Field study to identify requirements for smart logistics of European, US and Asian SMEs

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Abstract

Industry 4.0 also known as the "fourth industrial revolution" will positively affect not only manufacturing processes but also the connected supply chains. Through digitization, important control information, even at an inter-company level, will become available in real-time leading to great efficiency increases. However, the increasing trend of mass customization as well as supply chains that are spread globally over the world pone specific challenges to SMEs logistics to deliver products Just-in-Time (JIT), with low costs and the right quality. Moreover, up to now mostly big companies are boosting research and development in this field letting on the track small and medium-sized enterprises (SMEs). In this paper, we present the outcomes of expert workshops to identify requirements of SMEs in the field of smart logistics management. To give a global perspective, SMEs from Central Europe, the Northern part of the United States of America as well as from Northern Thailand are presented. The paper presents an explorative set of hypothesis for requirements as well as the outline of a survey for their further validation. It summarizes the results of the first phase within the European research project "SME 4.0 - Industry 4.0 for SMEs".

Keywords
Industry 4.0, smart logistics, small and medium-sized enterprises, logistics management, requirements

1. Introduction

The fourth industrial revolution or also called "Industry 4.0" is currently transforming the manufacturing and connected supply chain industry. After the advent of mechanization, electrification and computerization, it represents the increasing digitization and automation of the manufacturing industry, as well as the establishment of digital value chains to enable communication between products, machines and human operators (Lasi et al. 2014). In other words, the focus of Industry 4.0 is to combine the internet, information and communication technologies (ICT) with classical industrial processes (Bundesministerium für Bildung und Forschung 2012).

Another important transformation that comes with Industry 4.0 is the shift from a centralized to a decentralized control to reach a highly flexible production of customized products and services. A more and more individualization and personalization of products leads to customer interaction strategies like X-to-order (make-to-Order, Build-to-Order, Configure-to-Order and Engineer-to-Order) and ultimately to the concept of "mass customization" where products can be configured by the customer at costs similar to those of mass production. The increasing fusion of the IT environment with production and logistics allows to obtain flexible and reconfigurable manufacturing and logistics systems (Spath et al. 2013).

Another important part of Industry 4.0 are Cyber Physical Systems (CPS) that allow a self-organization and self-control of manufacturing and logistics systems (Rauch et al. 2016a; Rauch et al. 2016b). CPS are computers, sensors and actuators that are embedded in materials, equipment and machine parts and connected via the internet, the so-called "Internet of Things", allowing to merge the physical and digital world (Spath et al. 2013). A further big benefit that comes with the introduction of CPS is to obtain high amount of data that is available in real-time. This allows a better production planning and control (PPC) and to counteract from unforeseen events in manufacturing and logistics processes (Dallasega et al. 2015a; Dallasega et al. 2015b). Overall, the potential of a successful implementation of Industry 4.0 is enormous.

However, up to now, Industry 4.0 is mainly brought forward by bigger companies and small- and medium sized enterprises (SMEs) are risking to lose the train in this direction. According to the European commission, SMEs are characterized by having not more than 250 employees and an annual turnover of less than 50 million Euro or a balance sheet of no more than 43 million Euro (Kraemer-Eis and Passaris 2014). More in detail, micro and SMEs provide around 45% of the value added by manufacturing and around 59% of manufacturing employment and therefore they can be considered being the backbone of the European economy (Vidosav 2014). As the previous economic crisis showed, SMEs proved to be more robust than bigger companies because of their flexibility, their entrepreneurial spirit and their innovation capabilities (Matt 2007).

As such, the successful implementation of Industry 4.0 has to take place not only in large enterprises but in particular in SMEs. However, because of often-limited financial and human resources the implementation of Industry 4.0 represents a special challenge for SMEs. Up to now, SMEs are only partially ready to adapt Industry 4.0 concepts. Especially smaller enterprises face a high risk not being able to benefit from this industrial revolution. As a result, further research and action plans are needed to prepare SMEs for the stepwise introduction of Industry 4.0 (Sommer 2015).

According to the authors, SMEs will only benefit from Industry 4.0 by following customized implementation strategies, approaches, concepts and technological solutions that have been appropriately adopted. Otherwise, the current effort for publication and sensitization of SMEs for Industry 4.0 will not show the expected results.

The paper presents an explorative set of hypothesis of requirements to implement Industry 4.0 concepts in logistics processes of SMEs spread over the world. They were developed in the course of the research project "SME 4.0 – Industry 4.0 for SMEs" by using expert workshops with SMEs from the Northeast part of the United States of America, Central Europe and Northern Thailand. The last part of the paper gives a brief overview of a proposed confirmative validation by using a field study approach.

2. Related work

This section briefly summarizes related works regarding the assessment of requirements for Industry 4.0 implementation of companies and related works regarding Intelligent Logistics through ICT and CPS.

Glass et al. (2018) identified barriers for implementing Industry 4.0 in SMEs by investigating the literature and using a survey approach in German companies. They emphasized specific barriers of Industry 4.0 implementation like missing standardization and a not appropriate company strategy. Maasouman et al. (2015) developed a Lean Maturity Model and designed a framework for assessment of concepts like Just-in-Time in manufacturing cells of Canadian and Abu Dhabi companies. Schumacher et al. (2016) developed models for assessing the readiness and maturity of

Austrian companies regarding Industry 4.0. The model considers elements like the strategy of the organization, customer, people and technology. Qin et al. (2016) developed a framework to show the gap between the state of the art in UK companies and the requirements for Industry 4.0 readiness. Similarly, Andrea and Jiri (2017) analyzed Industry 4.0 requirements of Czech Republic companies where the digital representation of a factory in real time, the horizontal and vertical data integration and the self-controlling of manufacturing and logistics processes emerged. Furthermore, the results showed that education and qualification of employees is one of the main requirements for the implementation of Industry 4.0. Kamble et al. (2018) used interpretive structural modeling (ISM) and fuzzy technology to analysis the barriers to implement Industry 4.0 in Indian companies. Barriers like the lack of clear comprehension about IoT benefits, employment disruptions, organizational and process changes (needed to implement Industry 4.0) emerged. Luthra et al. (2018) evaluated key concepts and challenges of implementing Industry 4.0 in Indian manufacturing companies with a special focus on sustainable supply chain management. Here, technological as well as an appropriate strategic orientation of the company emerged as the main challenges for Industry 4.0 implementation. Furthermore, Industry 4.0 will also provide new opportunities to enable the development of smart products and smart services in SMEs (Issa 2017).

In the following paragraph, a brief overview about related works in the field of Intelligent Logistics through ICT and CPS is presented. To date, logistics management has been progressed concretely with the advancement of ICT and CPS (Zimao 2010; Maslarić et al. 2016; Moser and Říha 2019, Tu et al. 2018, Dalenogare et al. 2018). Digitalization offers transparency and synchronization of material flows and information flow (Chadil et al. 2008, He et al. 2009). It allows that inventories can be tracked and required information can be shared across the supply chain (Perego et al. 2011) via standardized interfaces (Helo and Szekely 2005) and platforms (Qu et al. 2016; Du et al. 2017). Up to now, data and information safety and security issues have been raised in literature as highly important especially for SMEs (Gupta and Hammond 2005; Cantor, 2008; Quanxi and Bing 2009; Berghaus et al. 2018; Xu et al. 2018).

3. Explorative investigation of requirements of smart logistics for SMEs

The empirical investigation of requirements for the application of smart logistics for SMEs was based on expert workshops. Thereby, the expert workshops followed pre-defined methodological guidelines to systematically evaluate the requirements of smart logistics in SMEs. In the next paragraph, the authors will describe the expert workshops based on the consolidated criteria for reporting qualitative research (CORE) checklist (Tong et al. 2007).

The expert workshops were conducted by the Free University of Bolzano (Italy), the University of Leoben (Austria), the Worcester Polytechnic Institute (USA) and the Chiang Mai University (Thailand) in the timeframe between 09th of June 2017 and 22nd of March 2018. The Technical University of Kosice has carried out an additional workshop on 23rd of June 2017, which could not be included in the further analyses due to a diverging methodological approach. The research team at each of the involved universities was comprised of the faculty members including at least one full professor, two assistant professors respectively two postdocs and two early stage researchers (PhD students).
The experts were randomly selected from SME business directories by using an ex-ante selection approach. According to the literature, the expert sample has included a mixture of different SMEs to comprise diverse points of view (Mayer 2002). In this investigation, the research team has defined an expert by having crucial, clear and accessible knowledge in the areas of production and /or logistics management in SMEs. Therefore, the expert's knowledge is based on confident statements and should not include unspecific assumptions (Mayer 2002, Bogner et al. 2005, Woschank 2018).

The workshops have started with a short presentation of the research project. After that, the research team systematically recorded, clustered and analyzed statements for the requirements of smart logistics in SMEs based on the methodological guidelines and according to the three pre-defined sub-sections. The evaluation of the collected requirements was based on a qualitative content analysis (Mayring 2010).

In sum, the research team has conducted 6 workshops with 37 participating SMEs and 67 participating experts. The quantitative content analysis resulted in 548 statements for further investigation. Moreover, the statements for smart logistics in SMEs were divided in the sub-sections "smart and lean x-to-order supply chains", "intelligent logistics

through ICT and CPS", "smart and automated logistics systems and vehicles" and "main barriers and difficulties for SMEs".

3.1. Hypothesis of requirements of smart and lean x-to-order supply chains

This paragraph contains the explorative set of hypothesis for requirements for smart logistics SMEs that were collected during the SME4.0 workshops. Thereby, the sub-section focuses on the development of requirements for smart and lean x-to-order supply chains.

LEAN and AGILITY

This cluster encompasses requirements that allow a production on-demand and delivery Just-in-Time as well as ensure flexible supply chains. The identification and avoidance of material flow breaks and the timing of orders to minimize transportation costs were mentioned. Moreover, the optimization of material yields at the vendor and the grouping of trucking routes of complimentary suppliers were recorded. According to the workshop participants, a mechanism for self-assembly of data/information flows is needed.

REAL TIME STATUS

This cluster includes the requirements for an infrastructure and digital feedback system, which monitors the status of production, storage and shipping in real-time. Especially, the short-term availability of information about the delivery status is very important for a proper supply chain management. Moreover, the visibility of the supplier's status in real time for a quick access to information for an improved supplier risk management was mentioned.

DIGITIZATION, CONNECTIVITY and NETWORK

This cluster entails mainly the necessity for an improved customer-supplier connection to gain the ability to communicate and/or share capacity, materials, infrastructure and information with internal and external customers and suppliers. Information should be provided and visualized everywhere and every-time to reduce waiting times and unnecessary delays.

The requirement of increasing transparency by visualizing stocks and delivery times throughout the supply chain by interconnecting suppliers with manufacturers and customers over the internet was recorded. Here, aggregator websites to determine short-term availability of material or capacity in the supplier network, e.g. following the example of Skyscanner for the search of flights, were mentioned. The requirement for a digitized process from customers to suppliers to avoid causes of missing parts/materials and increase the reliability of suppliers was recorded. Here, the following practical example was named by the experts: "when an order is received, the system should generate the bill of materials and automatically send the purchase order to suppliers". More in detail, the need for an automatic on-site measurement and electronic submission of order data to the fabrication shop was collected. Furthermore, the geographical visualization of transport routes for the analysis of losses and inefficiencies in delivery routes was recorded.

TRACKING, PPC and WMS

This cluster includes the requirements of digitally tracking and localizing (tracing) of products throughout supply chains. Advanced PPC methodologies and tools should forecast demand changes quickly by interacting with internal and external systems for planning, control and logistics. As a specific requirement, the automatic triggering of orders for tools and materials when processed orders come in was recorded. Moreover, the need of automatic "Pull" systems that allow a synchronized workflow across networked machines to minimize down time, tool changes and predictive maintenance was listed.

Moreover, a better knowledge of the state of the art in warehouse management systems (WMS) was registered. Here, as specific requirement, an automatic adjustment of inventory levels through low inventory levels that automatically trigger stock runs was collected. Furthermore, according to the participants, warehouse management systems should be implemented in a way that allows for easy exchange and storage of all needed information concerning command control and logistics. Moreover, an automated and permanent inventory control by comparing

planned vs. actual data and the intuitively visualization of where material is stored in the warehouse, were mentioned.

CULTURE, PEOPLE and IMPLEMENTATION

In this cluster, the SME's needs to access the financial, informational, digital, physical and educational resources to ensure that Industry 4.0 is fully realized rather than passed by are summarized. The increase of visibility of Industry 4.0 among professionals who might not have been exposed to it otherwise was collected. The requirement of Top Management being aware and supporting Industry 4.0 to avoid missing acceptance throughout the company was mentioned. Moreover, the need of qualified and trained employees to implement and handle Industry 4.0 concepts in daily business was recorded. Here, the participants stated that employees should be specifically trained in software and data collection. For a successful implementation of Industry 4.0 into SMEs the necessity of having an overview of existing Industry 4.0 concepts and tools for logistics and their suitability for SMEs for specific industry sectors was mentioned. Here, the need of a specific distinction of SMEs in countries with high-labor cost and countries with low-labor cost was specified.

3.2. Hypothesis of requirements of intelligent logistics through ICT and CPS

This sub-section focuses on requirements of intelligent SME logistics through ICT and CPS. Thereby, digitalization in logistics was considered as one of the most important ones.

DIGITALIZATION

Digitalization encompasses the visualization of material flow from upstream to downstream companies. This includes the visualization of tools and parts used throughout the supply chain processes. The technology which supports digitalization in the supply chain should be implemented in the entire supply chain to avoid incompatibility. Digitalization could be implemented in order receiving, procurement process as well as in logistical risk warning systems. However, digitalization should limit the accessibility of related stakeholders to obtain optimal data.

REALTIME STATUS AND TRACKING SYSTEMS

Real time status and tracking systems are crucially important for SME logistics processes in terms of supply chain monitoring. This includes the monitoring of shipment status of materials. Real time status can also assist in the predictive maintenance process. The tracking system provides better real time status, for example, inventory tracking, multiple parts tracking through multiple processes to monitor the status of production.

CONNECTIVITY

Intelligent SME logistics requires standardized data interfaces between supply chain partners like suppliers, manufactures and customers. Systems should be synchronized throughout the supply chain to avoid re-work and communication interruptions. Data is required to be integrated to support single database systems. Suppliers are encouraged to use designated barcode or RFID systems that are mutually arranged.

WMS

Warehouse Management Systems (WMS) were mentioned as one of the most significant elements to support smart logistics in SMEs. Requirements like the automated assistance in order and distribution processes based on historical assumptions were mentioned. The provision of data for inventory decision making such as inventory turns and reorder point arrangements to support Economic Order Quantities (EOQ) was mentioned. WMS can also allocate and optimize storage locations and display accurate locations for product pick up.

LEAN AND EASE OF USE

According to the workshop results, the implementation of smart logistics concepts should be lean, understandable and easy to use. For example, the experts proposed that "a supplier list with delivery times should always be available and up to date in order to avoid delays and necessary rescheduling processes with the vendors".

SECURITY AND SAFETY

According to the workshop participants, security and safety issues should be supported along smart logistics in SMEs. Here, specifically the internal traffic optimization for safety and efficiency in the workplace and required ICT to monitor and control safety in driverless transport systems were mentioned. Moreover, the ensuring of data security and intellectual property protection were recorded.

3.3. Hypothesis of requirements of smart and automated logistics systems and vehicles

The third section "automated logistics systems and vehicles for SMEs" was defined as the analysis of existing approaches and technologies for automation in SME Logistics (e.g., autonomous guided vehicles, mobile shuttles, and flexible automated warehouse systems), as well as the definition of the potential of their application in practice and their suitability for SMEs. Based on the analyses from the expert workshops, the research results were aggregated to the clusters "automation", transport and WMS", "Lean" and "digitalization and connectivity".

AUTOMATION

The cluster automation includes requirements for decreasing the manual workload in logistics systems. Thereby the experts mainly focused on the automated labeling of products, automatic picking and delivery, automated storage systems for materials and transport containers and the automated removal of scape in the course of the production process. Moreover, the participants were interested in cause-effect analyses aiming at the impact of automation approaches on business success.

TRANSPORTATION AND WMS

This cluster contains the automated material transport by using driverless transport systems (AGVs) including all related activates (e.g., loading, transport, unloading, safety issues) aiming at a fast and cost-efficient distribution of materials. Moreover, the cluster includes the automation of warehouses by using warehouse management systems (WMS), automated inventory monitoring, and automated systems for the ongoing operation and maintenance of warehouse systems.

LEAN

This cluster mainly includes strategies to increase the material efficiency in automated logistics systems. Thereby, the reduction of buffer stocks, raw material, WIP and finished parts were recorded. Moreover, the usage of advanced planning techniques was mentioned as a further requirement.
Additionally, the reduction of buffer stocks at the workplace, preventive "rhythms" (delivery, preparation, etc.), grouping complimentary suppliers (trucking routes), efficient storage and removal systems for the holding of raw material, WIP, finished parts, parts produced and packaged at machines and moved to shipping were mentioned.

DIGITALIZATION AND CONNECTIVITY

This sub-section comprises the automation of information flow activities in logistics systems. Thereby, the requirements included the automated tracking of prices, the automation of processes (e.g. the generation of bill of materials) and the automated communication between different systems.
Moreover, the workshop participants mentioned the sharing of transport capacities, the flexibility regarding the scalability of logistics systems and the predictive maintenance of logistics systems as further requirements.

3.4. Outline of the questionnaire

From the workshop results, the requirement analysis of three sub-sections are summarized and used to develop a questionnaire to conduct a field study by using a questionaire in a next stage. The questionnaire was designed based on a Likert 1-4 scale to avoid neutral responses. Level 4 indicates the most important while Level 1 indicates the least important one (Table 1).

Table 1. Outline of questionnaire to validate hypothesis for requirements

First hypothesis of requirements	Level of Importance			
	1	2	3	4
A) Smart and Lean x-to-order Supply Chains				
A1) LEAN AND AGILITY				
(1) The identification and avoidance of material flow breaks throughout the supply chain.				
(2) A production on-demand and delivery of products just in time to the customer.				
(3) A mechanism for self-assembly of data/information flows of smart logistics systems.				
A2) REAL TIME STATUS				
(4) The availability of data in real-time about the status of production, storage and shipping throughout the supply chain (at suppliers and customers)				
A3) DIGITIZATION, CONNECTIVITY and NETWORK				
(5) The digital connection of customers and suppliers to gain the ability to communicate and/or share information, capacity, materials and infrastructure.				
(6) The geographical visualization of transport routes for the analysis of inefficiencies in delivery routes.				
A4) TRACKING, PPC and WMS				
(7) A digitally tracking and locating of products throughout the supply chain.				
(8) Advanced Production Planning and Control (PPC) tools that allow forecasting rapidly demand changes by interacting with internal and external systems for planning, control and logistics.				
(9) Transparency of inventory levels and storage locations as well as an automated stock refill in warehouses.				
A5) CULTURE, PEOPLE and IMPLEMENTATION				
(10) Top Management is aware and supports Industry 4.0 for a successful implementation.				
(11) The qualification and training of employees in software and data collection tools.				
(12) SMEs have knowledge about existing and suitable Industry 4.0 concepts and tools for logistics management.				
B) Intelligent Logistics through ICT and CPS				
B1) DIGITALIZATION				
(13) The visibility of material flow along supply chains from upstream to downstream companies.				
(14) The tools and parts visualization within the supply chain.				
(15) The digitalization of the overall procurement process.				
(16) Limitation of data accessibility to different stakeholders in the supply chain.				
B2) REALTIME STATUS AND TRACKING SYSTEM				
(17) Real time tracking in material shipment status (from supplier to focal company).				
(18) Real time tracking about order production.				
(19) Real time tracking in product shipment (from company to customers).				

(20) Real time tracking on machine maintenance to assist accurate predictive maintenance.				
B3) CONNECTIVITY				
(21) Standardized data interface between supply chain partners.				
(22) Single database system along the supply chain.				
(23) Using mutually designated barcode or RFID systems among suppliers.				
B4) WAREHOUSE MANAGEMENT SYSTEM (WMS)				
(24) Automatic ordering system managed by vendors.				
(25) Product location optimization to support put away and pick up processes.				
(26) Automated distributing parts to points of use.				
(27) Inventory decision support data through WMS.				
B5) LEAN AND EASE OF USE				
(28) Specific work instructions by using ICT along the supply chain.				
(29) Intuitive software for SMEs.				
(30) Digital-Assist-System for SME user.				
B6) SECURITY AND SAFETY				
(31) Internal traffic optimization software to increase safety in workplace.				
(32) Data security and IP Protection in intelligent SME logistics.				
C) Smart and automated Logistics Systems and Vehicles				
C1) AUTOMATION				
(33) Automated storage of material.				
(34) Automation of material flow processes.				
C2) TRANSPORT AND WMS				
(35) Material transport using driverless transport systems.				
C3) LEAN				
(36) Lean strategies for increasing the material efficiency in logistics systems.				
C4) DIGITALIZATION AND CONNECTIVITY				
(37) Automated information flow in logistics systems.				

4. Triangulated validation by using a field study approach

In the first step of the systematic investigation of requirements for smart logistics in SMEs, the research team conducted expert workshops based on a qualitative content analysis. Thereby, the expert statements were systematically recorded, clustered and analyzed based on the pre-defined sub-sections "smart and lean x-to-order supply chains", "intelligent logistics through ICT and CPS", "smart and automated logistics systems and vehicles" and "main barriers and difficulties for SMEs".

In addition to this exploratory-based research approach, the authors propose to conduct a field study for further investigation. In this second step, the field study will be used as confirmative research method to ensure a higher level of external validity, transferability, and generalizability of the preliminary research results (Bortz and Schuster 2010). This mixed method design is supported by a multitude of studies in logistics management (e.g., Soni and Kodali (2012), Golicic and Davis (2012), Boyer and Swink (2008)) and will be used to create fruitful insights for the holistic understanding of the requirements of smart logistics in SMEs. In addition, the causal mechanisms between the requirements and logistics key performance indicators will be investigated by applying structural equation modelling procedures (SEM).

5. Conclusions and outlook

SMEs will only benefit from Industry 4.0 by following customized implementation strategies, approaches, concepts and technological solutions. Otherwise, the current effort for publication and sensitization of Industry 4.0 will not show the expected results. The paper presents an explorative set of hypothesis of requirements for the application of Industry 4.0 concepts in logistics processes based on expert workshops with SMEs. The expert workshops were conducted by the Free University of Bolzano (Italy), the University of Leoben (Austria), the Worcester Polytechnic

Institute (USA) and the Chiang Mai University (Thailand). The hypothesis were elaborated according to three main research directions of the project SME4.0: 1) smart and lean x-to-order supply chains, 2) intelligent logistics through ICT and CPS and 3) smart and automated logistics systems and vehicles for SMEs. From the workshops different elements emerged to be important for the definition of requirements like lean and ease of use, agility, real time status, tracking, connectivity, WMS, automation, transportation, security and safety. The second part of the paper presents the outline of a questionnaire that will be used in a next step to confirmatively validate the set of hypothesis for the requirements of smart logistics by using a large-scale sample. It will be used as explanatory research method to ensure a higher level of external validity, transferability, and generalizability of the preliminary research results. Furthermore, the causal mechanisms between the requirements and logistics key performance indicators will be investigated by applying structural equation modelling procedures (SEM).

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References

Andrea Benessova and Jiri Tupa, Requirements for Education and Qualification of People in Industry 4.0, *Procedia Manufacturing*, vol. 11, pp. 2195-2202, 2017.

Berghaus G., Kessler, R., Dmitriyev, V., Gomez, J. M., Ermittlung der Digitalisierungspotentiale von nicht-digitalen Geschäftsprozessen, *HMD Praxis der Wirtschaftsinformatik*, vol. 55, no. 2, pp. 427-444, 2018.

Bogner, A., Littig, B., Menz, W., *Das Experteninterview. Theorie, Methode, Anwendung*, 2nd ed. Wiesbaden: Verlag für Sozialwissenschaften, 2005.

Bortz, J. & Schuster, C., *Statistik für Human- und Sozialwissenschaftler*, 7th ed. Berlin et al.: Springer, 2010.

Boyer, K.K., Swink, M.L., Empirical elephants - Why multiple methods are essential to quality research in operations and supply chain management, *Journal of Operations Management*, vol. 26, no. 3, pp. 337–348, 2008.

Bundesministerium für Bildung und Forschung, *Zukunftsbild „Industrie 4.0"*, Bundesministerium für Bildung und Forschung, Berlin, p. 9, 2012.

Chadil, N., Russameesawang, A., Keeratiwintakorn, P., Real-time tracking management system using GPS, GPRS and Google earth, In *Proceedings of the 5th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology*, vol. 1, pp. 393-396, 2008.

Cantor, D. E., Workplace safety in the supply chain: a review of the literature and call for research, *International Journal of Logistics Management*, vol. 19, no. 1, pp. 65-83, 2008.

Dalenogare, L. S., Benitez, G. B., Ayala, N. F., Frank, A. G., The expected contribution of Industry 4.0 technologies for industrial performance, *Journal of Production Economics*, vol. 204, pp. 383-394, 2018.

Dallasega, P., Rauch, E., Matt, D. T., Fronk, A., Increasing productivity in ETO construction projects through a lean methodology for demand predictability, *Proceedings of the 5th International Conference on Industrial Engineering and Operations Management (IEOM)*, art. no. 7093734, pp. 1-11, 2015a.

Dallasega, P., Rauch, E., & Matt, D. T., Sustainability in the supply chain through synchronization of demand and supply in ETO-companies, *Procedia CIRP*, vol. 29, pp. 215-220, 2015b.

Du, J., Sugumaran, V., Gao, B., RFID and Multi-Agent Based Architecture for Information Sharing in Prefabricated Component Supply Chain, *IEEE Access*, vol. 5, pp. 4132-4139, 2017.

Glass, R., Meissner, A., Gebauer, C., Stürmer, S., Metternich, J., Identifying the barriers to Industrie 4.0, Procedia CIRP, vol. 72, pp. 985-988, 2018.

Golicic, S. L. Davis, D. F., Implementing mixed methods research in supply chain management, *International Journal of Physical Distribution & Logistics Management*, vol. 42, no. 8/9, pp. 726–741, 2012.

Gupta, A., Hammond, R., Information systems security issues and decisions for small businesses: An empirical examination, *Information management & computer security*, vol. 13, no. 4, pp. 297-310, 2005.

He, W., Tan, E.L., Lee, E.W., Li, T.Y., A solution for integrated track and trace in supply chain based on RFID & GPS, In *Proceedings of IEEE Conference on Emerging Technologies & Factory Automation*, 2009, pp. 1-6, 2009.

Helo, P., Szekely, B., Logistics information systems: an analysis of software solutions for supply chain co-ordination, *Industrial Management & Data Systems*, vol. 105, no. 1, pp. 5-18, 2005.

Issa, A., Lucke, D., Bauernhansl, T., Mobilizing SMEs towards Industrie 4.0-enabeled Smart Products, *Procedia CIRP*, vol. 63, pp. 670-674, 2017.

Kamble, S.S., Gunasekaran, A., Sharma, R., Analysis of the driving and dependence power of barriers to adopt industry 4.0 in Indian manufacturing industry, Computers in Industry, vol. 101, pp.107-119, 2018.

Kraemer-Eis, H., Passaris, G., SME Securitization in Europe, *Journal of Structured Finance*, vol. 20, no. 4, pp. 97-106, 2015.

Lasi, H., Fettke, P., Kemper, H.-G., Feld, T., Hoffmann, M., Industry 4.0, *Business & Information Systems Engineering*, vol. 6, no. 4, pp. 239-242, 2014.

Luthra, S., Mangla, S.K., Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies, *Process Safety and Environmental Protection,* vol. 117, pp. 168–179.

Maasouman, M.A., Demirli, K., Assessment of Lean Maturity Level in Manufacturing Cells, *IFAC-PapersOnLine*, vol. 48, no. 3, pp. 1876–1881, 2015.

Maslarić, M., Nikoličić, S., Mirčetić, D., Logistics response to the industry 4.0: the physical internet, *Open Engineering*, vol. 6, no. 1, pp. 511-517, 2016.

Matt, D.T., Reducing the Structural Complexity of Growing Organizational Systems by Means of Axiomatic Designed Networks of Core Competence Cells, *Journal of Manufacturing Systems*, vol. 26, pp. 178-187, 2007.

Mayer, H.O., *Interview und schriftliche Befragung. Entwicklung, Durchführung und Auswertung*, Munich: Oldenbourg, 2002.

Mayring P., *Qualitative Inhaltsanalyse*, In: Mey G., Mruck K. (eds) Handbuch Qualitative Forschung in der Psychologie, VS Verlag für Sozialwissenschaften, 2010.Moser, C., Říha, K., Digitalization of Information-Intensive Logistics Processes to Reduce Production Lead Times at ENGEL Austria GmbH: Extending Value Stream Mapping with Subject-Oriented Business Process Management, In *Digitalization Cases,* Springer, Cham, pp. 293-312, 2019.

Perego, A., Perotti, S., Mangiaracina, R., ICT for logistics and freight transportation: a literature review and research agenda, *International Journal of Physical Distribution & Logistics Management*, vol. 41, no. 5, pp. 457-483, 2011.

Qin, J., Liu, Y., Grosvenor, R., A Categorical Framework of Manufacturing for Industry 4.0 and Beyond, *Procedia CIRP*, vol. 52, pp. 173-178, 2016.

Qu, T., Lei, S.P., Wang, Z.Z., Nie, D.X., Chen, X., Huang, G.Q., IoT-based real-time production logistics synchronization system under smart cloud manufacturing, *International Journal of Advanced Manufacturing Technology*, vol. 84, no. 1-4, pp. 147-164, 2016.

Quanxi, L., Bing, Y., The Research of Security Logistics Management System Based on RFID*, Journal of Hunan University of Technology*, vol. 5, 030, 2009.

Rauch, E., Dallasega, P., Matt, D.T., The way from lean product development (LPD) to smart product development (SPD), *Procedia CIRP*, vol. 50, pp. 26-31, 2016a.

Rauch, E., Seidenstricker, S., Dallasega, P., Hämmerl, R., Collaborative cloud manufacturing: design of business model innovations enabled by cyberphysical systems in distributed manufacturing systems, *Journal of Engineering*, Article ID 1308639, 2016b.

Schumacher, A. Erol, S., Sihn, W., A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises, *Procedia CIRP*, vol. 52, pp. 161-166, 2016.

Sommer, L., Industrial revolution-industry 4.0: Are German manufacturing SMEs the first victims of this revolution?, *Journal of Industrial Engineering and Management*, vol. 8, no. 5, pp. 1512-1532, 2015.

Soni, G., Kodali, R., A critical review of empirical research methodology in supply chain management, *Journal of Manufacturing Technology Management*, vol. 23, no. 6, pp. 753-779, 2012.

Spath, D., Ganschar, O., Gerlach, S., Hämmerle, T. K., Schlund, S., *Produktionsarbeit der Zukunft – Industrie 4.0*, Fraunhofer Verlag, Stuttgart, pp. 2-133, 2013.

Tu, M., Lim, M. K., Yang, M.-F., *IoT-based production logistics and supply chain system – Part 1: Modeling IoT-based manufacturing supply chain*, Industrial Management & Data Systems, vol. 18, no. 1, pp. 65-95, 2018.

Tong, A., Sainsbury, P., Craig J. Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups, International journal for quality in health care, vol. 19, no. 6, pp. 349-357, 2007.

Vidosav, D.M., Manufacturing Innovation and Horizon 2020-Developing and Implement „New Manufacturing ", *Proceedings in Manufacturing Systems*, vol. 9, no. 1, pp. 3-8, 2014.

Woschank M. E., *The impact of decision making process maturity on decision making efficiency, Riga: University of Lativa, 2018.*

Xu, L. D., Xu, E. L., Li, L., Industry 4.0: state of the art and future trends, *International Journal of Production Research*, vol. 8, pp.2941-2962, 2018.

Zimao, Z., On the Development Direction of Enterprise Logistics Digitalization Construction at the Economic Era, *Value Engineering*, vol. 36, no. 013, 2010.

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