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Smart Manufacturing for Industry 4.0 using Radio Frequency Identification (RFID) Technology

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ABSTRACT

Industry 4.0 (I4.0) presents a unique challenge of efficiently transforming traditional manufacturing to smart and autonomous systems.Integrating manufacturing systems, materials, machinery, operators, products and consumers, improve interconnectivity and traceability across the entire product life cycle in order to ensure the horizontal and vertical integration of networked Smart Manufacturing (SM) systems. Manufacturing functions of Material Handling (MH)-control, storage, protection and transport of raw materials, work in process (WIP) and finished products- throughout a manufacturing and distribution process will need a revamp in ways they are currently being carried in order to transition them into the SM era. Radio Frequency Identification (RFID), an Automated Identification Data Capture (AIDC) technology increasingly being used to enhance MH functions in the (SM) industry, due to opportunities it presents for item tracking, out of sight data capturing, navigation and space mapping abilities. The technology readiness level of RFID has presented many implementation challenges as progress is being made to fully integrate the technology into the preexisting MH functions. Recently, many researchers in academia and industry have described various methods of using RFID for improving and efficiently carrying out MH functions as a gradual transition is being made into I4.0 era. This paper reviews and categorize research finding regarding RFID application developments according to various MH functions in SM, tabulates how various I4.0 enablers are needed to transform various traditional manufacturing functions into SM. It aims to let more experts know the current research status of RFID technology and provide some guidance for future research.

Keywords: Industry 4.0; radio frequency identification; smart manufacturing; material handling

INTRODUCTION

Industry 4.0 (I4.0) brings Computerization and Interconnection of manufacturing materials and equipment's into traditional manufacturing by enhancing it with smart and autonomous systems fueled by data and machine learning (Bernard Marr 2018). Industry 4.0 aims to employ high level of automation and interconnection between the physical and virtual world -Cyber Physical Production System (CPPS)- to attain higher level of operational productivity and efficiency in manufacturing execution and material handling functions (Alcácer & Cruz-Machado 2019; Rajput & Singh 2019). Smart manufacturing, Smart Factories, Smart Products etc. are closely related terms to Industry 4.0 that are used to describe the future of manufacturing that allows for enhanced flexibility in production; achieved through automation of production processes, seamless data transmission throughout a manufacturing and supply chain which consequently leads to increased product variety, efficient use of manufacturing resources and reduced carbon emissions.

Industry 4.0 comprises of nine key technologies (Alcácer & Cruz-Machado 2019) illustrated in figure And the implementation of RFID technology as an enabler of I4.0 is a sub category of Internet of Manufacturing Things (IoMT or IoT).

I4.0 characterizes the horizontal and vertical integration of networked manufacturing systems through value networks and the end-to-end digital integration of engineering (Henning 2013) enabled via cyber- physical systems (CPS), Internet of Things (IoT), and cloud computing (Ding et al.

FIGURE 1: Key Pillars of Industry 4.0

2018). In a CPPS, former manufacturing architecture will be equipped with I4.0 enablers to make them self-aware (aware manufacturing), so they carry out simple or complicated logical task and make manufacturing execution decisions (Azouz & Pierreval 2019; Bagheri et al. 2015; Gräßler et al. 2016) autonomously.

Main elements of Cyber Physical Systems like adaptability, plug and produce, decentralization, digitalization are controlled via RFID and other Automated Identification and Data Capture (AIDC) enablers. RFID plays an important role in data acquisition systems, tracking of material flow on shop floors and through-out the distribution phase of the product. RFID when implemented in manufacturing firms, enables them achieve complex production system and to perform better life cycle assessment of their products (Fet et al. 2013).

A next generation of RFID technology application is presented by Siemens SIMATIC RF600 technology with built-in OPC UA interoperability that opens doors to new applications to manufacturers. With Siemens MindSphere and Internet of Things (IoT) cloud application the SIMATIC RF600 is poised to enable a global platform for managing field- level data across wide geographic expanses, while also applying advanced analytics for real-time asset visibility and predictive capabilities to support more informed and faster decision making (Li et al. 2018).

Published documents in the recent decade have been collected from Scopus database (Figure 2) which shows the growing trend in academia and industry research regarding RFID technology application in the scope of Industry 4.0, Smart Manufacturing and Smart Products.

RFID SYSTEM

RFID, arguable the most manufactured device (Jacob & Thiemann, 2017) and a key AIDC component in the manufacturing industry, serves various functions of monitoring the constant changes of position, manufacturing process stages, and other attributes of tagged objects etc. (Ding et al. 2017).

1. A typical RFID system comprises of three components:
2. An active or passive tag which is a tiny programmable electronic circuit - that holds the Electronic Product Code (EPC) and other information to be transmitted about a product
3. A tag reader which comprises of an antenna and transceiver which communicate with RFID tags and transfer the information to the processing devices.And, A host data processing system (Huang et al. 2011).

Communication established between a reader and the tag is generally distributed to a remote database for information storage and processing purposes (Duroc & Tedjini 2018).

The main difference between RFID tags is in their powering method. Table 1 shows distinguishing characteristic features between passive and active RFID tags, and other application differences. An operating characteristic disadvantage of RFID tags is, they require continuous signal from a reader to provide continuous real time location of tagged objects (Lee & Park 2019).

TABLE 1. Classification of RFID Tags by Powering Method and Application (Todorovic et al. 2014) (Kuhn et al. 2016) (Jia et al. 2019)

Tags	Powering Method	Operating Frequency (Range)	Application	Typical Industry (ISO Number)
Active	Contain on board battery	400-960 MHz (> 10m) 2.45-5.8 GHz (>100m)	High Perimeter / Geo-Location tracking, Shop floor mapping, Data Storage etc.,	Manufacturing logistics (ISO 15459), Construction/ Mining Sites (ISO 18047), Army, Shipping Airlines (ISO 18000), etc.,
Passive	Electric field generated by reader antenna (See Figure 3)	125-135 kHz (<0.5m), 13.56 MHz (< 1.0m), 400-960 MHz (<10m)	Access Control, Theft Prevention, Low perimeter Object tracking.	Farming (ISO 11784), Security, Brewery, Pharmaceutical, Health, etc.,

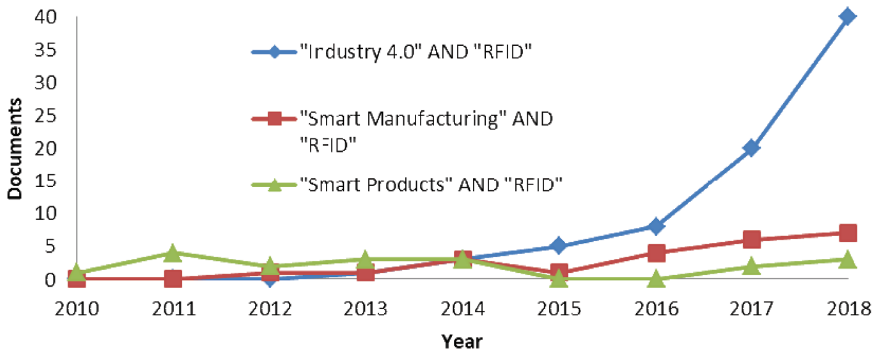

FIGURE 2. Statistic from Scopus database in Published documents by year search keywords: (TITLE-ABS-KEY ("Industry 4.0" AND "RFID") AND TITLE-ABS-KEY ("Smart Manufacturing" AND "RFID") AND TITLE-ABS-KEY ("Smart Products"AND "RFID") AND PUBYEAR > 2009 (Scopus - Sources, 2019)

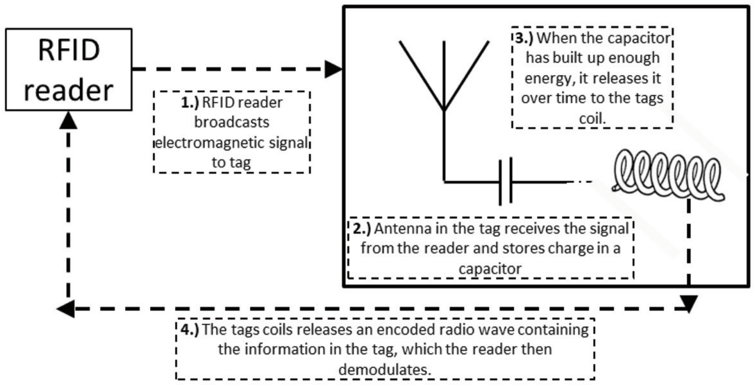

FIGURE 3. Illustration of Retrieving Data from a Passive RFID tag adapted from (Todorovic et al. 2014)

RFID systems are designed to operate on different frequencies depending on the size and sensitivity of data to be read and in what environmental condition reading will be done (Todorovic et al. 2014). Generally, the operating frequency of well-established RFID technology ranges from 125KHz to several GHz though the standard Industrial, Scientific and Medical (ISM) operating range of RFID is in the Super High Frequency (SHF) band around 5.8GHz. Table 1 shows various operating radio frequency ranges of RFID and their various applications adapted from (Kuhn et al. 2016) and ISO standards for RFID to improve compatibility across various Industry sectors (Jia et al. 2019).

Amongst other AIDC technologies used in the manufacturing industry, RFID introduces several advantages over barcoding in that its operation does not require line-of-sight, clean environments, and the stored data are modifiable (Motamedi et al. 2013). Unlike barcodes that provide categorical-level information, RFID technology facilitates distinguishing individual items through unique EPC values (Zhou & Piramuthu, 2013). Barcodes still dominate the market due to their low cost as compared to RFID. However, due to the numerous advantages of RFID systems compared to barcodes and to a further extent, traditional labels (Costa et al. 2013), RFID systems are now beginning to conquer new mass markets.

TABLE 2. Key Enablers needed to transition Traditional Manufacturing functions into Smart Manufacturing for Industry 4.0

Traditional Manufacturing	Enablers	Smart Manufacturing	References
Automated Machines	RFID, Wireless Sensor Networks (WSN), IoT	Interoperability, Human Robot Collaboration, Cyber Physical Systems (CPS)	(Gräßler et al. 2016; Gräßler & Yang, 2016; Zhang et al. 2011)
Monitoring of Manufacturing Processes, Location Systems	RFID, UWB, GPS	Real Time Location Service (RTLS), Product Visibility	(Lu et al. 2018; Z. Yang et al. 2016)
Product Information	RFID, Cloud Storage, IoT	Big Data Production, Decentralization, Product End of Life Management	(Åkerman et al. 2016; Zhong et al. 2015)
Material Processing, Transport and Safety	RFID, Global Positioning System (GPS), IoT	Automated Product Storage and Retrieval, Automated Guided Vehicle (AGV) Navigation Systems, Status Monitoring of Perishable Goods, Automated Route Sheet Development	(Lu et al. 2018; Zhai et al. 2017)
Production Resources, Workshop Environment	GPS, RFID, WSN, UWB	Smart Manufacturing Objects (SMO's), Ubiquitous Manufacturing Environment, Digital Workshop Maps Virtualization	(S. Huang et al. 2017; Z. Yang et al. 2016; Zhang et al. 2011; Zhong et al. 2015)
Consumer demand, Enterprises, Retailers, Complex Product/ Information flow,	IoT, RFID, Cloud Service, Big Data		
Inventory Control, Consumer Product Goods (CPG)		Socialized Manufacturing Resources (SMRs), Service Oriented Manufacturing	(Zhang et al. 2011; Zhong et al. 2015)
Pallets, Warehouse Management	RFID, Big Data	Mass Customization Production, Smart Shelves, Fast Moving Consumer Goods (FMCG)	(Zhong et al. 2013)
Just In Time (JIT) Manufacturing			
	RFID, UWB	Smart Routing, ASRS, Automated Identification	(Bechtsis et al. 2018)
	IoT, RFID	Dynamic Just In Time (JIT) Manufacturing	(Xu & Chen, 2016)

MOTIVATION FOR RFID INTEGRATED MANUFACTURING

With Germany's proposed "industry 4.0" plan (Alcácer & Cruz-Machado 2019; Wagner et al. 2017), Intelligent/ Smart Manufacturing has become a key objective of the current manufacturing industry's development. The ripple effect of Internet of things (IoT) in the tech industries coupled with the growth of complex customer demands has pushed for advancements in old manufacturing methods to enter a new age of Internet of Manufacturing Things (IoMT) (S. Huang et al. 2017). Among other enablers of IoMT such as Wireless Network Sensors (WNS), Artificial intelligence (AI), Virtual Reality (VR), Holographic Workshop Map (HWM) Block Chain, (Rajput & Singh 2019) etc., and their functions, Manufacturing Objects (MO) tracking, monitoring of manufacturing resources and Real-Time Location System (RTLS) is developed on the basis of Radio Frequency Identification (RFID) and Ultra Wide Band (UWB) (S. Huang et al. 2017; Lee & Park 2019; Liu et al. 2019).

shows how RFID and other I4.0 enablers can be used to help transition traditional manufacturing functions into SM.

In the following sections, the roles of RFID in various material handling/manufacturing functions are briefly introduced and implementation methods discussed by various researchers are summarized in Table 3 Research summary of RFID Implementation examples in Material Handling functions to enable I4.0

RFID IN MANUFACTURING: AN INDUSTRY 4.0 ENABLER.

In this section, various roles of RFID as an industry 4.0 enabler in manufacturing and material handling functions such as; *Material transport/logistics, Material Inventory, Manufacturing Planning and Control, Manufacturing Execution Systems and Material End of Life Management* are briefly introduced.

A comprehensive review of research made into each functions mentioned above are categorized in Table 3. Research summary of RFID Implementation examples in Material Handling functions to enable I4.0

Material transport is a major focus point in improving productivity in today's product diversified manufacturing organizations (Ghadimi et al. 2019). Companies that want to remain competitive must constantly control and improve manufacturing performance through employing efficient means of controlling material flow throughout a manufacturing plants (Arkan et al. 2013). In the era of Internet of Manufacturing Things(IoMT), Intelligent/Autonomous Guided Vehicles (IGVs/AGVs) are innovations that could assist efficiently management of material handling transport and logistics in and out of manufacturing floors, and other sectors/ industries such as container terminals, in agriculture and healthcare.

Inventory control in large manufacturing industries, raw material and WIP process flow through the manufacturing floor generates large quantity of complex data that are difficult to manage with current traditional means. Also the possibility of information distortion on a large scale due to data inaccuracy and mismanagement arises (Chongwatpol & Sharda, 2013). Furthermore, financial impacts of inventory inaccuracy suffered by manufacturing firms include not only the cost of direct inventory loss but also the increasing holding and shortage cost (Qin et al. 2017). In various means to curb inventory inaccuracy by implementing RFID are presented.

While typical traditional *Manufacturing Execution systems (MES)* using traditional indoor positioning algorithms face several difficulties in tracking MOs for IoMT, MES inI4.0 monitors efficiently various MOs in dynamic shop floors by leveraging the efficiency of information flow across functional layers for planning and control (Z. Yang et al. 2016) enabled by various I4.0 enablers presented in

Finally, implementing RFID in *Material End of Life Management* presents opportunities for manufacturers to recover information about their produce after it has reached a consumer's end. As A.K. Parlikad et al. in a study pointed that fundamental obstacle in making efficient product recovery decisions is the loss of information associated with the product after the point-of-sale (Parlikad & McFarlane, 2007). With the right information collected available to manufactures after a product life span, EOL management such as product recovery decisions such as remanufacturing of products when possible (Zhou & Piramuthu, 2013), enabling proper disposal of product to reduce carbon footprints, etc., becomes possible.

CONCLUSION

This review attempts to contribute to the growing discussion concerning a new industrial revolution trend. RFID implementation methods being used to transform preexisting production machines and manufacturing functions to fit into the context of industry 4.0 are discussed. RFID could be said to be a forerunner for IoT (Åkerman et al. 2016), CPS, IoS, and on a broader view a very key component in building Smart Manufacturing systems and achieve the goal of industry 4.0. The presented works on implementations of RFID in this review is clear proof that, as the technology readiness of RFID increases, a full implementation of the technology in our current manufacturing functions will in no time allow us achieve the full transition into the next era of the industrial revolution. Regarding future works and the way forward, it became evident after gathering and classifying research used for this study, that despite the possibilities and opportunities of RFID discussed in this paper, RFID generally have reliability/stability issues, problematic when it comes to large scale implementation and requires a personnel's with high skills of technical knowhow in order to manage efficiently. Hence further research and implementation experiments are still required for the technology in order to harness its full potential. From a proof of concept trial the use of RFID technology to

TABLE 3. Research summary of RFID Implementation examples in Material Handling functions to enable I4.0

Material Handing Function	RFID Implementation	References
Product Safety; Data & Manufacturing Resource Protection	• Improved equipment utilization, reduce medical error and reduce disruption in medical procedures by ensuring equipment location availability. • Monitor location of mining staff underground where ultra-high frequency network are not distorted by mining conditions. • Monitor and alert Staff about appropriate Personal Protective Equipment (PPE) in various sections on a manufacturing floor. • Quality control of tagged perishable items in inventory. • Tractability of raw material through production to distribution supply chain. • Mutual encryption of product Data embedded in a tag using Pseudo-Random Number Generators encryption. • Decentralization method of storing plant process data and ease of accessibility without external network connection.	(Qu et al. 2011) (Wei, Zhu, & Du, 2011) (Bauk, Schmeink, & Colomer, 2016) (Ichwani et al. 2018) (Costa et al. 2013) (Bibi et al. 2017; Steinberg et al. 2014) (Che, et al. 2008) (Segura et al. 2016)
Material Inventory and Transport;	• Rationalizing material movement within manufacturing floors while enabling visualization of material activities in real time. • Location and tracking of vehicles in a holding lot through pre-delivery process while recording each process operation in a tag. • Handling cargo with high value of time to enhance reduction in shipping time, inventory, operation and labor cost. • RFID enabled Smart shelves to automatically update a manufacturer or retailer of inventory level and state of raw materials or Consumer goods. • RFID enabled Shopping cart to automatically bill customers of selected items and alert retailers to restock shelves of particular fast moving consumer goods. • RTLS based on RFID and UWB for work shop mapping for AGVs to achieve new workshop visibility level and process control. • RFID Security Clearance for controlling personnel access to company and product information or data. • RFID enabled manufacturing objects converting them into Smart Manufacturing Objects to create a Ubiquitous Environment to support logistics management.	(Dai et al. 2012; Zhong et al.2015) (Ilie-Zudor, Kemény, Van Blommestein, Monostori, & Van Der Meulen, 2011) (Hsu, Shih, & Wang, 2009) (Zhu et al. 2012) (Yewatkar et al. 2016) (S. Huang et al. 2017) (Sarac et al. 2010) (Kuzmina et al. 2019) (Zhang et al. 2011; Zhong et al. 2015) (Zhang et al. 2011)
Planning and Control	• Implemented Visibility Based Scheduling for tracking of raw material and WIPs to adjust production process and inventory restocking based on RFID. • Implemented RFID and IoT to facilitate JIT manufacturing by improving information sharing between stakeholders to form dynamic JIT. • RFID enabled physical objects tracking in a production system to improve efficient Job Scheduling. • Tagged raw materials and WIPs through manufacturing process to enable recreation of carried out processes in a virtual domain to study, develop efficient means of carrying out manufacturing processes, analyze accidents after they occur for future prevention.	(Chongwatpol & Sharda, 2013) (Thiesse & Fleisch, 2008) (Iacovidou et al. 2017)
Manufacturing Execution Systems	• Modularized and flexible framework for an RFID middleware system to improve shop floor planning, execution and control in a Ubiquitous manufacturing enterprise. • Shop floor mapping method for real time manufacturing execution system utilizing Online Sequential – Extreme Machine Learning. • RFID real time MES for Mass Customization Production (MCP) shop floor management, manufacturing data collection, real time scheduling and WIP tracking. • RFID and Hybrid Flow Shops	(Fang et al. 2013) (Z. Yang et al. 2016) (Zhong et al. 2013) (Zhong et al. 2013)
End Of Life (EOL)	• RFID enabled in products to collect information for product end of life assessment. • Data collected from RFID enabled FMCG are used to estimate number of a particular FMCG needed to be produced for a particular locality to reduce over production. • Possibility of RFID enabled product containers recovered for reuse in a closed loop supply chain management.	(Parlikad & McFarlane, 2007) (Kuzmina et al. 2019) (Manavalan & Jayakrishna, 2019; T. Yang et al. 2018)

measure microenterprises turnover, S. de Mel et al. pointed out some technical challenges in the actual implementation of RFID in real life. It was discovered that;

RFID-technology is more difficult to use, and more time-consuming to employ, than envisaged (De Mel et al. 2016),

RFID technology works reasonably well for paper products, but very poorly for most products sold by microenterprises (De Mel et al. 2016) and Gjeldum N et al. Also specifically reported after carrying out a Performance analysis of an RFID implemented system that; for higher quantity of data an RFID system could result in very bad performance (Gjeldum et al. 2018) if data collected is not properly implemented. Similarly Raput et al. listed RFID as a challenge of linking Industry 4.0 and current Circular Economy due to challenges RFID poses when collecting large amount of data (Rajput & Singh, 2019; Schütze et al. 2018). Conclusively, the side effects of human workers to RFID radio waves over a long period of time have been discussed in (Mladineo et al. 2019) and various measures of lowering health hazards have been proposed such as; taking into account limited performance of RFID read and write heads during the design phase of a manual assembly workstation (Gjeldum et al. 2018). Furthermore, (Arumugam & Engels 2008) performed a study quantifying the Specific Absorption Rate (SAR) of the human body when exposed to RFID radio waves. Their study presented a visual way of quantifying SAR impacts of various power output for a 7.4dB RF antenna in terms of distances to the human head.

REFERENCES

Åkerman, M., Fast-Berglund, Å. & Ekered, S. 2016. Interoperability for a Dynamic Assembly System. *Procedia CIRP* 44: 407-411.

Alcácer, V. & Cruz-Machado, V. 2019. Scanning the Industry 4.0: A Literature Review on Technologies for Manufacturing Systems. *Engineering Science and Technology, an International Journal* 22(3): 899-919.

Arkan, I. & Van Landeghem, H. 2013. Evaluating the performance of a discrete manufacturing process using RFID: A case study. *Robotics and Computer-Integrated Manufacturing*, *29*(6): 502-512.

Arumugam, D. D. & Engels, D. W. 2008. Impacts of RF Radiation on the Human Body in a Passive RFID Environment. *IEEE Antennas and Propagation Society International Symposium* 12(1): 8-11.

Azouz, N. & Pierreval, H. 2019. Adaptive smart card-based pull control systems in context-aware manufacturing systems: Training a neural network through multi-objective simulation optimization. *Applied Soft Computing Journal* 75: 46-57.

Bagheri, B., Yang, S., Kao, H. A. & Lee, J. 2015. Cyber-physical Systems Architecture for Self-Aware Machines in Industry 4.0 Environment. *IFAC-PapersOnLine* 48(3): 1622-1627.

Bauk, S., Schmeink, A. & Colomer, J. 2016. An RFID model for improving workers' safety at the seaport in transitional environment. *Transport* 33(2): 353-363. 512

Bechtsis, D., Tsolakis, N., Vlachos, D., & Srai, J. S. 2018. Intelligent Autonomous Vehicles in digital supply chains: A framework for integrating innovations towards sustainable value networks. *Journal of Cleaner Production* 181: 60-71.

Bernard Marr. (2018). What is Industry 4.0? Here's A Super Easy Explanation For Anyone. https://www.forbes.com/sites/bernardmarr/2018/09/02/what-is-industry-4-0-heres-a-super-easy-explanation-for-anyone/#2294b3a09788 [22 May 2019]

Bibi, F., Guillaume, C., Gontard, N. & Sorli, B. 2017. A review: RFID technology having sensing aptitudes for food industry and their contribution to tracking and monitoring of food products. *Trends in Food Science and Technology* 62: 91-103.

Che, W., Deng, H., Tan, W. & Wang, J. 2008. A Random Number Generator for Application in RFID Tags. *Networked RFID Systems and Lightweight Cryptography*: 279-287. Springer Berlin Heidelberg.

Chongwatpol, J. & Sharda, R. 2013. RFID-enabled track and traceability in job-shop scheduling environment. *European Journal of Operational Research* 227(3): 453-463. https://doi.org/10.1016/j.ejor.2013.01.009

Costa, C., Antonucci, F., Pallottino, F., Aguzzi, J., Sarriá, D. & Menesatti, P. 2013. A Review on Agri-food Supply Chain Traceability by Means of RFID Technology. *Food and Bioprocess Technology* 6(2): 353-366.

Dai, Q., Zhong, R., Huang, G. Q., Qu, T., Zhang, T. & Luo, T. Y. 2012. Radio frequency identification-enabled real-time manufacturing execution system: a case study in an automotive part manufacturer. *International Journal of Computer Integrated Manufacturing* 25(1): 51-65.

De Mel, S., Herath, D., McKenzie, D. & Pathak, Y. 2016. Radio frequency (un)identification: Results from a proof-of-concept trial of the use of RFID technology to measure microenterprise turnover in Sri Lanka. *Development Engineering* 1: 4-11.

Ding, K., Jiang, P. & Su, S. (2018). RFID-enabled social manufacturing system for inter-enterprise monitoring and dispatching of integrated production and transportation tasks. *Robotics and Computer-Integrated Manufacturing* 49: 120-133.

Ding, K., Jiang, P., Sun, P. & Wang, C. 2017. RFID-Enabled Physical Object Tracking in Process Flow Based on an Enhanced Graphical Deduction Modeling Method. *IEEE Transactions on Systems, Man, and Cybernetics: Systems* 47(11): 3006-3018.

Duroc, Y. & Tedjini, S. 2018. La RFID: une technologie clé au service de l'humanité. *Comptes Rendus Physique* 19: 64-71.

Fang, J., Qu, T., Li, Z., Xu, G. & Huang, G. Q. 2013. Agent-based Gateway Operating System for RFID-enabled ubiquitous manufacturing enterprise. *Robotics and Computer-Integrated Manufacturing* 29(4): 222-231.

Fet, A. M., Margrethe Aspen, D. & Ellingsen, H. 2013. Systems engineering as a holistic approach to life cycledesigns. *Ocean Engineering* 62: 1-9.

Ghadimi, P., Wang, C., Lim, M. K. & Heavey, C. 2019. Intelligent sustainable supplier selection using multi-agent technology: Theory and application for Industry 4.0 supply chains. *Computers and Industrial Engineering* 127: 588-600.

Gjeldum, N., Mladineo, M., Crnjac, M., Veza, I. & Aljinovic, A. 2018. Performance analysis of the RFID system for optimal design of the intelligent assembly line in the learning factory. *Procedia Manufacturing* 23(2017): 63-68.

Gräßler, I., Pöhler, A. & Pottebaum, J. 2016. Creation of a Learning Factory for Cyber Physical Production Systems. *Procedia CIR*, 54: 107-112.

Gräßler, I. & Yang, X. 2016. Interdisciplinary Development of Production Systems Using Systems Engineering. *Procedia CIRP* 50: 653-658.

Hsu, C. I., Shih, H. H. & Wang, W. C. 2009. Applying RFID to reduce delay in import cargo customs clearance process. *Computers and Industrial Engineering* 57(2): 506-519.

Huang, S., Guo, Y., Zha, S., Wang, F. & Fang, W. 2017. A Real-time Location System Based on RFID and UWB for Digital Manufacturing Workshop. *Procedia CIRP* 63: 132-137.

Huang, Y., Williams, B. C. & Zheng, L. 2011. Reactive, model-based monitoring in RFID-enabled manufacturing. *Computers in Industry* 62: 811-819.

Iacovidou, E., Purnell, P. & Lim, M. K. 2017. The use of smart technologies in enabling construction components reuse: A viable method or a problem creating solution? *Journal of Environmental Management* 216: 214-223. 3

Ichwani, S. N., Wulandari, R., Septiani, W. & Astuti, P. 2018. Model of refrigerated display-space allocation for multi agro-perishable products considering markdown policy. *IOP Conference Series: Materials Science and Engineering* 337: 012019

Ilie-Zudor, E., Kemény, Z., Van Blommestein, F., Monostori, L. & Van Der Meulen, A. 2011. A survey of applications and requirements of unique identification systems and RFID techniques. *Computers in Industry* 62(3): 227-252.

Jacob, P. & Thiemann, U. 2017. New ESD challenges in RFID manufacturing. *Microelectronics Reliability* 76: 395-399.

Jia, M., Komeily, A., Wang, Y. & Srinivasan, R. S. 2019. Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications. *Automation in Construction* 101: 111-126.

Kagermann, H., Helbig, J., Hellinger, A., & Wahlster, W. (2013). *Recommendations for implementing the strategic initiative INDUSTRIE 4.0: Securing the future of German manufacturing industry; final report of the Industrie 4.0 Working Group*. Forschungsunion. https://books.google.com.cy/books?id=AsfOoAEACAAJ.

Kuhn, P., Schmidt, P., Meyer, F. & Grabmaier, A. 2016. Comparison on Powering Passive Sensor RFID via Variation of Modulation Indexes. *Procedia Engineering* 168: 1626-1629.

Kuzmina, K., Prendeville, S., Walker, D. & Charnley, F. 2019. Future scenarios for fast-moving consumer goods in a circular economy. *Futures* 107: 74-88.

Lee, Y. J. & Park, M. W. 2019. 3D tracking of multiple onsite workers based on stereo vision. *Automation in Construction* 98: 146-159.

Li, J.-Q., Yu, F. R., Deng, G., Luo, C., Ming, Z., & Yan, Q. (2017). Industrial internet: A survey on the enabling technologies, applications, and challenges. *IEEE Communications Surveys & Tutorials,* 19(3): 1504-1526.

Liu, S., Zhang, Y., Liu, Y., Wang, L. & Wang, X. V. 2019. An 'Internet of Things' enabled dynamic optimization method for smart vehicles and logistics tasks. *Journal of Cleaner Production* 215: 806-820.

Lu, S., Xu, C., Zhong, R. Y., & Wang, L. (2018). A passive RFID tag-based locating and navigating approach for automated guided vehicle. *Computers and Industrial Engineering*, 125: 628-636.

Manavalan, E. & Jayakrishna, K. (019. A review of Internet of Things (IoT) embedded sustainable supply chain for industry 4.0 requirements. *Computers and Industrial Engineering* 127: 925-953.

Mladineo, M., Veza, I., Gjeldum, N., Crnjac, M., Aljinovic, A. & Basic, A. 2019. Integration and testing of the RFID-enabled Smart Factory concept within the Learning Factory. *Procedia Manufacturing* 31: 384-389.

Motamedi, A., Soltani, M. M., & Hammad, A. (2013). Localization of RFID-equipped assets during the operation phase of facilities. *Advanced Engineering Informatics* 27(4): 566-579.

Parlikad, A. K. & McFarlane, D. 2007. RFID-based product information in end-of-life decision making. *Control Engineering Practice* 15(11): 1348-1363.

Qin, W., Zhong, R. Y., Dai, H. Y. & Zhuang, Z. L. 2017. An assessment model for RFID impacts on prevention and visibility of inventory inaccuracy presence. *Advanced Engineering Informatics* 34: 70-79.

Qu, X., Simpson, L. T. & Stanfield, P. 2011. A model for quantifying the value of RFID-enabled equipment tracking in hospitals. *Advanced Engineering Informatics* 25(1): 23-31.

Rajput, S., & Singh, S. P. 2019. Connecting circular economy and industry 4.0. *International Journal of Information Management* 49: 98-113.

Sarac, A., Absi, N. & Dauzere-Pérès, S. 2010. A literature review on the impact of RFID technologies on supply chain management. *International Journal of Production Economics* 128(1): 77-95.

Schütze, A., Helwig, N. & Schneider, T. 2018. Sensors 4.0 – smart sensors and measurement technology enable Industry 4.0. Journal of Sensors and Sensor Systems 7(1): 359-371.

Segura Velandia, D. M., Kaur, N., Whittow, W. G., Conway, P. P. & West, A. A. 2016. Towards industrial internet of things: Crankshaft monitoring, traceability and tracking using RFID. *Robotics and Computer-Integrated Manufacturing* 41: 66-77.

Steinberg, M. D., Kassal, P., Tkalčec, B., & Murković Steinberg, I. 2014. Miniaturised wireless smart tag for optical chemical analysis applications. *Talanta* 118: 375-381.

Thiesse, F., & Fleisch, E. 2008. On the value of location information to lot scheduling in complex manufacturing processes. *International Journal of Production Economics* 112(2): 532-547.

Todorovic, V., Neag, M. & Lazarevic, M. 2014. On the usage of RFID tags for tracking and monitoring of shipped perishable goods. *Procedia Engineering* 69:1345-1349.

Wagner, T., Herrmann, C. & Thiede, S. 2017. Industry 4.0 Impacts on Lean Production Systems. *Procedia CIRP* 63: 125-131.

Wei, Q., Zhu, S. & Du, C. 2011. Study on key technologies of Internet of Things perceiving mine. *Procedia Engineering* 26: 2326-2333.

Xu, Y. & Chen, M. 2016. Improving Just-in-Time Manufacturing Operations by Using Internet of Things Based Solutions. *Procedia CIRP* 56: 326-331.

Yang, T., Fu, C., Liu, X., Pei, J., Liu, L. & Pardalos, P. M. 2018. Closed-loop supply chain inventory management with recovery information of reusable containers. *Journal of Combinatorial Optimization* 35(1): 266-292.

Yang, Z., Zhang, P. & Chen, L. 2016. RFID-enabled indoor positioning method for a real-time manufacturing execution system using OS-ELM. *Neurocomputing* 174: 121-133.

Yewatkar, A., Inamdar, F., Singh, R., Ayushya & Bandal, A. 2016. Smart Cart with Automatic Billing, Product Information, Product Recommendation Using RFID & Zigbee with Anti-Theft. *Procedia Computer Science* 79: 793-800.

Zhai, C., Landers, A. & Zhang, B. 2017. An RFID-based solution for monitoring sprayer movement in an orchard/vineyard. *Precision Agriculture* 19(3): 1-20.

Zhang, Y., Huang, G. Q., Qu, T., Ho, O. & Sun, S. 2011. Agent-based smart objects management system for real-time ubiquitous manufacturing. *Robotics and Computer-Integrated Manufacturing* 27(3): 538-549.

Zhong, R. Y., Dai, Q. Y., Qu, T., Hu, G. J. & Huang, G. Q. 2013. RFID-enabled real-time manufacturing execution system for mass-customization production. *Robotics and Computer-Integrated Manufacturing* 29(2): 283-292.

Zhong, R. Y., Huang, G. Q., Lan, S., Dai, Q. Y., Chen, X. & Zhang, T. 2015. A big data approach for logistics trajectory discovery from RFID-enabled production data. *International Journal of Production Economics* 165: 260-272.

Zhou, W. & Piramuthu, S. 2013. Remanufacturing with RFID item-level information: Optimization, waste reduction and quality improvement. *International Journal of Production Economics* 145(2): 647-657.

Zhu, X., Mukhopadhyay, S. K. & Kurata, H. 2012. A review of RFID technology and its managerial applications in different industries. *Journal of Engineering and Technology Management - JET-M* 29(1): 152-167.