirements, under the following characteristics: (1) two GPS check-In per day, (2) LTE-M connectivity, (3) offline storage, (4) SSL-protected Internet connectivity with 256-bit AES encryption and (5) 5-year battery life.

The implementation of these GPS-based technologies confirms that smart technologies have high potential, mainly for asset management. According to Nel and Jooste [12], it has been shown that the use of asset data analysis facilitates the management of their performance, so there is a need to create technological platforms that allow obtaining consistent and real-time information to Informed decision making. By implementing the proposal with GPS systems for external locations, the control and monitoring of the company's welding equipment were improved. Automatic updating of locations was also achieved, through the use of this technology. The company estimates that with this implementation you can obtain levels of reliability in the inventory close to 99%, which would lead to decrease equipment losses, generating savings on an annual average of 553, 634 USD.

Other particular benefits achieved with this proposal were: (1) improvement in the efficiency for data collection of equipment (quantity and location), (2) increase in the reliability of the inventory of welding equipment and (3) improvements in access of the complete history of the movements of the teams, such as dates, times, locations among others.

The integration of GPS technology with the RFID-based TAM system allows traceability in locations inside and outside the company, in addition to ensuring real-time inventory reliability. Keeping asset locations updated was also one of the benefits achieved through this proposal.

4 Conclusions

Considering that "it can only be understood, what can be measured", technology-based traceability is a key tool that supports and provides a global vision throughout the processes of the supply chain. Currently, Industry 4.0 demands a higher priority for traceability even among the most conventional companies. CPS in industrial operations requires innovative technologies that allow efficient production, in a sustained supply chain, and completely connected to its different processes, from supply to the final customer.

Industry 4.0 also requires the identification and location of assets within the supply chain instantaneously to obtain information on their origin, storage, and status. Monitoring the current status of an asset through traceability technology allows **us to** provide the necessary tools for operational analysis, proposing more efficient routes and production processes. The balance in the use of technologies, for the traceability with the systems of administration of supplies, inventories, and finished products, arises as a response to the constant variations in customer demands. RFID, GPS, and RTLS are tools that are used in logistics, affecting the improvement in visibility, security, and risk reduction throughout the supply chain.

As was shown in the case study studied in this article, through the implementation of traceability technology such as GPS, it is possible to ensure the reliability of inventories and at the same time reduce the losses associated with the lack of visibility of assets along the supply chain. The use of massive data of GPS positions, in the assets of the company, also allowed to detect bottlenecks, achieving greater efficiency in logistics operations.

Acknowledgement
This article was supported by PRODEP Universidad Autonoma del Estado de Hidalgo [grant number UAEH-EXB-152].

References

[1] TELUKDARIE, A., BUHULAIGA, E., BAG, S., GUPTA, S., LUO, Z.: Industry 4.0 implementation for multinationals, *Process Safety and Environmental Protection,* Vol. 118, No. August, pp. 316-329, 2018. doi:10.1016/j.psep.2018.06.030

[2] PETCHROMPO, S., PARLIKAD, A.: A review of asset management literature on multi-asset systems, *Reliability Engineering and System Safety*, Vol.181, No. January, pp. 181-201, 2019. doi:10.1016/j.ress.2018.09.009

[3] BASOLE, R., NOWAK, M.: Assimilation of tracking technology in the supply chain, *Transportation Research Part E*, Vol. 114, No. June, pp. 350-370, 2018. doi:10.1016/j.tre.2016.08.003

[4] GANDHEWAR, R., GAURAV, A., KOKATE, K., KHETAN, H., KAMAT, H.: Cloud-Based Framework for IoT Application with Asset Management, *Third International Conference on Electronics, Communication, and Aerospace Technology (ICECA),* pp. 920-925, 2019.

[5] FERNANDEZ-CARAMES., T.M., BLANCO-NOVOA, O., SUAREZ-ALBELA, M., FRAGA-LAMAS, P.: A UAV and Blockchain-Based System for Industry 4.0. Inventory and Traceability Applications, *Proceedings (International Electronic Conference on Sensors and Applications)*, pp. 1-7, 2019. doi:10.3390/ecsa-5-05758

[6] PITTMAN, P., ATWATER, Y.: *APICS Dictionary*, 15th Edition, APICS, Chicago. 2016.

[7] BSI. British Standards Institute, PAS55:2008-1:2008: *Specification for the optimized management of physical assets*. 2008.

[8] METSO, L., KANS, M.: An ecosystem perspective on asset management information, *Proceedings of MPMM 2016. Sweden*, 2017. doi:10.1515/mspe-2017-0022

[9] MALETIČ, D., MALETIČ, M., AL-NAJJAR, B., GOMISCEK, B.: Development of a Model Linking Physical Asset Management to Sustainability Performance: An Empirical Research, *Sustainability,* Vol. 10, No. 12, pp. 1-20, 2018. doi:10.3390/su10124759

[10] HASTINGS, N.A.: *Physical asset management*. Springer, London. 2010.

[11] LIMA, E. S., COSTA, A.: Improving Asset Management under a regulatory view, *Reliability Engineering and System Safety*, Vol. 190, No. October, pp. 143-160. 2019. doi:10.1016/j.ress.2019.106523

[12] NEL, C.B.H., JOOSTE, J.L.: A technologically-driven asset management approach to managing physical assets- A literature review and research agenda for smart asset management, *South African Journal of Industrial Engineering,* Vol. 27, No. 4, pp. 50-65, 2016. doi:10.7166/27-4-1478

[13] TANTIK, E., ANDERL, Y R.: Integrated data model and structure for the asset administration shell in Industrie 4.0, *Procedia CIRP*, Vol. 1, pp. 86-91, 2017. doi:10.1016/j.procir.2017.01.048

[14] BOUGDIRA, A., AKHARRAZ, I., AHAITOUF, A.: A traceability proposal for industry 4.0, *Journal of Ambient Intelligence and Humanized Computing,* pp. 125-139. 2019. doi:10.1007/s12652-019-01532-7

[15] HALAWA, F., DAOUD, H., LEE, I., LI, S.W., YOON, Y., CHUNG, S.: Introduction of a real time location system to enhance the warehouse safety and operational efficiency, *International Journal of Production Economics,* Vol. 224, No. June, pp. 1-21, 2020. doi:10.1016/j.ijpe.2019.107541

[16] BISIO, I., SCIARRONE, A., ZAPPATORE, S.: A new asset tracking architecture integrating RFID, Bluetooth Low Energy tags and ad hoc smartphone applications, *Pervasive and Mobile Computing*, Vol.

31, No. September, pp. 79-93, 2016. doi:10.1016/j.pmcj.2016.01.002

[17] LOUW, L., WALKER, M.: Design and implementation of a low-cost RFID track and trace system in a learning factory. In D. Mourtzis & G. Chryssolouris (Eds.), *8th Conference on Learning Factories - Advanced Engineering Education & Training for Manufacturing Innovation*, Vol. 23, pp. 255-260, 2018. doi:10.1016/j.promfg.2018.04.026

[18] TSAI, M. H., PAN, C., WANG, C., CHEN, J., KUO, C.: RFID Medical Equipment Tracking System Based on a Location-Based Service Technique, *Journal of Medical and Biological Engineering*, Vol. 39, No. September, pp.163-169, 2019. doi:10.1007/s40846-018-0446-2

[19] PARK, J. W., CHEN, J., CHO, Y K.: Self-corrective knowledge-based hybrid tracking system using BIM and multimodal sensors, *Advanced Engineering Informatics*, Vol. 32, No. April, pp. 126-138, *2017. doi:*10.1016/j.aei.2017.02.001

[20] BEN-DAYA, M., HASSINI, E., BAHROUN, Z.: Internet of things and supply chain management: a literature review, *International Journal of Production Research*, Vol. 57, No. 15-16, pp. 4719-4742, 2017. doi:10.1080/00207543.2017.1402140

[21] ZHONG, R.Y., XU, X., KLOTZ, E., NEWMAN, S.: Intelligent Manufacturing in the Context of Industry 4.0: A Review, *Engineering*, Vol. 3, pp. 616-630, 2017. doi:10.1016/J.ENG.2017.05.015

[22] LEE, I., LEE, K.: The Internet of Things (IoT): Applications, Investments, and Challenges for Enterprises, *Business Horizons*, Vol. 58, No. 4, pp. 431-440, 2015. doi:10.1016/j.bushor.2015.03.008

[23] SUBRAHMANYA-TEJESH, S.B., NEERAJA, S.: Warehouse inventory management system using IoT and open-source framework, *Alexandria Engineering Journal*, Vol. 57, No. 4, pp. 3817-3823, 2018. doi:10.1016/j.aej.2018.02.003

[24] CYPLIK, P., OLESKOW-SZLAPKA, J., TOBOLA, A., ADAMCZAK, M.: Building a model for assessing the maturity of polish enterprises in terms of logistics 4.0 assumptions, *Procedia International Scientific Conference Business Logistics in Modern Management*, pp. 105-120, 2019.

[25] CAMPOS, J., SHARMA, P., GOROSTEGUI-GABIRIA, U., JANTUNEN, E., BAGLEE, D.: A big data analytical architecture for the Asset Management, *Procedia CIRP*, Vol. 64, pp. 369-374, 2017. doi:10.1016/j.procir.2017.03.019

[26] RONG, K., HU, G., LIN, Y., SHI, Y., LIANG, L.: Understanding business ecosystem using a 6C framework in internet-of-Things-based sectors, *International Journal of Production Economics*, Vol. 159, No. January, pp. 41-55, 2015. doi:10.1016/j.ijpe.2014.09.003

[27] KANS, M., GALAR, D., THADURI, A.: Maintenance 4.0 in Railway Transportation Industry, *Proceedings of the 10th World Congress on Engineering Asset Management (WCEAM 2015)*, Vol. 3, pp. 317-331, 2016. doi:10.1007/978-3-319-27064-7_30

[28] VINITYSOFT.: Tool & Asset Manager. [Online], Available: https://www.vinitysoft.com/tool-asset-management-software/, [24 May 2019], 2019.

Review process

Single-blind peer review process.