Internet of Things Applications in Production Systems

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Abstract: The Internet of Things field has been applied in industries for different purposes. This paper presents a literature review of Internet of Things applications in the production system. A taxonomy with five categories has been employed in this review: Sector, Technology, Production Phase, Practical Application and Benefit. The sectors, technology and production phase where IoT is being introduced practically or theoretically have been identified, and the benefits of IoT in production systems have been collected and classified. This research presents the advantages of applying Internet of Things in production systems, which helps not only production systems managers in practical implementations, but also researchers to identify research gaps for future research.

1 INTRODUCTION

Although no universal definition exists for Internet of Things (IoT), the core concept is that everyday objects can be equipped with identifying, sensing, networking and processing capabilities, which will allow them to communicate with one another, and with other devices and services, over the Internet to achieve some useful objective (Atzori et al., 2010). According to Miorandi et al., (2012), the three main system-level characteristics of IoT are: Anything communicates, Anything is identified and Anything interacts.

New technologies are necessary to apply IoT. Gubbi et al., (2013) identify three more technical components of IoT: (a) Hardware, made up of sensors, actuators and embedded communication hardware; (b) Middleware, in demand storage and computing tools for data analytics; and (c) Presentation, novel easy-to-understand visualisation and interpretation tools which can be widely accessed on different platforms, and can be designed for distinct applications.

Based on a review of the literature, Whitmore et al., (2014) classify IoT applications into the following domains: smart infrastructure, healthcare, supply chains/ logistics, and social applications. In the supply chain/logistics domain, IoT can further improve efficiency in all the supply chain parts: production, distribution, transporting, and etc. The literature includes a few research works about IoT applied to production. This paper reviews them for the purpose of acquiring better knowledge about IoT applied to production, and also about the benefits of these proposals. We expect to show how the application of IoT can help managers of the production system in enterprises. For this review, Section 2 shows the methodology employed, Section 3 explains the taxonomy used to classify the different research works, and Section 4 includes the conclusions drawn from this research.

2 REVIEW METHODOLOGY

The literature on IoT applied to production was searched in scientific-technical bibliographic databases Google Academics and Scopus, which include publishing portals like Elsevier, IEEExplore or Springer. The literature on IoT applied to production was searched in scientific-technical bibliographic databases Google Academics and Scopus, which include publishing portals like Elsevier, IEEExplore or Springer.

The search criteria applied were combinations of “production”, “production system”, “manufacturing” with “Internet of Things”, ”Internet of Manufacturing Things” and “IoT” in the titles and keywords of the papers. In the first search, 31 references were found in the last 4 years (2010-

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2014). These papers were reviewed and 21 references, which actually dealt with the proposal of this paper, were selected. These references were obtained from journals (23,81%), book sections (23,81%) and conferences (52,38%). Table 1 shows the papers found, the difficulties presented in each paper and the proposal to solve them with IoT.

3 TAXONOMY

The taxonomy employed in this review considers five categories. Some of these categories have been proposed after considering that they have been helpful in other production and supply chain reviews like (Mula et al., 2010), (Carnevalli and Miguel, 2008) or (Melo et al., 2009). These categories are:

Sector: this represents the industrial sector where IoT has been applied; e.g., garments, agriculture, etc. Each sector has its own production processes.

Technology: this presents the technologies that have been used to apply IoT.

Production Phase: all the selected references focus on one part of the production system given the complexity of this system. This category indicates the production system phase that the papers have addressed.

Table 1: Literature reviewed.

Author	Problem
Cao et al., (2011)	A new architecture of the toy production material tracking system based on key technologies of IoT
Castro et al., (2011)	A management application architecture based on IoT for the identification and classification of automatic oxygen cylinders to make all the information available during the production process
Cuiyun and Yuanhang (2010)	A study of the influence of an IoT application on production and logistics in an enterprise
Houyou et al., (2012)	Automation systems in manufacturing supported by IoT to support flexibility and agility in manufacturing
Hu et al., (2011)	An IoT monitoring platform to monitor all the critical control points (CCPs) to ensure food safety during a sausage production process
Isenberg et al., (2011)	Research about suitability and cooperation in collaborative production environments for autonomic and agile processes based on IoT and autonomous objects
Lee et al., (2012)	The use of radio frequency identification (RFID) technology to capture real-time data, which is helpful in monitoring resources utilisation during production.
Liu and Xu (2013)	An integrated management framework of a satellite product manufacturing workshop based on IoT
Lvqing (2011)	A mechanical production monitoring system based on IoT technology to replace traditional manual entry method
Meyer et al., (2011)	An approach for a monitoring and control system to enable new ways in which disturbances can be dealt with in order to increase the robustness of overall plan execution
Qu et al., (2012)	A traceability system based on IoT to address the food safety problems of cucumbers
Stephan et al., (2010)	Using Digital Object Memories throughout a product's life cycle by focusing on the production part of the value chain
Vossiek et al., (2010)	Skilful combination of different Auto-ID technologies and the incorporation of sensor data provided by production machinery and control systems
Wang and Chen (2013)	A new manufacturing inventory management model based on IoT technology
Wang and Liu (2014)	Applications of IoT technology to the agricultural products supply chain to improve the operation efficiency of a supply chain of agricultural products
Wuest et al., (2012)	A Product Avatar representation of product lifecycle information of an Intelligent Product on the social network Facebook
Yuan et al., (2013)	Development of a system based on IoT technology to verify that IoT promotes workshop process visualisation developments
Zhang et al., (2014)	The proposed IoMT aims to design an easy-to-deployment infrastructure to form an active sensing manufacturing environment and to timely monitor, control and optimise the production process.
Zhiliang et al., (2013)	A new project that merges Personal Digital Assistant (PDA) in manufacturing shop with Workshop Internet of Things (WIoT).
Zuehlke (2010)	Smart Factory KL, a multi-vendor research and demonstrator facility for smart production technologies based on IoT

Table 2: IoT in production systems: Industrial Sectors.

Sector	Author
General	Cuiyun and Yuanhang (2010), Isenberg et al., (2011), Houyou et al., (2012), Lvqing (2011), Meyer et al., (2011), Wang and Chen (2013), Stephan et al., (2010), Wuest et al., (2012), Yuan et al., (2013), Zhang et al., (2014), Zhiliang et al., (2013), Zuehlke (2010)
Agriculture	Qu et al., (2012), Shengduo and Jian (2012), Wang and Liu, (2014)
Food	Hu et al., (2011)
Toys	Cao et al., (2011)
Garment	Lee et al., (2012)
Metal	Vossiek et al., (2010)
Aerospace	Liu and Xu (2013)
Chemical	Castro et al., (2011)

Practical Application: many research works provide a proposal as to how to apply IoT in production, but they do not apply the proposal to a real company. So this approach indicates if the proposal has been validated in a real situation or not.

Benefit: this category includes the benefits from applying IoT in the production system in accordance with the reviewed literature.

3.1 Sector

Basing on the industrial sector, papers can be classified into a) a general sector (if the paper presents an application in production, but does not specify a sector); or b) a specific sector, where seven industrial sectors were identified: Food, Toys, Garments, Agriculture, Metal, Aerospace and Chemical. Table 2 shows the sectors found and the authors who applied his approach in each sector.

3.2 Technology

According to (Tan and Koo, 2014), there are three kinds of technologies in IoT for data acquisition: two-dimensional code, RFID and sensors. Two-dimensional (2D) codes use black and white pixels laid out on a plane to store information. RFID is a wireless automatic identification technique that uses radio frequency signals to identify a target and to obtain messages. Sensors are objects that can acquire data. This classification has been used as a basis to review the technologies included in the reviewed literature. Table 3 provides the data acquisition technologies to implement IoT.

3.3 Production Phase

According to (Cuatrecasas, 1994), the production

Table 3: IoT in the production system: Technology.

Author	2D codes	RFID	Sensors	Others
Cao et al., (2011)	X	X	X	Servers
Castro et al., (2011)		X	X	6LoWPAN
Cuiyun and Yuanhang (2010)		X		Server
Houyou et al., (2012)			X	Wireless network
Hu et al., (2011)		X	X	Wireless network
Isenberg et al., (2011)		X	X	
Lee et al., (2012)	X	X	X	Mobile Communication Network, Cameras
Liu and Xu (2013)		X	X	Server, Wireless Network, GPRS
Lvqing (2011)	X	X	X	
Meyer et al., (2011)	X	X	X	Three dimensional code, GPS, Wireless network, Server
Qu et al., (2012)		X		3G
Shengduo and Jian (2012)	X	X	X	Video Surveillance Technology, GPS
Stephan et al., (2010)	X	X		Object Memory Server
Vossiek et al., (2010)		X	X	
Wang and Chen (2013)		X	X	
Wang and Liu (2014)		X	X	Wireless and wired network, Server
Wuest et al., (2012)				Social Network
Yuan et al., (2013)		X	X	Wireless Network
Zhang et al., (2014)		X	X	Zigbee
Zhiliang et al., (2013)	X		X	Wireless network, LAN, Server
Zuehlke (2010)		X	X	Bluetooth, Zigbee, Wireless Network

system is composed of three phases: Planning Operation and Control. Planning is composed of Sales Forecasting, Capacity Planning, Production Planning and Production Order and Programming. The Operation phase includes Replenishment and Material and Resources Management, Productive Process and Client Supply. In the control phase, the company must be sure that product requirements have been achieved, which represent Production, Quality and Stock Control.

Table 4: Subphase codes.

Phase	Subphase	Code
Planning	Sales Forecasting	SF
	Capacity Planning	CP
	Production Planning	PP
	Production Order and Programming	PO&P
Operations	Replenishment and Material and Resources Management	R&MRM
	Productive Process	PPS
	Client Supply	CS
Control	Production	PC
	Quality	QC
	Stock	SC

These phases have been used to classify the reviewed based on the production phase that the literature authors have dealt with. Table 4 provides the code of these phases and Table 5 classifies each paper according to the production phase (or phases) where IoT has been applied.

3.4 Practical Application

Five references include real IoT applications for the production area. Lee et al., (2012) apply their proposal in THC, a Hong Kong-based garment manufacturing company. Zhang et al., (2014) presents an industrial case study by applying their proposed event model to a shop floor to analyse its key production performance. Isenberg et al., (2011) design a scenario that illustrates an autonomous assembly system for an automotive tail-light by working with IoT. (Vossiek et al., 2010) do not apply their proposal in any company, but their research is based on real company information. Finally, (Castro et al., 2011) carry out a proposal with collaboration from the operators and/or staff responsible for managing oxygen cylinders.

The benefits of these real applications have been included in the following point.

Table 5: Production phases of the reviewed works.

Author	Planning				Operations			Control		
	SF	CP	PP	PO&P	R&MRM	PPS	CS	PC	QC	SC
Cao et al., (2011)							O	O		
Castro et al., (2011)								O	O	O
Cuiyun and Yuanhang (2010)		X					X	X		
Houyou et al., (2012)						X		X		
Hu et al., (2011)					O		O			
Isenberg et al., (2011)		X	X							
Lee et al. (2012)						O		X	X	
Liu and Xu (2013)							X			
Lvqing (2011)							X			
Meyer et al., (2011)								X	X	O
Qu et al., (2012)							O	O		
Shengduo and Jian (2012)								O	O	
Stephan et al., (2010)								O	O	
Vossiek et al., (2010)							O		O	
Wang and Chen (2013)					X			O		
Wang and Liu (2014)							O			
Wuest et al., (2012)				O				X	O	O
Yuan et al., (2013)								O		
Zhang et al., (2014)					X		X	O		
Zhiliang et al., (2013)						O		O		
Zuehlke (2010)						X		X		
Total	0	2		1	3	4	9	15	7	3

*X represents the phase of the work indicated by the author.
O represents the phase of the work deduced by the content of the paper.

3.5 Benefits

Cuiyun and Yuanhang (2010) identify benefits for the production area into two main groups: 1) benefits related to information management in production, 2) Other benefits in production.

According to this identification, all the benefits found in this review are classified into the following groups.

In the first group, the benefits found are: *unique identifier*, each product has its own identifier in the production system, without repetition*; monitoring reading information*, information is taken automatically and can be supervised; *real-time information*, managers can see all the information on the real status in production; *more accessible information*, managers can take production information and sharing in the easiest way; *improving information quality*, monitoring information is more accurate and free of errors; and *improving transparency information*, it is possible to obtain further information, which was previously hidden.

Table 6: Benefits for production systems.

	Benefits	Acronym
Information	Unique identifier	UI
	Monitoring reading information	MRI
	Real-time information	RTI
	More accessible information	MAI
	Improving information quality	IIQ
	Improving transparency of information	ITI
Other	Reducing production cost	RPC
	Improving quality production	IQP
	Improving efficiency	IE
	Improving service level	ISL
	Better synchronisation of processes	BSP
	Reducing overstocking and understocking	ROU
	Monitoring production	MP
	Better quality product	BQP

Other benefits covers *reducing production costs*, information is of better quality and the waste produced by mistakes in production can be avoided; *improving quality production*, like detecting real-time disturbances; *improving efficiency*, like reducing energy consumption; *improving service level,* with quicker processes and better quality information; *better synchronisation of processes*, due to the real-time information provided; *reducing overstocking and understocking*, transparency-related information avoids possible mistakes in production and allows better control in production; *monitoring production*, due to the intelligence that IoT provides the system with to better control production.

To summarise these benefits, Table 6 provides acronyms of each benefit. Table 7 identifies the papers that deal with these benefits and the percentages of each benefit are represented in the graphs in Figures 1 and 2. These graphs show that the most repeated benefit in the first group (information management) is *real-time information* and the most repeated benefit in the second group (other benefits) is *improving quality production*.

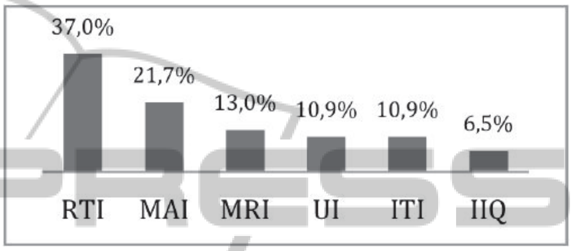

Figure 1: Percentages of benefits in information.

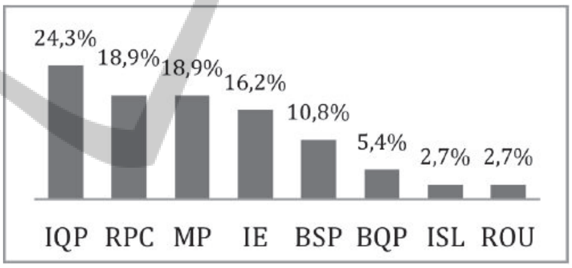

Figure 2: Percentages of other benefits.

Table 8 identifies the benefits in each production phase. The cells inside the table show the number of papers that include the benefit in that phase. The bottom of the table summarises the number of benefits cited in that production phase. Very few papers deal with IoT in the planning and operation production phase, so reported benefits are limited. However, it is important to highlight the capacity planning phase since only two papers deal with this phase, although ten benefits were identified in these papers for this phase. The phase with the most benefits is Client Supply. The benefit that appears the most is Real-Time Information, which appears in eight different phases.

4 CONCLUSIONS

This work reviews IoT applications in production systems. To do this review, a taxonomy based on the

Table 7: Benefits of the reviewed works.

Authors	Benefits in information						Other benefits							
	UI	MRI	RTI	MAI	IIQ	ITI	RPC	IQP	IE	ISL	BSP	ROU	MP	BQP
Cao et al., (2011)	X													
Castro et al., (2011)		X	X	X										
Cuiyun and Y. (2010)	X	X	X	X	X		X	X	X	X				X
Houyou et al., (2012)			X				X	X					X	
Hu et al., (2011)			X	X		X	X				X	X		
Isenberg et al., (2011)			X											
Lee et al., (2012)			X											
Liu and Xu (2013)			X					X					X	
Lvqing (2011)			X											
Meyer et al., (2011)	X		X	X	X			X			X			X
Qu et al., (2012)		X	X	X										
Shengduo and J. (2012)	X	X	X					X	X					
Stephan et al., (2010)			X	X		X	X	X	X		X		X	
Vossiek et al., (2010)					X	X	X	X	X					
Wang and Chen (2013)						X		X	X					
Wang and Liu (2014)			X	X										
Wuest et al., (2012)						X							X	
Yuan et al., (2013)		X	X	X									X	
Zhang et al., (2014)			X	X										
Zhiliang et al., (2013)	X		X				X	X	X		X		X	
Zuehlke (2010)		X	X	X			X						X	
Total Percentage (%)	11	13	37	22	6	11	19	24	16	3	11	3	19	5

Table 8: Benefits in each production phase of the reviewed works.

	SF	CP	PP	PO&P	R&MRM	PPS	CS	PC	QC	SC
UI	0	1	0	0	0	1	2	5	2	1
MRI	0	1	0	0	0	1	2	6	2	1
RTI	0	2	1	0	2	3	7	12	5	2
MAI	0	1	0	0	2	1	5	8	3	2
IIQ	0	1	0	0	0	0	2	2	2	1
ITI	0	0	0	1	2	0	2	3	3	1
RPC	0	1	0	0	1	3	3	5	2	0
IQP	0	1	0	0	1	2	3	7	4	1
IE	0	1	0	0	1	1	2	5	1	0
ISL	0	1	0	0	0	0	1	1	0	0
BSP	0	0	0	0	1	1	1	3	2	1
ROU	0	0	0	0	1	0	1	4	0	0
MP	0	0	0	1	0	3	1	2	2	1
BQP	0	1	0	0	0	0	2	2	1	1
Benefits cited	0	10	1	2	8	9	14	14	12	10

* Cells show the number of papers that include the benefit in that phase

analysis of five characteristics was used: Sector, Technology, Practical Application, Production Phase and Benefit.

By way of conclusion, we can state that IoT is a new research field in production systems. It is possible to find general proposals for a wide range of industrial sectors, but also a specific proposal for given industrial sectors. However, very few of these proposals have had a real application in industry.

The predominant technologies in the application of IoT for production systems are RFID and sensors. Regarding the planning, operation and control phases in production systems, the application of IoT focuses mainly on the control phase.

Most of the found proposals are applications to production control, followed by quality control and stock control. All the authors indicate that IoT applications contribute with benefits in production systems. These benefits are not only for better management information in production (e.g., real-time information or improving information quality), but also benefits for other aspects of the production system (e.g., reducing production costs and improving efficiency).

In this review, some gaps in the literature on IoT application in production system have been identified. Based on these gaps and seeing how IoT applications can help managers of the production system, some near future lines of research arise: 1) most proposals are general for the production of any company, but there are very few applied proposals; 2) the predominant technology used to implement IoT is RFID. Although it offers many advantages, IoT with other technologies would be interesting for it to be applied or combined with it; 3) some industrial sectors, where experiments with IoT are being done, have been identified, but new research works could be conducted in other industrial sectors; 4) IoT Applications in the production area concentrate mainly on the control phase. Hence further research should also be conducted in planning and operation phases and subphases.

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REFERENCES

Atzori, L., Iera, A., & Morabito, G. (2010). The Internet of Things: A survey. *Computer Networks*, *54*.

Cao, Y. L., Li, W. F., & Song, W. (2011). Research on Materials Tracking in Toy Production Based on the Internet of Things. *Advanced Materials Research*, *314-316*.

Carnevalli, J. A., & Miguel, P. C. (2008). Review, analysis and classification of the literature on QFD—Types of research, difficulties and benefits. *Int. Journal of Production Economics*, *114*.

Castro, M., Guillen, A., Fuster, J. L., Jara, A. J., Zamora, M. A., & Skarmeta, A. F. G. (2011). Oxygen Cylinders Management Architecture Based on Internet of Things. In *2011 Int. Conf. on Computational Science and Its Applications (ICCSA)*.

Cuatrecasas, L. (1994). Organización y gestión de la producción en la empresa actual. *Barcelona: CPET*.

Cuiyun, M., & Yuanhang, H. (2010). Discussion on the Application of Internet of Things in Logistics Production Management. In *2010 Int. Conf. on E-Business and E-Government (ICEE)*.

Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer Systems*, *29*.

Houyou, A. M., Huth, H.-P., Trsek, H., Kloukinas, C., & Rotondi, D. (2012). Agile manufacturing: General challenges and an IoT@Work perspective. In *2012 IEEE 17th Conf. on Emerging Technologies Factory Automation (ETFA)*.

Hu, T., Zheng, M., & Zhu, L. (2011). Research Application of the Internet of Things Monitor Platform in Meat Processing Industry. In J. J. Park, H. Jin, X. Liao, & R. Zheng (Eds.), *Proceedings of the Int. Conf. on Human-centric Computing 2011 and Embedded and Multimedia Computing 2011*. Springer Netherlands.

Isenberg, M.-A., Werthmann, D., Morales-Kluge, E., & Scholz-Reiter, B. (2011). The Role of the Internet of Things for Increased Autonomy and Agility in Collaborative Production Environments. In D. Uckelmann, M. Harrison, & F. Michahelles (Eds.), *Architecting the Internet of Things*. Springer Berlin Heidelberg.

Lee, C. K. H., Choy, K. L., Law, K. M. Y., & Ho, G. T. S. (2012). An intelligent system for production resources planning in Hong Kong garment industry. In *IEEE Int. Conf. on Industrial Engineering and Engineering Management*.

Liu, J., & Xu, W. (2013). Technical State Monitoring and Evaluation of Aerospace Product Manufacturing Workshop Based on Internet of Things. In *Green Computing and Communications (GreenCom), 2013 IEEE and Internet of Things (iThings/CPSCom), IEEE Int. Conf. on and IEEE Cyber, Physical and Social Computing*.

Lvqing, Y. (2011). The analysis and design of machinery production monitoring system based on Internet of

Things. Presented at the *2011 International Conference on Electronics, Communications and Control (ICECC)*.
Melo, M. T., Nickel, S., & Saldanha-da-Gama, F. (2009). Facility location and supply chain management – A review. *European Journal of Operational Research*, *196*.
Meyer, G. G., Hans Wortmann, J. C., & Szirbik, N. B. (2011). Production monitoring and control with intelligent products. *Int. Journal of Production Research*, *49*.
Miorandi, D., Sicari, S., De Pellegrini, F., & Chlamtac, I. (2012). Internet of things: Vision, applications and research challenges. *Ad Hoc Networks*, *10*.
Mula, J., Peidro, D., Díaz-Madroñero, M., & Vicens, E. (2010). Mathematical programming models for supply chain production and transport planning. *European Journal of Operational Research*, *204*.
Qu, B., Jing, X., Wang, X., Li, Y., & Liang, Y. (2012). Design on Cucumber Traceability System Based on the Internet of Things. In D. Li & Y. Chen (Eds.), *Computer and Computing Technologies in Agriculture V*. Springer Berlin Heidelberg.
Shengduo, L., & Jian, Z. (2012). Research and Development of Management Platform for Precision Ecological Agriculture Based on the Internet of Things. In W. Zhang (Ed.), *Software Engineering and Knowledge Engineering: Theory and Practice*. Springer Berlin Heidelberg.
Stephan, P., Meixner, G., Koessling, H., Floerchinger, F., & Ollinger, L. (2010). Product-mediated communication through digital object memories in heterogeneous value chains. In *2010 IEEE Int. Conf. on Pervasive Computing and Communications (PerCom)*.
Tan, J., & Koo, S. G. M. (2014). A survey of technologies in internet of things (Vol. Marina Del Rey, CA). Presented at the *9th IEEE International Conference on Distributed Computing in Sensor Systems, DCOSS 2014, IEEE Computer Society*.
Vossiek, M., Miesen, R., & Wittwer, J. (2010). RF identification and localization - recent steps towards the internet of things in metal production and processing. Presented at the *2010 18th Int. Conf. on Microwave Radar and Wireless Communications (MIKON)*.
Wang, H., & Chen, X. (2013). Internet of Things Technology-Based Manufacturing Inventory Management. In *2013 Int. Workshop on Computer Science in Sports*. Atlantis Press.
Wang, X., & Liu, N. (2014). The application of internet of things in agricultural means of production supply chain management. *Journal of Chemical and Pharmaceutical Research*, *6*.
Whitmore, A., Agarwal, A., & Da Xu, L. (2014). The Internet of Things-A survey of topics and trends. *Information Systems Frontiers*.
Wuest, T., Hribernik, K., & Thoben, K.-D. (2012). Can a Product Have a Facebook? A New Perspective on Product Avatars in Product Lifecycle Management. In L. Rivest, A. Bouras, & B. Louhichi (Eds.), *Product Lifecycle Management. Towards Knowledge-Rich Enterprises*. Springer Berlin Heidelberg.
Yuan, L., Guo, Y., Jiang, J., & Nian, L. (2013). The Research on Monitoring of Discrete Manufacturing Process Based on Internet of Things. In *Green Computing and Communications (GreenCom), 2013 IEEE and Internet of Things (iThings/CPSCom), IEEE Int. Conf. on and IEEE Cyber, Physical and Social Computing* .
Zhang, Y., Wang, W., Liu, S., & Xie, G. (2014). Real-Time Shop-Floor Production Performance Analysis Method for the Internet of Manufacturing Things. *Advances in Mechanical Engineering*, *2014*, e270749.
Zhiliang, F., Xin, W., Guangrong, Y., & Tao, D. (2013). PDA-Based Application and Research for Workshop Internet of Things. In *Green Computing and Communications (GreenCom), 2013 IEEE and Internet of Things (iThings/CPSCom), IEEE Int. Conf. on and IEEE Cyber, Physical and Social Computing*.
Zuehlke, D. (2010). SmartFactory—Towards a factory-of-things. *Annual Reviews in Control*, *34*.