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Managerial and Industry 4.0 solutions for fashion supply chains

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Abstract

Purpose – The purpose of this paper is to present a structured framework whose objectives are to identify, analyse and eliminate fashion-luxury supply chains inefficiencies.

Design/methodology/approach – A Lean Manufacturing tool, the 5-Whys Analysis, has been used to find out the root causes associated with the problem identified from a data analysis of production orders of a fashion-luxury company. A case study, which explains the methodology and illustrates the capability of the tool, is provided.

Findings – This tool can be considered a suitable instrument to identify the causal factors of inefficiencies within luxury supply chains, suggesting potential countermeasures able to eliminate the problems previously highlighted. In addition, enabling technologies that deal with Industry 4.0 are associated with the root causes to enable further improvement of the supply chain.

Practical implications – The effectiveness and practicality of the tool are illustrated using an industrial case study concerning an international Italian signature in the world of fashion-luxury footwear sector.

Originality/value – This framework provides practitioners with an operative tool useful to highlight where the major inefficiencies of fashion-luxury supply chains take place and, at the same time, individuates both the root causes of inefficiencies and the corresponding corrective actions, even considering Industry 4.0 enabling technologies.

Keywords Supply chain management, 5-Whys analysis, Industry 4.0, Fashion industry, Luxury industry, Planning and scheduling

Paper type Research paper

1. Introduction

In the fashion industry, the luxury supply chain has received rising attention with the rapid growth of global fashion industry and brands. Statistics of (Statista) show that, in 2019, the luxury industry has recorded a growth of about 2.8% in annual turnovers, with an estimated additional growth of 1.7% for the period 2019–2023. This growth was significant especially in Italy where, in 2019, the luxury industry recorded a growth of about 3.0% in annual turnover (Statista).

According to Jain (2019), luxury is often defined as "*. . .*fashion market sector that stands out for the careful search of quality in the product and for the innovation of the models offered". It is also characterized by short life cycles of products, high volatility and low predictability of the demand market, linked to market trends; and high impulse purchasing (Christopher *et al.*, 2004). Short life cycles and high unpredictability of demand are usually due to the fact that the models on sale try to capture the trends of the moment, which are

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highly variable and driven by phenomena such as cinema and social media. Moreover, due to the high degree of customization of the products (e.g., colour, size, style), there is a further increase of the difficulties in production management, which lead to extended intervals of time, typically about six months from the commissioning of the product to the exposition at the final customer (Sull and Turconi, 2008). Additional problems are caused by frequent changes of specification by the customer (Afshari and Benam, 2011).

Despite the variety and complexity of the phases that affect the life of the product, the supply chain has to be able to accept the unpredictable demands of the market and to respond, as quickly as possible, to the demand of end customers, maintaining the high-quality standards required by the luxury sector.

As a result, the fundamental aim is to create an agile supply chain (Cao *et al.*, 2008). So, in order to ensure adequate customer service, there are no doubt that quick and reliable suppliers, proper product quality, accurate transportation and inventory control, efficient and valuable information flow and high-accuracy demand forecasting are all critical elements in supply chain management (SCM) (Hanne and Dornberger, 2016).

This can be achieved through a review of business flows (Preiss and Murray, 2005), remodelling procedures (Adhikari *et al.*, 2020), or introducing new tools to better perform the activities (Kwok and Wu, 2009), and through the implementation of Information and Communication Technology (ICT) devices that allow a digitization of data of the entire supply chain (Bertolini *et al.*, 2007), bringing it closer to the world of *Industry 4.0* (I4.0).

I4.0 refers to recent technological advances where Internet and supporting technologies (e.g. embedded technologies) serve as a backbone to integrate physical objects, human actors, intelligent machines, product lines and processes across organizational boundaries to form a new kind of intelligent, networked and agile supply chain (Schuh *et al.*, 2017).

The *fourth industrial revolution* is becoming more and more important within the industrial landscape. According to this, both the technical and scientific literature proposed different neologisms related to the fashion industry and I4.0 such as Fashion 4.0 (Behr, 2018), Textile 4.0 (Küsters *et al.*, 2017) and Apparel 4.0 (Gökalp *et al.*, 2018). It is important to note how Textile 4.0 refers to processes related to the textile industry that are significantly different from those involved in the footwear industry. So, being this paper the result of the study with a footwear company, our research better fits with Fashion 4.0 and Apparel 4.0 neologisms.

However, the industrial context analysed in this paper is far from the objectives indicated in the literature to achieve full I4.0 maturity. In particular, the fashion-luxury industries, especially the Italian luxury manufacturers, where there is always a high level of craftsmanship, have just started to adopt technologies related to I4.0 (Salvador, 2018).

Owing to these considerations, the fashion-luxury sector is constantly evolving and the need to increase the efficiency of production, SCM and product development is growing (Takamitsu and Gobbo Jr, 2019). The aim is to short the time-to-market of a new product maintaining a high level of customization. So, new tools must be introduced that allow practitioners to analyse in a structured way production and supply chain problems in order to start projects with a continuous improvement logic (Carmignani and Zammori, 2015). Therefore, the focus of our manuscript is to present:

(1) A simple tool that can assist practitioners (1) to analyse fashion supply chains inefficiencies, (2) identify their root causes and (3) to develop and implement adequate countermeasures. The investigation tool used is the 5-Whys analysis.

(2) How I4.0 technologies can help to eliminate the root causes identified, describing, at the same time, the difficulties for the introduction of these new technologies. In addition, we want to discuss, from a practical viewpoint, the introduction of I4.0 in the fashion sector, integrating theoretical postulates (e.g. Gökalp *et al.*, 2018).

(3) The limitations related to the fashion-luxury supply chain due to a production entrusted to highly artisanal companies, which is typical of the Italian manufacturers (Merlo, 2018).

The remainder of this paper is organised as follows. In Section 2, relevant literature review is provided. It analyses manuscripts dealing with the importance of proper information exchange in the supply chain for the planning and scheduling activities. In addition, we focused the attention on a specific topic mostly considered by fashion manufacturers: New product development (NPD) phase. Section 3 justifies the utilization of the 5-Whys Analysis as investigation tool. In order to show the operating principles and results of the proposed framework, a practical application in an international Italian company of the fashion-luxury footwear sector is presented in Section 4. In the same section, particularly attention has been focused on recent developments regarding enabling technologies of I4.0. Section 5 outlines theoretical and practical implications. Finally, Section 6 is devoted to conclusions and future remarks.

2. Literature review

According to Caniato *et al.* (2008) the main success factors of a fashion-luxury company are high level of quality, heritage of craftsmanship, exclusivity of products, emotional appeal, brand reputation, recognizable style and association with a country of origin. So far, the fashion-luxury sector has given greater importance to quality than production efficiency (Carmignani and Zammori, 2015). In Italy, fashion-luxury companies have turned to production districts made up of small and medium enterprises (SMEs) where quality and craftsmanship represent the strengths (Merlo, 2018). However, with the growth of *fast fashion* (Sull and Turconi, 2008), also the luxury brands have required suppliers to be more flexible and faster to meet market demand (Carmignani and Zammori, 2015). This means to rapidly change production strategies, with the associated risk of encounter issues during the implementation of improvements project which involve the entire supply chain. Indeed, the management is particularly complex due to various factors that lead to the high unpredictability of the demand.

As stated in Section 1, fashion supply chains are highly consumer-demand driven and face many operational challenges coming from high demand and supply side uncertainties. To address the described issues several authors proposed different approaches. Hilletofth and Hilmola (2008) indicated the most suitable supply chain strategy to adopt, Simatupang *et al.* (2004) described supply chain coordination mechanisms and McCullen and Towill (2001) reported four material flow principles to reduce bullwhip effect. Finally, Carmignani and Zammori (2015) proposed a framework to implement the Lean/TQM model in a luxury supply chain, highlighting how, while Lean principles still apply, the implementation methods and tools must be adapted to the fashion sector.

Besides, a common issue related to SCM is the miscommunication between supply chain partners. It is crucial but immensely challenging for fashion companies provide the needed information (e.g. demand forecasting, real-time sales data, consumer return and feedback, inventory status) to other members to improve the overall supply chain performance. According to this, the fashion literature has clustered into two main categories, which both define a critical step towards the correct flow of information across the entire supply chain:

(1) The importance of information exchange in the supply chain for the planning and scheduling production activities;

(2) The management of operations and the exchange of information during the NPD phase.

Starting with the first point, it is important to highlight how the exchange of information along the supply chain is fundamental, not only for the planning and scheduling activities but also for all operations regarding it (Anand and Goyal, 2009). By a way of example, in addition to receive information from vendors, fashion suppliers may also influence retailer decisions by sharing the information available to them (Liu and Özer, 2010).

In order to reach a good level of planning and scheduling of all the members of the supply chain, the main fashion brand, *i.e.*, the leader in the supply chain which plans activities at various levels, must know the production capacity and delivery times of the supply chain partners. These aspects are underlined, in different manners, in the papers of Yao and Liu (2009) and Dolgui *et al.* (2019).

Wen *et al.* (2019) highlighted how, both in the technical and in the scientific literature, a very useful way to achieve good levels of coordination within the supply chain is the proper stipulation of contracts between the members of the chain. Different types of contracts have been drawn up (see, for instance, Liu and Özer, 2010).

One way to improve the exchange of information and introduce the world of I4.0 along the fashion-luxury supply chain is to adopt digital data. It is important to underline the differences between two terms related to digital data in I4.0: *digitization* and *digitalization*. According to Schumacher *et al.* (2016) digitization means "...the introduction of new technologies that can allow using digital data and describes the conversion of continuous analogue, noisy and smoothly varying information into clear bits of 1s and 0s". Digitalization means "...a change in the business of a company and describes the social implications of increased computer-assistance, new media and communication platforms for economy, society and culture".

In a supply chain, data of interest not only concern historical data (e.g. the production capacity and delivery times) but also real-time data (e.g. inventory level, customer traffic, product return, and consumer feedback), future trends and knowledge of competitors. Digital data allow a quick and easy sharing of information with business partners achieving, at the same time, greater integration of the supply chain. Melkonyan *et al.* (2019) suggested to adopt new digital technologies in order to achieve greater transparency, reliability and flexibility. Chen (2010) stated that business resources are used more efficiently with an integrated SCM. Finally, Zhong *et al.* (2015) stated how information from Big Data can be used to create effective logistic plan, production plan and scheduling. Confirming the importance of the analysis of the data collected, Banica and Hagiu (2016) stated that fashion companies that invest in implementing solutions for gathering, processing and analysing internal data, combined with external consumer and market data, have a competitive advantage in the marketplace.

In addition, focusing the attention on the second point of the numbered list mentioned above, another critical point towards the correct flow of information across the entire supply chain regards the NPD phase. NPD is a process developed in several stages. Among them, the research and development of new products usually take place during the period prior to fashion shows and fairs (*e.g.* the Pitti Florence fair, Milan and Paris fashion weeks), where first sales and commercial launches of new products are recorded (Bandinelli *et al.*, 2013).

Usually, the design of a new collection of a fashion-luxury brand starts about six months before a fashion show debut (Takamitsu and Gobbo Jr, 2019). However, the market demand for new models is growing, so it is necessary to speed up the NPD processes (D'Avolio *et al.*, 2019). According to Choi *et al.* (2005), a key factor for the success of a new product is the time-to-market. The NPD concerns several areas for improvements such as the development time of a new product, and the easiness with which it can be industrialized (Rauch *et al.*, 2017). Moreover, communication covers a fundamental role in this phase because NPD concerns multiple business areas and suppliers which are involved in the development and industrialization phases (Lanarolle *et al.*, 2016). Indeed, according to Shen *et al.* (2016), many fashion brands move from the traditional Original Equipment Manufacturing (OEM) strategy to the Original Design Manufacturing (ODM) strategy. In this context, brands supervise and approve the progress of the work. Especially in sampling and industrialization phase, revisions of the new models and exchanges of information are frequent in order to correctly conceive the final product. Since NPD is shared among several members of the supply chain, the rapid and proper sharing of information is fundamental.

According to Ciappei and Simoni (2005), companies that use advanced information and communication technologies in the NPD phase have a higher success rate. To improve collaboration between supply chain partners during the NPD phase, product lifecycle management (PLM) software (SW) are emerging. As stated by Sen (2008), these SW reduce the product development time. In addition, even Big Data can be used to help the design of new products helping in the choice of new articles to be developed (Banica and Hagiu, 2016).

Based on the state of the art analysis, and to the best of the author's knowledge, a structured and operative framework able to (1) highlight the most recurring problems along a supply chain due to a limited sharing of information, (2) identify the associated roots causes and (3) suggest possible improvements highlighting, at the same time, how enabling technologies of I4.0 can help supply chains to grow and, consequently, meet new market demands is still missing.

3. Root cause analysis and 5-Whys

Solving problems requires to identify their root causes and, later, to develop and implement adequate countermeasures. In this regard, root cause problem solving (RCPS) can be considered as a structured problem-solving approach using simple standardised tools to identify and resolve critical problems encountered in manufacturing operations. RCPS analysis tools commonly used are cause-and-effect (CED) diagram, interrelationship diagram, current reality tree and the 5-Whys analysis (Murugaiah *et al.*, 2010).

Among them, the 5-Whys analysis has been successfully implemented in many industrial contexts to investigate and categorize the root causes of events with health, safety, environmental, reliability, quality and production issues (Benjamin *et al.*, 2015; Murugaiah *et al.*, 2010). Ohno (1988) described the 5-Whys as "the basis of Toyota's scientific approach. . .by repeating why five times, the nature of the problem as well as its solution becomes clear". Thanks to its ease of use, 5-Whys is still receiving attention in the literature (Gangidi, 2019), and several authors proposed a combined implementation with other analysis and improvement tools (Braglia *et al.*, 2017).

Differently from other more sophisticated problem-solving techniques, the 5-Whys does not involve advanced statistical tools and is particularly suitable to be integrated into several industrial contexts. Moreover, differently from Ishikawa Diagram, i.e. a CED diagram, the 5-Whys does not represent cause categories that should be evaluated as having been potential contributors to the sequence of events. These categories change from user to user. So, a typical issue of the Ishikawa Diagram is that if the correct categories for the event at hand are not selected, key causes and contributing factors could be overlooked (Barsalou, 2014). Finally, 5-Whys quickly identifies the root cause of a problem, without using extraordinarily tedious and time-consuming tools such as, for instance, the Failure Mode and Effects Analysis.

Actually, the "lack of rigour" could be a drawback of 5-Whys analysis, as the analysts are not required to test for sufficiency the root causes generated. In addition, this technique requires adequate knowledge of the system under study and of the effect to investigate. If the cause is unknown to the analyst, using 5-Whys may not lead to any meaningful answers. Finally, according to Latino *et al.* (2019), people tend to use this tool as individuals and not in a team, and they rarely back up their assertions with evidence.

However, in our study, the 5-Whys analysis was conducted in collaboration with different expertise to validate the root causes found through empirical analysis. Besides, each identified problem was associated with multiple root causes. Therefore, with the aim of maintaining operational simplicity and speed in carrying out the analysis, combined approaches have not been used and more complex techniques have not been considered. Nevertheless, the purpose for which we use this tool in our approach offers a guarantee about its adequacy.

4. The 5-Whys analysis in an international firm

An international Italian signature in the world of fashion-luxury footwear sector has been assisted in the analysis of its supply chain during the launch of an internal project. The firm started the project because it registered a lot of misalignments between the planned activities and real ones, causing a lot of troubles to satisfy customers due date.

In order to understand the dynamics of the supply chain, the standard production processes were initially studied and mapped (as-is analysis), analysing in detail the planning, programming and control phases. The analysis started with the study of the deviation, in terms of delivery dates, measured between the planning and the actual release of the product. This was the consequence of several inefficiencies such as the lack of:

(1) A shared system for measuring and monitoring performances;

(2) The connections between the local production system and the signature (updating of the progress of the orders);

(3) The reliability of the results of the production planning process.

Then, in order to explore the cause-and-effect relationships between inefficiencies, the analysis team decided to apply the *5-Whys Analysis*. It was executed by a team composed of operation, design and managers. The manager of the supply chain was appointed as leader of the working team.

As will be shown in the next sections, the analysis was performed according to two processes of interest:

(1) Misalignments in the planning of the product and process industrialization phases;

(2) Misalignments between the production planning of the supply chain and the actual release of the product.

4.1 Misalignments in the planning of the product and process industrialization phases

The industrialization phase consists of two sequential sub-phases: the product industrialization phase, where the bill of materials is completed, and the process industrialization phase, where the final specifications of the production processes are defined. The rapid development of a new product is an essential phase at the start of a new selling season. Only when the new model is ready the order can be sent to the producer to start the production phase. Consequently, if the industrialization phase is late, also the production phase may have trouble to respect the orders due date.

About 321 orders of the product industrialization phase and 220 orders of the process industrialization phase were extracted from a database. The number of orders differed because only the orders in which the dates of all the subphases have been considered. In both cases, only working days were considered and a subphase was deemed to be delayed if the misalignment between planned and actual time was greater than one week (five working days).

4.1.1 Misalignments in the planning of the product industrialization phase. Two subphases were taken as reference for product industrialization:

(1) *Start of industrialization*: initial phase of the industrialization process

(2) *Model Ok*: phase at the end of which the definition of the new model was completed

The product industrialization phase was already late in the first phase in 62.0% of cases, while the *Model Ok* phase was late in 39.3% of cases. For the *Start of industrialization* phase was granted on average 2.55 days, while for the *Model Ok* phase was granted on average

26.7 days. Individual activities took an average of 2.05 and 18.9 days, respectively. Delays were mostly accumulated in the first phase with an average delay of 21.6 days.

In order to identify the root causes of the inefficiencies highlighted, the 5-Whys Analysis was performed (Figure 1).

The root causes showed a lack of management capacity on the part of the shoe factories regarding the industrialization of the product. The only cause attributable to several players in the supply chain was the lack of materials to produce test products for industrialization due to the absence of manufacturing-lines dedicated to the production of semi-finished products at all levels of the supply chain.

In Figure 1 it is possible to see the managerial solutions and the tools identified that deal with:

(1) Greater sharing of knowledge of product industrialization activities;

(2) Making the shoe factories more flexible in order to compensate the peaks of work received;

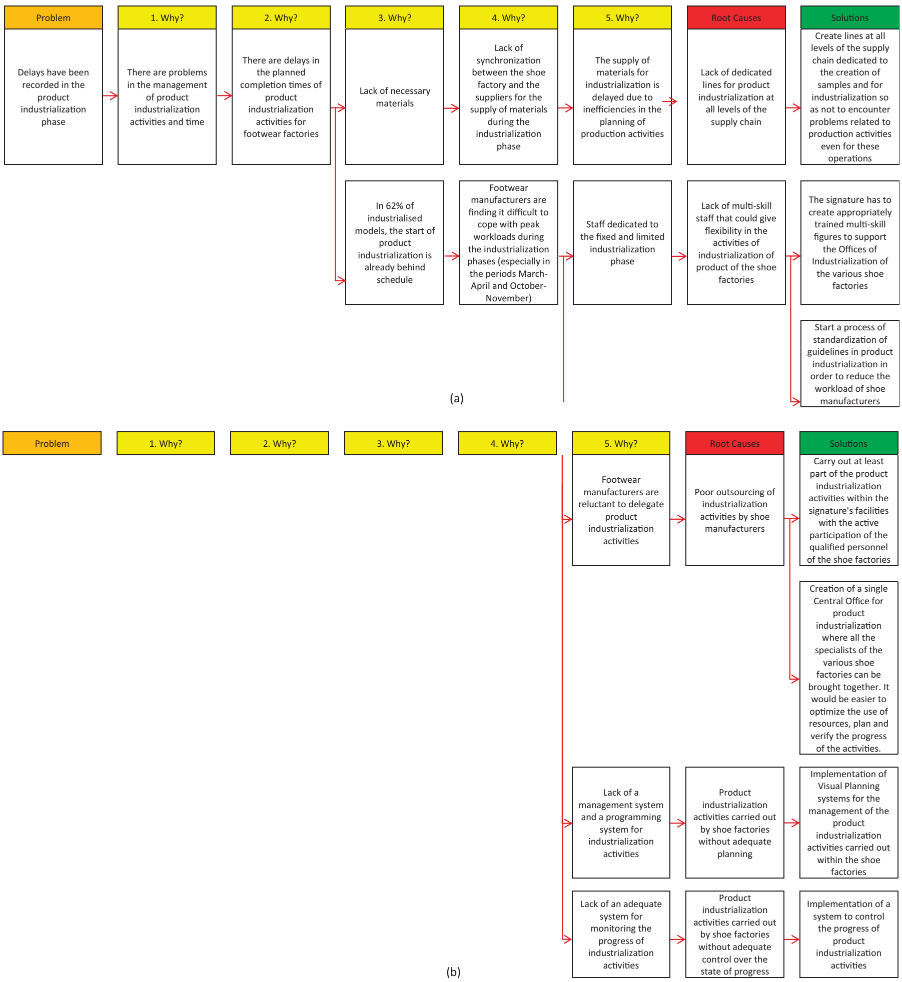

Figure 1.
The 5-Whys analysis for the product industrialization phase

(3) Introducing systems dedicated to the planning and control of the progress of industrialization activities (PLM, visual planning systems).

By starting a staff training process, internal resources could be reallocated to the industrialization activities. Moreover, by standardizing some guidelines of product industrialization, the workload of the shoe factories could be reduced. Finally, by introducing a scheduling system for planning activities and a system to monitor the progress of production, it would be possible to optimize the management of this phase.

4.1.2 Misalignments in the planning of the process industrialization phase. The data related to the process industrialization phase were collected on reports compiled manually and were available as secondary data. The following subphases were taken as reference:

(1) *Model Ok*: phase at the end of which the definition of the new model was completed.

(2) *Hollow cutter Ok*: phase at the end of which were completed the tools that allow a precise cut of the uppers.

(3) *Upper Ok*: phase at the end of which all the instructions necessary for the realization of the upper were collected.

No significant delays were registered in the *Model Ok* subphase, while *Hollow cutter Ok* and *Upper Ok* registered an average increase of processing time of 28 and 56%, respectively. Figure 2 reports the 5-Whys analysis performed.

The analysis showed that the process industrialization activities were poorly managed from an operational point of view. In addition, no tools were used to monitor the progress of an order. Finally, it was highlighted how these activities were carried out for an excessive number of models, which could not reach the production phase.

A managerial and a technical solution, i.e. the introduction of a new visual tool, were identified and reported below:

(1) Select new models to be developed completely or as a matter of priority, based on a cost analysis;

(2) Improve the monitoring status of the progress of the process industrialization activity, adopting Visual management systems (see, for instance, Parry and Turner, 2006) and starting to use digital systems for the collection of information.

By switching to a digital format for collecting process industrialization data and implementing the above solutions, it would be easier to manage industrialization activities and streamline the entire industrialization process by reducing the number of models to be developed during this phase.

4.2 Misalignments between the production planning of the supply chain and the actual release of the product

As already highlighted for the industrialization phase, the exchange of informations within the supply chain is essential. Only through the shared knowledge of the partners' capabilities

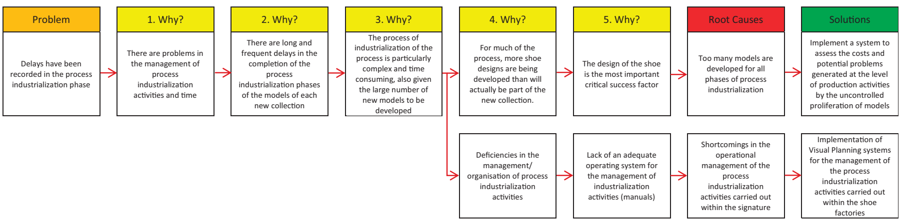

Figure 2.
The 5-Whys analysis for the process industrialization phase

is possible to synchronize the production flow. One department with a lack in the sharing of informations was the supply chain planning department. Without reliable data on the performance of the various supply chain partners, it is impossible to satisfy a production plan. The misalignment in the transfer of the orders between the supply chain members causes a lot of trouble in the management of the production systems of the single companies, causing further delays.

11,723 production orders were analysed. 81% of them had an overall lead time (LT, measured in working days) that deviated by at least one working week (five days) from what was planned. Considering only late orders as relevant, 70% of them exceeded the planned delivery times. These relevant results were the starting signal to try to identify the root causes of these misalignments between planned and real activities. Even in this context, the 5-Whys analysis was carried out (Figure 3).

Multiple root causes were registered at various levels of the supply chain: *(1)* signature, *(2)* shoe factories, *(3)* uppers and other suppliers of semi-finished products and *(4)* tanneries.

Some were linked to technical/technological deficiencies (e.g. long and costly setup activities), others to management gaps in the supply chain (e.g. use of unreliable production times of companies to plan activities). So, managerial and lean-oriented solutions and tools (SW and hardware) were associated with each root cause. The solutions proposed were linked to:

(1) Improve communication channels within the supply chain;

(2) Increase knowledge of the production capacities of the actors in the supply chain;

(3) Obtain more information on the progress of work orders;

(4) The introduction of contractual and management policies that lead to the achievement of specified production standards and of the synchronization of the supply chain;

(5) The introduction of SW systems (e.g. Capacity requirement planning, CRP; Supply Chain Event Management, SCEM) that allow to better manage the supply chain;

(6) SMED activities to speed up machine setup times and allow the adoption of small production batches.

The digitization of data played a fundamental role in many of the proposed solutions because it would allow a direct sharing of information between the various actors in the supply chain. The use of SCEM would be fundamental for achieving greater coordination. SCEM provides timely event-related information that can be used to identify and correct disruptions and malfunctions in operational supply-chain processes (Bodendorf and Zimmermann, 2005). By digitizing information, transmitting it via SW like SCEM and sharing it via Cloud systems, using material tracking systems such as RFID and analysing the data obtainable from the actors of the supply chain (Data Analytics), the reference signature would obtain a greater knowledge of the status of the entire supply chain. The signature could be able to carry out more effectively the planning of activities and react promptly to the emergence of delays or problems encountered during the production of specific production orders.

4.3 Improvement through industry 4.0 technologies

As stated above, enabling technologies of I4.0 were associated with the root causes carried out in order to evidence how the technologies could help to improve the management of the supply chain, by eliminating the root causes identified.

The technologies related to I4.0 are recognized as enabler to enhance the production rate, production flexibility and agility (Bertola and Teunissen, 2018). The future aim is to create a *smart factory* described as "... a manufacturing solution that reach high level of flexibility and adaptivity through a collaboration between industrial partners" (Radziwon *et al.*, 2014).

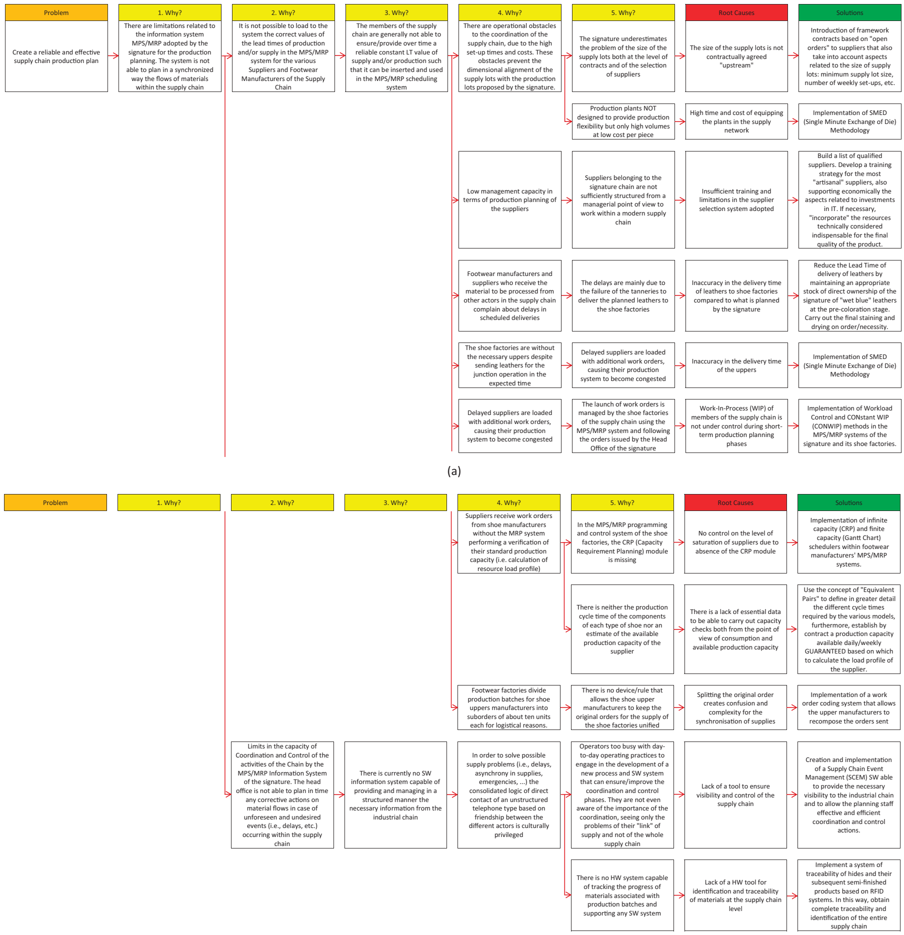

Figure 3.
The 5-Whys analysis for production planning misalignments

All these features must be enhanced in a footwear supply chain. According to this, this work is the result of a collaboration with a firm interested in gradually involving his industrial partner to I4.0 technologies in order to reach the improvements listed above.

We took as reference the nine enabling technologies defined by Boston Consulting (Bcg), which are the same indicated in the 2016 “Piano Nazionale Industria 4.0” of the Italian Ministry of Economic Development (Mise): Industrial Internet, Cloud, Cybersecurity, Big Data Analytics, Simulation, Horizontal and Vertical Integration, Additive Manufacturing, Autonomous Robots, Augmented Reality.

Table 1 includes enabling technologies in the columns, while the rows show the root causes identified in Section 4.1.1 (Figure 1), 4.1.2 (Figure 2), and 4.2 (Figure 3) (rows). If an enabling technology could bring effort in eliminate a root cause, the corresponding cell in Table 1 shows a mark.

Autonomous Robots and Additive Manufacturing are not reported in Table 1. Regarding Autonomous Robots, luxury brands entrust their product development and production to

Table 1. Enabling technologies of I4.0 associated with the root causes identified during the analysis

Problems	Root causes	Enabling technologies: Big data analytics	Simulation	Horizontal and vertical system integration	The industrial internet of things	The cloud	Augmented reality
Delays have been recorded in the product industrialization phase	Lack of dedicated lines for product industrialization at all levels of the supply chain		X				
	Lack of multi-skill staff that could give flexibility in the activities of industrialization of product of the shoe factories						X
	Poor outsourcing of industrialization activities by shoe manufacturers			X			
	Product industrialization activities carried out by shoe factories without adequate planning	X		X			
	Product industrialization activities carried out by shoe factories without adequate control over the state of progress			X	X		
Delays have been recorded in the process of industrialization phase	Too many models are developed for all phases of process industrialization	X					
	Shortcomings in the operational management of the process industrialization activities carried out within the signature			X			
Create a reliable and effective supply chain production plan	The size of the supply lots is not contractually agreed "upstream"		X	X			
	Insufficient training and limitations in the supplier selection system adopted	X					
	Inaccuracy in the delivery time of leathers to shoe factories compared to what is planned by the signature	X		X			
	Inaccuracy in the delivery time of the uppers	X		X			
	Work-In-Process (WIP) of members of the supply chain is not under control during short-term production planning phases	X		X	X		
	No control on the level of saturation of suppliers due to absence of the CRP module	X		X			
	There is a lack of essential data to be able to carry out capacity checks both from the point of view of consumption and available production capacity	X		X			
	Splitting the original order creates confusion and complexity for the synchronisation of supplies			X			
	Lack of a tool to ensure visibility and control of the supply chain	X		X	X	X	
	Lack of a HW tool for identification and traceability of materials at the supply chain level			X	X	X	

Italian craftsmen for the quality that they can achieve with their craftsmanship. This sector is associated with a low level of automation. According to Maurtua *et al.* (2012), the main reasons for not considering this technology are (1) the high number of product variants and (2) the complexity of the manufacturing and assembly process. These motivations lead to disregard the creation of *dark factories* [1] in this sector because the human labour has a primary role. On the other hand, Additive Manufacturing could be associated with improvement in the realization of prototype of polymeric components like outsole of a sneaker (Manoharan *et al.*, 2013). However, we did not find any correlation with the root causes identified during the analysis.

Below there is a list of improvements that could be implement in the footwear supply chain by introducing the enabling technologies indicated in Table 1:

(1) *Horizontal and vertical integration. Horizontal integration* of the supply chain aims to integrate resources and information systems along the value chain of product life cycle in order to obtain cooperation between supply chain companies (Stock and Seliger, 2016). *Vertical integration* aims at the connection between different hierarchical and aggregation levels along the path of value creation that passes through the production lines, but also through other departments (e.g. the sales department or Research and Development, R&D) (Zhou *et al.*, 2015). The importance of horizontal and vertical integration is confirmed in Behr (2018).

(2) *Big data analytics.* Through data collected and shared among various members of the supply chain, it would be possible to obtain reliable information regarding the performance of each partner for both industrialization and production activities. Data could also be collected to assist the selection of products to be developed, by analysing the markets trends. This is justified by Banica and Hagiu (2016) which clearly demonstrate the usefulness of Big Data in the apparel industry.

(3) *Simulation.* With the results obtained from the data analysis and creating a *Digital Twin* [2] of the supply chain, alternative production scenarios could be studied that allow optimizing the production activities (e.g. the choice of the optimal production lot, or the evaluation of the optimal production layout) as shown in Dang *et al.* (2016).

(4) *Industrial internet.* Through communication between production processes and products, production progress could be recorded automatically, allowing continuous monitoring of the progress of production. The importance of Internet of Things (IoT) in supply chain and the role of Cyber Physical System (CPS) are explained in Manavalan and Jayakrishna (2019).

(5) *Cloud.* Cloud services would enable the rapid sharing of information held by individual members of the supply chain, leading to transparency in the supply chain and also allowing to collect data for future analysis. This is justified in Banica and Hagiu (2016) and in (SupplyChain digital).

(6) *Augmented reality.* It permits to quickly train staff members, allowing companies to reallocate internal staff according to workloads.

As just reported, a fundamental step towards the integration of the supply chain is the digitization of the various activities. The digitalization of the supply chain aims to create a single integrated ecosystem able to harmonize and manage the planning of purchases, production, stocks, distribution and services, with the final aim to guarantee a high quality of products and services to the end customer. Therefore, the production planning and production advancement system introduced by the signature can be seen as a digital platform that allows end-to-end visibility into all stages of supply chain planning and supports decision-making and execution.

SCEM could help to integrate the supply chain and to rapidly react to unexpected events. By collecting data from the entire supply chain, it is possible to improve the ability of these systems to respond to unforeseen events by obtaining a proactive SCEM as illustrated in the work of Bodendorf and Zimmermann (2005). Also new versions of MESs (Manufacturing Execution Systems) could help in the coordination and in the scheduling activities of the entire supply chain.

Useful tools that can help fashion supply chains to start thinking as a smart manufacturing system have been introduced. According to Kusiak (2018), smart manufacturing is a fully integrated, collaborative manufacturing system that responds in real time to meet changing demands and conditions in the factory, in the supply network and in customer needs. In this context, it is relevant to control communications between machines and it is possible with CPS, defined as transformative technologies for managing interconnected systems between its physical assets and computational capabilities (Lee *et al.*, 2015), and IoT, that represent connected devices to Internet, leading to a machine-to-machine (M2M) communication (Benattia and Ali, 2008). Besides, it is also possible to reach a greater level of interconnection linking together human, devices (things), data and industrial processes leading to Internet of Everything (IoE). According to Miraz *et al.* (2018), IoT is only related with devices, while IoE includes M2M communication, machine-to-people (M2P) and technology assisted people-to-people (P2P) interactions. Reaching this level of interconnection could lead to use a *connected enterprise* strategy that allows a company to enable informed, adaptive and proactive decisions through the connection of people, equipment and processes (Otieno *et al.*, 2017).

However, the companies of the Italian fashion-luxury supply chains are mainly SMEs. These companies have limited resources and present gaps in terms of cognitive and organizational assets. Consequently, the introduction of new technologies must be gradual and assisted by professional experts (Li *et al.*, 2018).

5. Discussion

This paper is the result of the application of the *5-Whys Analysis* able to identify the root causes associated with the most effective inefficiencies encountered in the analysis of a fashion-luxury supply chain. To the best of our knowledge, this is the first time that 5-Whys Analysis is performed in the analysis of a fashion supply chain. The whole analysis is easily reproducible and does not involve statistical tools or other more sophisticated problem-solving techniques. The 5-Whys Analysis is conducted in collaboration with different expertise to validate the root causes found through empirical analysis. This is particularly important because the implementation of the solutions concerns not only the signature but also the suppliers.

Moreover, in the proposed framework, I4.0 technologies are related to the root causes identified to allow a further improvement of the fashion supply chain. According to Davies *et al.* (2017) improvements in the management of production flows (e.g. with Lean Production methods) are mutually supported by the introduction of technologies related to I4.0. Waste-free processes are considered facilitators of I4.0 and I4.0 can strengthen process performances. Besides, the entire process described must be seen from the perspective of continuous improvement. In this logic, we report below some improvement projects implemented by the firm in order to eliminate the root causes identified during the analysis:

(1) Implementation of new methods of management of tanneries with postponement techniques to reduce the delivery time of leathers.

(2) Implementation of dashboards to monitor and control the performance of suppliers.

(3) Introduction of SW (CRP, PLM) to support activity planning and product management.

(4) Alignment of data on processing time available to shoe manufacturers.

In logic 4.0, improvements started with the digitization of data and the transfer of information through web platforms. Pilot projects were also launched to monitor the progress of the production of tanneries and shoe factories through RFID systems.

It is important to underline that the Italian firm, which collaborates with several SMEs, has to assume the role of supporting and directing investments of companies with limited economic resources to allow a complete development of the supply chain, not only from a technological point of view but also managerial and organizational. The signature outlines improvement that start with the review of production flows, industrialization and management of orders associated with the introduction of I4.0 technologies. Performance improvement of suppliers allows the firm to create a more efficient network.

6. Conclusions and future developments

This paper presents a structured framework which objectives are to identify, analyse and eliminate luxury supply chains inefficiencies.

The validity of the tool is confirmed by an industrial application included in this article. The results obtained demonstrate how the tool can provide guidance and support to align companies' strategies and operations in the fashion-luxury supply chain. In addition, due to its structured step-by-step procedure, its implementation in interconnected electronic worksheets is simple assuring the ease of use for the user.

However, it was noted that in the apparel luxury industries, especially in the Italian luxury manufacturers, the body of knowledge related to the enabling technologies of I4.0 is rather limited.

In this direction, future research can concern the development of a maturity model to systematically assess fashion-luxury manufacturing companies' state-of-development in relation to the I4.0 vision. The maturity model must be studied with a dual purpose: scientific and practical. The scientific purpose aims at gaining solid data about the current state of fashion-luxury manufacturing companies and their I4.0 strategies to extract potential success factors. The practical purpose aims at enabling a company to rigorously evaluate their own I4.0 maturity and reflect the fitness of current enabling technologies. Furthermore, the real value of the introduction of I4.0 technologies in fashion-luxury supply chain can be assessed. These evaluations would prioritise the introduction of several technologies. It could be useful to define an "ad hoc" supply chain CPS conceived for the apparel industrial. The coupled model is a digital twin of the supply chain that operates in the cloud platform and simulates the health condition with an integrated knowledge from both data-driven analytical algorithms and other available physical knowledge. In this way, it is possible to increase the reliability of the supply chain.

Finally, this paper highlights the importance of the planning phase also linked to the release of a limited number of orders to minimize the WIP of suppliers. In this direction, future research could involve the development of a SCM model that follows the logic of the card-based systems used in production environments such as, for instance, Kanban, POLCA or COBACABANA.

Notes

1. Factories that are fully automated and require no human presence on-site
2. Digital twin is a virtual/digital representation of a physical entity or system

References

Adhikari, A., Bisi, A. and Avittathur, B. (2020), "Coordination mechanism, risk sharing, and risk aversion in a five-level textile supply chain under demand and supply uncertainty", *European Journal of Operational Research*, Vol. 282 No. 1, pp. 93-107.

Afshari, H. and Benam, F.H. (2011), "Retail logistics", in Farahani, R. and Kardar, L. (Eds), *Logistics Operations and Management*, Iran Khodro Industrial Group (IKCO), Iran, pp. 267-289.

Anand, K.S. and Goyal, M. (2009), "Strategic information management under leakage in a supply chain", *Management Science*, Vol. 55 No. 3, pp. 438-452.

Bandinelli, R., Rinaldi, R., Rossi, M. and Terzi, S. (2013), "New product development in the fashion industry: an empirical investigation of Italian firms", *International Journal of Engineering Business Management*, Vol. 5 No. 31, pp. 91-99.

Banica, L. and Hagiu, A. (2016), "Using big data analytics to improve decision-making in apparel supply chains", in Choi, T.-M. (Ed.), *Information Systems for the Fashion and Apparel Industry*, Woodhead Publishing, Sawston, pp. 63-95.

Barsalou, M.A. (2014), *Root Cause Analysis – A Step-By-Step Guide to Using the Right Tool at the Right Time*, CRC Press, Boca Raton, Florida.

Behr, O. (2018), "Fashion 4.0 – digital innovation in the fashion industry", *Journal of Technology and Innovation Management*, Vol. 2 No. 1, pp. 1-9.

Benattia, A. and Ali, M. (2008), "Convergence of technologies in the machine-to-machine (M2M) space", *Proceedings of the IEEE International Conference on Applied Electronics 2008, Pilsen, Czech Republic, 2008*, pp. 9-12.

Benjamin, S.J., Marathamuthu, M.S. and Murugaiah, U. (2015), "The use of 5-WHYs technique to eliminate OEE's speed loss in a manufacturing firm", *Journal of Quality in Maintenance Engineering*, Vol. 21 No. 4, pp. 419-435.

Bertola, P. and Teunissen, J. (2018), "Fashion 4.0. Innovating fashion industry through digital transformation", *Research Journal of Textile and Apparel*, Vol. 22 No. 4, pp. 352-369.

Bertolini, M., Bottani, E., Rizzi, A. and Bevilacqua, M. (2007), "Lead time reduction through ICT application in the footwear industry: a case study", *International Journal of Production Economics*, Vol. 110 Nos 1-2, pp. 198-212.

Bodendorf, F. and Zimmermann, R. (2005), "Proactive supply chain event management with agent technology", *International Journal of Electronic Commerce*, Vol. 9 No. 4, pp. 57-90.

Braglia, M., Frosolini, M. and Gallo, M. (2017), "SMED enhanced with 5-Whys analysis to improve set-up reduction programs: the SWAN approach", *International Journal of Advanced Manufacturing Technology*, Vol. 90 Nos 5-8, pp. 1845-1855.

Caniato, F., Caridi, M., Castelli, C.M. and Golini, R. (2008), "A contingency approach for supply chain strategy in the Italian luxury industry: do consolidated models fit?", *International Journal of Production Economics*, Vol. 120 No. 1, pp. 176-189.

Cao, N., Zhang, Z., To, K.M. and Ng, K.P. (2008), "How are supply chains coordinated? An empirical observation in textile-apparel businesses", *Journal of Fashion Marketing and Management*, Vol. 12 No. 3, pp. 384-397.

Carmignani, G. and Zammori, F. (2015), "Lean-thinking in the luxury-fashion market: evidences from an extensive industrial project", *International Journal of Retail and Distribution Management*, Vol. 43 Nos 10/11, pp. 988-1012.

Chen, Z.-L. (2010), "Integrated production and outbound distribution scheduling: review and extensions", *Operations Research*, Vol. 58 No. 1, pp. 130-148.

Choi, W., Powell, N.B. and Cassill, N.L. (2005), "New product development and its applications in textiles", *Journal of Textile and Apparel, Technology and Management*, Vol. 4, pp. 1-28.

Christopher, M., Lowson, R. and Peck, H. (2004), "Creating agile supply chains in the fashion industry", *International Journal of Retail and Distribution Management*, Vol. 32 No. 8, pp. 367-376.

Ciappei, C. and Simoni, C. (2005), "Drivers of new product success in the Italian sport shoe cluster of Montebelluna", *Journal of Fashion Marketing and Management*, Vol. 9 No. 1, pp. 20-42.

Dang, Q.-V. and Pham, K. (2016), "Design of a footwear assembly line using simulation-based ALNS", *Procedia CIRP*, Vol. 40, pp. 596-601.

Davies, R., Coole, T. and Smith, A. (2017), "Review of socio-technical considerations to ensure successful implementation of Industry 4.0", *Procedia Manufacturing*, Vol. 11, pp. 1288-1295.

D'Avolio, E., Pinna, C., Bandinelli, R., Rinaldi, R. and Terzi, S. (2019), "When product development meets luxury: a case study analysis in fashion, food and furniture companies", in Rinaldi, R. and Bandinelli, R. (Eds), *Business Models and ICT Technologies for the Fashion Supply Chain*, Springer, Charm, pp. 15-24.

Gangidi, P. (2019), "A systematic approach to root cause analysis using 3 × 5 why's technique", *International Journal of Lean Six Sigma*, Vol. 10 No. 1, pp. 295-310.

Gökalp, E., Gökalp, M. and Eren, P. (2018), "Industry 4.0 revolution in clothing and apparel factories: apparel 4.0", in Gülseçen, S., Reis, Z.A., Gezer, M. and Erol, C. (Eds), *Industry 4.0 from the MIS Perspective, Peter Lang*, pp. 169-184.

Hanne, T. and Dornberger, R. (2016), *Computational Intelligence in Logistics and Supply Chain Management*, Springer, Charm.

Hilletofth, P. and Hilmola, O. (2008), "Supply chain management in fashion and textile industry", *International Journal of Services Sciences*, Vol. 1 No. 2, pp. 127-147.

Jain, S. (2019), "Exploring relationship between value perception and luxury purchase intention: a case of Indian millennials", *Journal of Fashion Marketing and Management*, Vol. 23 No. 4, pp. 414-439.

Kusiak, A. (2018), "Smart manufacturing", *International Journal of Production Research*, Vol. 56 Nos 1-2, pp. 508-517.

Küsters, D., Praß, N. and Gloy, Y.S. (2017), "Textile learning factory 4.0 – preparing Germany's textile industry for the digital future", *Procedia Manufacturing*, Vol. 9, pp. 214-221.

Kwok, S. and Wu, K. (2009), "RFID-based intra-supply chain in textile industry", *Industrial Management and Data Systems*, Vol. 109 No. 9, pp. 1166-1178.

Lanarolle, G., Seram, N. and Nanayakkara, J. (2016), "Apparel product development: an overview of existing models", *International Journal of Product Development*, Vol. 21 Nos 5-6, pp. 331-350.

Latino, M.A., Latino, R.J. and Latino, K.C. (2019), *Root Cause Analysis – Improving Performance for Bottom-Line Results*, 5th ed., CRC Press, Boca Raton, Florida.

Lee, J., Bagheri, B. and Kao, H.A. (2015), "A cyber-physical systems architecture for Industry 4.0-based manufacturing systems", *Manufacturing Letters*, Vol. 3, pp. 18-23.

Li, L., Su, F., Zhang, W. and Mao, J.Y. (2018), "Digital transformation by SME entrepreneurs: a capability perspective", *Information Systems Journal*, Vol. 28 No. 6, pp. 1129-1157.

Liu, H. and Özer, Ö. (2010), "Channel incentives in sharing new product demand information and robust contracts", *European Journal of Operational Research*, Vol. 207 No. 3, pp. 1341-1349.

Manavalan, E. and Jayakrishna, K. (2019), "A review of internet of things (IoT) embedded sustainable supply chain for Industry 4.0 requirements", *Computers and Industrial Engineering*, Vol. 127, pp. 925-953.

Manoharan, V., Chou, S.M., Forrester, S., Chai, G.B. and Kong, P.W. (2013), "Application of additive manufacturing techniques in sports footwear", *Virtual and Physical Prototyping*, Vol. 8 No. 4, pp. 249-252.

Maurtua, I., Ibarguren, A. and Tellaeche, A. (2012), "Robotic solutions for footwear industry", *Proceedings of 2012 IEEE 17th International Conference on Emerging Technologies & Factory Automation (ETFA 2012) in Krakow, Poland, 2012*, pp. 1-4.

McCullen, P. and Towill, D. (2001), "Achieving lean supply through agile manufacturing", *Integrated Manufacturing Systems*, Vol. 12 No. 7, pp. 524-533.

Melkonyan, A., Krumme, K., Gruchmann, T., Spinler, S., Schumacher, T. and Bleischwitz, R. (2019), "Scenario and strategy planning for transformative supply chains within a sustainable economy", *Journal of Cleaner Production*, Vol. 231, pp. 144-160.

Merlo, E. (2018), "Italian luxury goods industry on the move: SMEs and global value chains", in Donzé, P.Y. and Fujioka, R. (Eds), *Global Luxury*, Palgrave, Basingstoke, pp. 39-63.

Miraz, M.H., Ali, M., Excell, P.S. and Picking, R. (2018), "Internet of nano-things, things and everything: future growth trends", *Future Internet*, Vol. 10 No. 8, p. 68.

Murugaiah, U., Jebaraj Benjamin, S., Srikamaladevi Marathamuthu, M. and Muthaiyah, S. (2010), "Scrap loss reduction using the 5-Whys analysis", *International Journal of Quality and Reliability Management*, Vol. 27 No. 5, pp. 527-540.

Ohno, T. (1988), *Toyota Production System: Beyond Large-Scale Production*, Productivity Press, Cambridge, MA.

Otieno, W., Cook, M. and Campbell-Kyureghyan, N. (2017), "Novel approach to bridge the gaps of industrial and manufacturing engineering education: a case study of the connected enterprise concepts", *2017 IEEE Frontiers in Education Conference (FIE), Indianapolis, IN, 2017*, IEEE, pp. 1-5.

Parry, G.C. and Turner, C.E. (2006), "Application of lean visual process management tools", *Production Planning and Control*, Vol. 17 No. 1, pp. 77-86.

Preiss, K. and Murray, P. (2005), "Fashions of learning: improving supply-chain relationships", *Supply Chain Management*, Vol. 10 No. 1, pp. 18-25.

Radziwon, A., Bilberg, A., Bogers, M. and Madsen, E.S. (2014), "The smart factory: exploring adaptive and flexible manufacturing solutions", *Procedia Engineering*, Vol. 69, pp. 1184-1190.

Rauch, E., Dallasega, P. and Matt, D.T. (2017), "Critical factors for introducing lean product development to small and medium sized enterprises in Italy", *Procedia CIRP*, Vol. 60, pp. 362-367.

Salvador, S. (2018), "Fashion 4.0: an empirical analysis of how Northern Italian firms cope with Industry 4.0 Technologies", Master's thesis, University of Padova, Padova.

Schumacher, A., Sihn, W. and Erol, S. (2016), "Automation, digitization and digitalization and their implications for manufacturing processes", *Innovation and Sustainability International Scientific Conference. Sustainable in Bucharest, Romania, 2016*.

Sen, A. (2008), "The US fashion industry: a supply chain review", *International Journal of Production Economics*, Vol. 114 No. 2, pp. 571-593.

Shen, B., Li, Q., Dong, C. and Quan, V. (2016), "Design outsourcing in the fashion supply chain: OEM versus ODM", *Journal of the Operational Research Society*, Vol. 67 No. 2, pp. 259-268.

Simatupang, M., Victoria Sandroto, I. and Hari Lubis, S.B. (2004), "Supply chain coordination in a fashion firm", *Supply Chain Management*, Vol. 9 No. 3, pp. 256-268.

Stock, T. and Seliger, G. (2016), "Opportunities of sustainable manufacturing in Industry 4.0", *Procedia CIRP*, Vol. 40, pp. 536-541.

Sull, D. and Turconi, S. (2008), "Fast fashion lessons", *Business Strategy Review*, Vol. 19 No. 2, pp. 4-11.

Takamitsu, H. and Gobbo, J., Jr (2019), "News approaches (insights) to NPD on the fashion segment: the power of social networks and the system see now buy now", in Rinaldi, R. and Bandinelli, R. (Eds), *Business Models and ICT Technologies for the Fashion Supply Chain*, Springer, Charm, pp. 3-14.

Wen, X., Choi, T.-M. and Chung, S. (2019), "Fashion retail supply chain management: a review of operational models", *International Journal of Production Economics*, Vol. 207, pp. 34-55.

Yao, J. and Liu, L. (2009), "Optimization analysis of supply chain scheduling in mass customization", *International Journal of Production Economics*, Vol. 117 No. 1, pp. 197-211.

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

Zhou, K., Liu, T. and Zhou, L. (2015), "Industry 4.0: towards future industrial opportunities and challenges", *Proceedings of the 12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD) in Zhangjiajie, China, 2015, IEEE*, pp. 2147-2152.

Schuh, G., Anderl, R., Gausemeier, J., Ten Hompel, M. and Wahlster, W. (2017), "Industry 4.0 maturity index - managing the digital transformation of companies", available at: https://en.acatech.de/wp-content/uploads/sites/6/2018/03/acatech_STUDIE_Maturity_Index_eng_WEB.pdf (accessed 19 December 2019).

Dolgui, A., Ivanov, D., Sethi, S.P. and Sokolov, B. (2019), "Scheduling in production, supply chain and Industry 4.0 systems by optimal control: fundamentals, state-of-the-art and applications", *International Journal of Production Research*, Vol. 57 No. 2, pp. 411-432.

available at: https://www.statista.com/outlook/21030000/100/luxury-fashion/worldwide?currency=eur (accessed 3 December 2019).

available at: https://www.statista.com/outlook/21030000/141/luxury-fashion/italy (accessed 3 December 2019).

available at: https://www.bcg.com/it-it/capabilities/operations/embracing-industry-4.0-rediscovering-growth.aspx (accessed 20 April 2020).

available at: https://www.mise.gov.it/images/stories/documenti/Piano_Industria_40.pdf (accessed 20 April 2020).

available at: https://www.supplychaindigital.com/logistics/cloud-addresses-challenges-clothing-industry (accessed 12 December 2019).

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