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Industry 4.0 technologies and managers' decision-making across value chain. Evidence from the manufacturing industry

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ABSTRACT
The paper aims to identify how Industry 4.0 technologies affect the quality and speed of the managers' decision-making process across the different stages of the value chain, based on the example of the manufacturing sector. The paper adopts qualitative research, based on nine in-depth interviews with key informants, to capture senior executives' experiences with implementing Industry 4.0 technologies in their organisations. The research is focused on three manufacturing industries: the automotive, food and furniture industries. The research shows that depending on the stage of the value chain, different Industry 4.0 technologies are more suitable for the support of managers' decisions. Various Industry 4.0 technologies support decision-making at different stages of the manufacturing value chain. In the Design stage, 3D printing and scanning technologies play a crucial role. In the case of Inbound Logistics, robotisation, automation, Big Data analysis, and Business Intelligence are most useful. During the Manufacturing stage, robotisation, automation, 3D printing, scanning, Business Intelligence, cloud computing, and machine-to-machine (M2M) integration enable quick decision-making and speed up production. Sensors and the Internet of Things (IoT) optimise distribution in the Outbound Logistics stage. And finally, Business Intelligence supports decisions within the Sales and Marketing stage. It is also the most versatile technology among all particular stages. The paper provides empirical evidence on the Industry 4.0 technology support in decision-making at different stages of the manufacturing value chain, which leads to more effective value chain management, ensuring faster and more accurate decisions at each value-chain stage. When using properly selected Industry 4.0 technologies, managers can optimise their production processes, reduce costs, avoid errors and improve customer satisfaction. Simultaneously, Industry 4.0 technologies facilitate predictive analytics to forecast and anticipate future demand, quality issues, and potential risks. This knowledge allows organisations to make better decisions and take proactive actions to prevent problems.

KEY WORDS
Industry 4.0, decision-making, value chain, technologies, manufacturing industry

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Introduction

Decision-making is one of the most important daily activities in companies. The decision-making process is a logical sequence of activities. It can be defined as an outcome of evaluation processes leading to determining the most appropriate choice among several alternatives (Kaya & Kahraman, 2010), which should result in the highest success probability or greatest effectiveness. Accurate decisions should lead to high company performance (Shepherd et al., 2021); therefore, companies strive to obtain the best real-time data and create decision-support systems

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(Villalobos et al., 2019). Making accurate, fast and high-quality decisions is even more important in a dynamic, uncertain and turbulent environment. In this regard, digitisation and modern technologies can significantly facilitate the decision-making process (Ali & Kumar, 2011; Darwish et al., 2014; Wieder & Ossimitz, 2015; Janssen, van der Voort & Wahyudi, 2017). The much-discussed technologies include Industry 4.0 (I4.0), i.e., the Internet of Things (IoT), cloud computing, automation and advanced robotics, 3D printing and scanning, information and communication technologies solutions (ICT), as well as Business Intelligence (BI) systems, augmented reality (AR) and virtual reality (VR) (Henke & Wilmott, 2018). The development of such technologies enables the faster introduction of new products, sales via many different sales channels, and a rapid response to customer and market needs (Cañas et al., 2021). These should lead to a competitive advantage based on increased value for the customer while reducing costs. The typical manager's role will not be altered by Industry 4.0; however, the tools and techniques utilised to fulfil these management activities will change (de Sousa Jabbour, 2018; Pozzi et al., 2023; Ribeiro et al., 2021).

A helpful method for seeking a competitive advantage in particular processes and activities is value chain analysis, understood as a group of vertical activities that can add value to goods or services in the process from raw material to a finished product that is supplied to the consumer and/or end-user organisation (Simatupang, Ginardy & Handayati, 2018). At each value chain stage, managerial decisions are made, the consequences of which impact company effectiveness and competitive advantage. Porter (1999) indicated that information technology (IT) impacts how companies operate, leading to differentiation and cost reduction. Since then, value chain analysis has explored the strong linkage between information, material and fund flows with technologies, as well as constant progress towards adopting digital technologies (Núñez-Merino et al., 2020).

Studies show that in value chain analysis, particular technologies, such as RFID (Radio-Frequency Identification) and IoT, provide economic benefits to the business (Unhelkar et al., 2022) and impact operational performance, productivity and high visibility across multiple processes (Gomes et al., 2022). However, there is a lack of detailed research indicating which technologies support managerial decisions at various stages of the value chain.

As far as decision-making is concerned, there are studies on the impact of Industry 4.0 technologies on support of managerial decision-making (Wieder & Ossimitz, 2015; Janssen, van der Voort & Wahyudi, 2017; Neziraj & Shaqiri, 2018), but they do not discuss in detail the particularities of the value chain. Furthermore, there are studies relating to the digital transformation's impact on reshaping the manufacturing industry value chain (e.g., Savastano & Amendola, 2018), but they do not discuss the specifics of the decision-making process. Therefore, there is no information on which Industry 4.0 technologies support managerial decisions made at subsequent value chain stages, particularly regarding the speed and quality of decisions. These factors are extremely important for creating value at every stage of the chain. The stated research gap is valid as particular stages of the value chain, due to their specificity, require different decisions supported by different I4.0 technologies affecting the created value and competitive advantage. It can also be assumed that the variety of decisions within different value chain stages determines the variety of useful technologies. This leads to the question of how and to what extent different Industry 4.0 technologies support decision-making at particular value chain stages.

Thus, the paper aims to identify how Industry 4.0 technologies affect the quality and speed of the decision-making process across different value chain stages in the manufacturing sector. To achieve this aim, the paper presents qualitative research results based on the interview method with key informants (Alvesson & Lee Ashcraft, 2012). The interviews were conducted in the manufacturing sector. There are two major reasons behind this choice. First, this is an industry with widely implemented advanced Industry 4.0 technologies, enabling companies to produce smarter, faster and more effectively (Mehta, Butkewitsch-Choze & Seaman, 2018). Second, value chain analysis, inherent in the manufacturing sector (Nauhria, Kulkarni & Pandey, 2018), enables for tracking of the new technologies' impact on the quality and speed of decision-making in particular stages, which is crucial for the entire process of creating value for the customer. The analysis of how the technologies facilitate managerial decisions at every stage of the value chain allows for the identification of technologies that have an impact on the quality of decisions and their speed, and sometimes even complete elimination of the decisions themselves (decisions can be made autonomously by algorithms), creating value and leading to a competitive advantage.

This paper makes two main theoretical and practical contributions. First, it provides evidence that various Industry 4.0 technologies facilitate decision-making at different stages of the manufacturing value chain. In particular, the technologies' impact on the quality and speed of the decision-making process was examined. Second, knowledge about technology support leads to more effective value chain management. Particular technologies that speed up and/or improve the quality of decisions made by managers enable a value increase at each value chain stage. Faster and more accurate decisions allow for creating a competitive advantage over companies that do not have such support.

Following this introduction, the paper is structured as follows. First, the importance of the decision-making process across the value chain and the scope of I4.0 technological support for managerial decisions are discussed. Next, the research methodology is presented, the main findings of the research are analysed, and the main conclusions are drawn.

1. Literature review

1.1. Decision-making process across the value chain

Decision-making is a process of choosing from several alternatives to achieve a desired result (Eisenfuhr, 2011). It involves several interrelated stages, including identifying the problem, generating alternatives, evaluating alternatives, choosing an alternative, implementing the decision, and evaluating the decision's effectiveness (Lunenburg, 2010; Darwish et al., 2014). The definition of the decision-making process emphasises three key elements. First, decision-making involves choosing from several options; second, it is a process that involves more than a simple final choice among alternatives; and finally, the mentioned "desired result" involves a purpose or target resulting from the mental activity of a decision-maker to reach a final decision.

Information is among the most important factors in management decisions. Having detailed, accurate and timely information accelerates decision-making and prevents wrong decisions (Darwish et al., 2014). This is even more important considering the ever more uncertain business environment, which makes the decisions more risky, complex and demanding. Given that the decision result affects the success, failure and outcome of the organisation's future condition, the decision maker is expected to make fast, accurate and high-quality decisions. To avoid mistakes and errors, better decisions should be based on knowledge, experience, intuition, goals, diligence and more information to ensure better results (Neziraj & Shaqiri, 2018).

Rapid innovation, shortened product life cycles and fierce competition place great pressure on managers to make fast strategic decisions (Shepherd et al., 2021). Several factors influence the speed of strategic decisions: extensive analysis, power centralisation and conflict trigger interruptions in the decision process (Zehir & Özşahin, 2008). Fast decision-making is important in creating value for customers and gaining an advantage over competitors. To drive effective adaptation, decisions must be made quickly enough to keep up with changing external environment (Clark & Maggitti, 2012). Hence, decision speed is a key source of competitive advantage, enabling firms to respond rapidly to rivals' competitive moves and capitalise on emerging opportunities before they disappear (Shepherd et al., 2021).

Besides speed, decision quality is the other key aspect of decision-making research. It is based on information quality (Wieder & Ossimitz, 2015). Furthermore, there is an emphasis on the validity of the quality of the data and information that will serve as a basis for decision-making (Neziraj & Shaqiri, 2018). Raghunathan (1999) defined decision-making quality as the accuracy and correctness of decisions. Decision quality may improve or degrade when information quality and its processing improve (Raghunathan, 1999). As Wieder and Ossimitz (2015, p. 1165) indicated, "information reduces uncertainty for the decision-maker by assisting in the identification of the alternatives available, and/or by predicting the consequences of selecting an alternative". Prior studies show that the decision quality depends on the quality of the inputs and the process that transforms the inputs into outputs (Janssen et al., 2017). However, it must be noted that the quality and speed of the decisions are relative terms that may be assessed subjectively after the decision is made. In other words, whether the decision was of high quality and fast enough is assessed based on the results obtained from this decision (Gomes et al., 2022).

Decisions can be analysed from the value chain's perspective as this approach enables the assessment of the impact of decisions on the value creation in individual value chain stages. A value chain, a concept developed by Porter (1985), has become a tool for understanding how companies can create and sustain value for their customers and how to maximise it. A value chain is formed by several generic categories of primary activities (i.e., Inbound Logistics, Operations, Outbound Logistics, Marketing and Sales, and Service) and support activities (including the firm's infrastructure, human resources management, technology development, and procurement), which are useful in delivering valuable products or services to the market. At each value chain stage, managers make decisions aimed at maximising the created value and delivering it as quickly as possible. Value is an aggregation or a bundle of benefits added at every stage of the process, meaning that each activity has its unique value-added element (Simatupang et al., 2018). Research shows that this value is determined by the speed and quality of managerial decisions, especially since the external environment is complex and multidimensional (Bradley et al., 2011; Rosenbusch et al., 2013; Elbanna et al., 2020), and delivering this value is critical to customer satisfaction and a company's competitive advantage.

Although the concept introduced by Porter (1985) has been modified by other authors (e.g., Simatupang et al., 2018), including the innovation value chain (Hansen & Birkinshaw, 2007), the shared value chain (Porter & Kramer, 2011), and the design-driven innovation value chain (Verganti 2009), the traditional Porter's value chain framework is the most suitable approach for the analysis of physical goods and manufacturing industry.

The analysis of decision-making problems is extensively studied in academic literature, primarily because of the increasing significance of efficiency and the imperative to achieve optimal outcomes for businesses (e.g., Cui et al., 2021; Gomes et al., 2022). Similarly, value chain analysis is a commonly employed method for assessing the value generated by companies. Nonetheless, there is a lack of research that integrates the decision-making analysis across different value chain stages, particularly concerning the speed and quality of decision-making. This is particularly important in the current era of digital transformation within companies, which necessitates faster decision-making and the continual elimination of managerial mistakes.

1.2. Scope of I4.0 technological support for managerial decisions

In the era of the ongoing Fourth Industrial Revolution, also known as Industry 4.0, the digital and physical worlds are converging (Pham et al., 2019). So-called "general purpose technologies" (or "founding technologies"), usually perceived as a computer, the Internet and a smartphone (Jovanovic & Rousseau 2005), continue spreading to all economic sectors. However, there are also some disruptive technologies that have the greatest potential to upend the way the economy and society currently function. These technological solutions, referred to as Industry 4.0 (I4.0) technologies, include the Internet of Things (IoT), machine-to-machine (M2M) solutions, cloud computing, automation and advanced robotics (AAR), 3D printing and scanning, ICT solutions, and Business Intelligence (BI) systems (Henke & Wilmott, 2018). Similarly, Kearney (2020) perceived I4.0 as an ecosystem of five fundamental technologies: (1) artificial intelligence (AI), (2) the IoT, (3) 3D printing, (4) advanced robotics, and 5() wearables, augmented reality and virtual reality. Additionally, automated machine learning, quantum computing and 4D printing should also be listed among I4.0 technologies, even if the development of these solutions is still in the early stages (Kearney, 2020). The list of technologies is open because of continuous rapid development across various industries spending funds on research and development.

Technological advancement, including I4.0 technologies, creates a challenge to companies (Sousa et al., 2020) while facilitating their performance and development (Dalenogare et al., 2018; Hofmann & Rüsch, 2017; Liao et al., 2017; Robert et al., 2020). Companies can obtain various advantages depending on their level of technological readiness for Industry 4.0, their capacity to analyse data in real-time (Abdelmajied, 2022) and a general increase in their organisational efficiency (Stouthuysen, 2020; Oláh et al., 2020). To identify and comprehend the changes that must be made to maximise the benefits of I4.0 technologies, it is necessary to investigate the link between technologies and their use in decision-making processes.

The early I4.0 information technologies already played an important role in the decision-making process (Porter, 1985). Even more so today, in times of rapid changes and difficult competitive conditions, new technologies, including those of I4.0, improve the decision-making process by accelerating it and providing the necessary information in real-time (Neziraj & Shaqiri, 2018). As data becomes larger, more complex and more inexplicable, the limited mental capacities of humans pose difficulties in interpreting an unknown environment (Janssen et al., 2017), and this is where advanced Big Data technologies are greatly needed. Other positive effects arising from new technologies in the decision-making process include enabling the development and emergence of new tools tailored to the requirements of decision-makers, an increase in success in decision-making, and the ability to use stored data and information (Darioshi & Lahav, 2021; Gattiker & Goodhue, 2002; Loderer et al., 2020).

Several technologies and digitalisation solutions support managerial decision-making in the age of Industry 4.0, part of which may be supported by, e.g., computers, smart apps and advanced algorithms. The advancement of manufacturing systems necessitates faster and higher-quality decisions. Much more data is accessible than previously as systems organising and assessing the data and the parameters acquired from production provide efficient assistance to management in decision-making. The latest research emphasises the potential of one or more technologies to improve specific stages of the decision-making process. The proposed decision-making models are partly based on Industry 4.0 technologies, such as BD and AI (e.g., Kościelniak & Puto, 2015; Zolotová et al., 2020; Toušek et al., 2022), focusing primarily on operational assistance or concern autonomy in strategic decisions.

As Rosin et al. (2022) pointed out, managers appear to be anticipating the improvement of task-centred autonomy by Industry 4.0 technology. In this regard, managers' expectations seem to lead to substantial agreement on the amount of improvement provided by Industry 4.0 technologies in terms of governance autonomy. The influence of Industry 4.0 on the decision-making process has thus far been limited to the many decision-making tasks rather than the process as a whole (Ansari et al., 2020). Castelo-Branco et al. (2022) identified conditions conducive to the successful implementation of Industry 4.0 and looked for implications within the value chain from the smart factory through the value proposition to customer experience. They devised a model that considers the above-mentioned manifestations of Industry 4.0 along the value chain, which should be analysed in an integrated manner. Similarly, Schumacher et al. (2016) took the view that there are some organisational areas of the value chain that are affected by Industry 4.0 through strategy, culture, human resources and processes. Some authors focused on specific industries, e.g., Müller et al. (2019) stated that Industry 4.0 applications can be identified along the entire wood supply chain, and Bastug et al. (2020) explored Industry 4.0 applications utilised by seaports through website content analysis. However, to the best of the authors' knowledge, there is no research considering the opportunities provided by the collaborative contribution of specific Industry 4.0 technologies to the decision-making process across the whole value chain. Integrating these two areas is crucial for understanding the evolving competitive advantage sources.

2. Research methodology

2.1. Method

The paper adopted qualitative research based on the interview method (Alversson & Lee Ashcraft, 2012) to find and characterise new concepts, categories or relationships, which is especially important when a new phenomenon is under research, and there are insufficient explanations of a specific situation (Graebner et al., 2012). Additionally, such research is particularly suitable for understanding how such processes as decisions happen (Marschan-Piekkari & Welch, 2004). The research procedure (Fig. 1) covered nine steps and was consistent with the qualitative approach commonly used in social sciences (Symon & Cassell, 2012).

In-depth interviews were conducted to capture senior executives' experiences with implementing Industry 4.0 technologies in their organisations. The fundamental advantage of conducting in-depth interviews is that they foster an open environment, which aids in the problem examination from a wider viewpoint (Curasi, 2001). An interview scenario was created focusing on open-ended questions encouraging a discussion.

The main questions that were asked during the interview were about the types of I4.0 technologies adopted by the company across the whole value chain and the assessment of their positive (or negative) impact on the company's operation in general, and on the speed and quality of managerial decisions in particular.

During the interview, a 4.0 technology catalogue was used that included the following technologies: Big Data, 3D printing and scanning, virtual and augmented reality, IoT, M2M, blockchain, cloud computing, digital twins, RFID, automation and advanced robotics, smart sensors and wireless transmitters, Business Intelligence solutions (the list prepared based on Bartodziej, 2017; Hermann et al., 2016; Kearney, 2020). However, the authors remained open

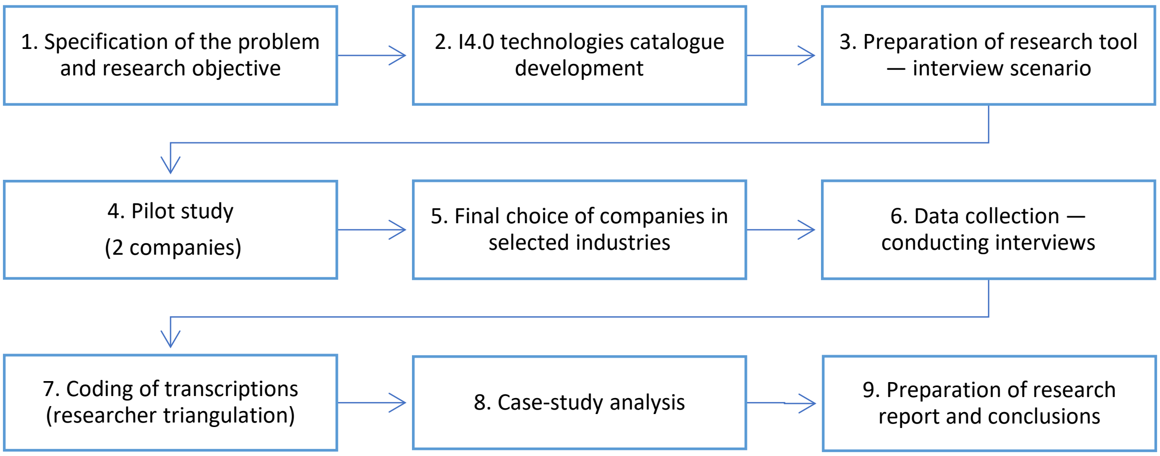

Fig. 1. Research design

to new technologies indicated by the interviewees. In this case, e.g., intelligent applications technology was added to the original list.

2.2. Data collection

In general, the adoption of Industry 4.0 technologies in Polish enterprises is rather slow (when compared to highly developed economies) due to several hurdles to their implementation. Thus, for several reasons, this research focused on three selected manufacturing industries: the automobile, food and furniture industries. First, these industries have embraced digital transformation and use I4.0 technologies in various ways (e.g., Konur et al., 2021; Yasin et al., 2021). The manufacturing industry widely utilises advanced I4.0 technologies, which help companies produce goods more efficiently and effectively. Second, these industries are critical to the Polish economy, forming an important part of the manufacturing industry (Statistics Poland, 2022). Besides, value chain analysis is an integral part of the manufacturing industry, allowing for the measurement of the impact of new technologies on decision-making speed and quality at specific stages of the production process (Nauhria et al., 2018). This is essential for creating value for customers.

A purposeful sampling of companies was employed. These companies were selected based on respective industries' reported maturity in adopting I4.0 technologies (according to The Smart Industry Readiness Index (SIRI) 2020). In other words, the assumption was that the analysed organisations were experiencing or had undergone technology 4.0 deployment across at least some parts of the organisation.

The study was carried out in June–August 2021 among senior managers responsible for Industry 4.0

Tab. 1. Company characteristics

INDUSTRY	COMPANY	YEAR OF ESTABLISHMENT	MAIN PRODUCTS	EMPLOYMENT	REVENUE (MILLION EUR)
FOOD INDUSTRY	Alpha	1993	Dairy products	800	149
	Beta	2012	Fruit and vegetable juices	350	115
	Gamma	1990	Diverse assortment of products	n/a	1 300
FURNITURE INDUSTRY	Zeta	2002	Furniture	100-250*	2,1
	Eta	2014	Furniture	100-250*	28
	Kappa	2006	Furniture	100-250*	148
AUTOMOTIVE INDUSTRY	Lambda	2004	Automotive parts	220	32
	Sigma	2003	Automotive parts	1900	301
	Omega	2007	Automotive parts	730	41

* Note: precise data unavailable

technology implementation and representing five large (over 250 employees) and four medium-sized companies (50–249 employees). Selected characteristics of the companies, i.e., year of establishment, revenue, employment and main products, are presented in their responses. It was also determined by the time frame available to the managers for the interviews. The interviews were recorded and then transcribed.

The interviews were performed remotely due to the restrictions imposed by the Covid-19 pandemic. The overall time of all the interviews was 15 hours and 45 minutes, with each interview lasting an average of 105 minutes. The longest interview lasted over two hours, while the shortest lasted only 55 minutes. The duration of the interviews was caused by disparities in the respondents' approaches and openness.

2.3. Data analysis

Two researchers analysed the transcripts independently to confirm the reliability and validity of the results' interpretation (researcher triangulation). The researchers created and then used a code book and a catalogue of perceived I4.0 technologies.

To identify particular stages of the value chain, Porter's value chain (1985) framework was adopted, which is particularly useful for analysing the manufacturing industry and physical goods when focusing on corporate areas with a primary role in customer value creation. The analysis considered only generic categories of primary activities, as their role is crucial in creating added value. These included project/design, inbound logistics, manufacturing, outbound logistics, and sales and marketing. The authors were aware of the importance of the support activities involved in sustaining the primary activities, but as they were often fully outsourced, an analysis based on the interviews proved incomplete. Similarly, customer service/post-sales activities were excluded as no impact of 4.0 technology was identified. At the same time, the investigation was expanded to include a project/design stage, which significantly impacts the final value creation. As business process digitalisation is gradually reconfiguring every aspect of operating and organisational activities along the entire value chain (Savastano et al., 2018), the partially followed idea was "the innovation value chain" proposed by Hensen and Birkinshaw (2007), who perceive the design stage of the value chain as crucial ("primary") for a company's success. The stages of the value chain were directly declared by the respondents who, while discussing the impact of the I4.0 technologies, described the decisions and defined the stage of the value chain at which they were made.

As far as the identification of technologies and value chain activities are concerned, in most cases, they were mentioned directly during the interviews. A similar approach was used for the indicated support for decision speed and quality. The interview focused on the impact of technologies on the speed and quality of decisions. The decision-making speed was defined as the time necessary to make a decision or even transfer the decision-making to intelligent or automation systems. The decision-making quality was defined based on Raghunathan (1999) as the accuracy and correctness of decisions and the compliance of the achieved effects with the assumed goals. Decision speed and quality were assessed subjectively by the respondents.

3. Research findings

All the analysed manufacturing industry companies use I4.0 technologies to some extent, facilitating managerial decisions. Table 2 summarises the research results in terms of I4.0 technologies applied by these companies and the declared impact of the technologies on the speed and quality of managers' decisions within particular stages of the value chain. The subsequent analysis is conducted sequentially on successive stages of the value chain and focuses mostly on the chosen individual technologies and their impact that was mentioned repeatedly by more than one analysed business entity.

Design plays a growing role in so-called "input activities". Competition is fierce, and with unified products in terms of quality (the same sub-suppliers), the design stage plays a key role in creating value. At the project/design stage, decisions focus on correct planning and adapting the product to the customer's needs as quickly as possible. Almost all analysed companies use 3D printing and scanning to design prototypes and quickly create an offer for customers. As one of the managers exemplifies: "This greatly shortens the design process because previously we collected the dimensions in traditional form and now we take a photo, and after a while, we have a model in the design program for 3D printing" (Lambda). Additionally, this technology allows for faster verification of product concepts: "We use 3D additive printing technology mainly for prototyping and test-

Tab. 2. Identified I4.0 technologies and the quality and speed of managers' decision-making across the value chain — research results

VALUE CHAIN		PROJECT/DESIGN		INBOUND LOGISTICS (E.G. SUPPLIER MANAGEMENT, WAREHOUSING)		MANUFACTURING		OUTBOUND LOGISTICS (WAREHOUSING, DISTRIBUTION)		SALES AND MARKETING	
INDUSTRY	FIRM	SPEED	QUALITY	SPEED	QUALITY	SPEED	QUALITY	SPEED	QUALITY	SPEED	QUALITY
FOOD	ALPHA					Automation of production decisions — fast validation of materials and finished products (3D scanning)	Elimination of production errors resulting from wrong decisions (3D scanning, smart sensors IoT/M2M)				
	BETA	Designing prototypes and creating an offer for customers in a short time (3D printing)	Facilitating decisions on the flexible adaptation of the offer to market needs (3D printing)					Faster identification and elimination of errors in logistics (automation & robotisation)	Identification and elimination of errors in logistics (automation & robotisation)		
	GAMMA	Fast decisions based on real-time data analysis (Business Intelligence)	Support for innovation decisions based on research (Big Data)	Support for decisions on warehousing — autonomous storage (automation & robotisation)	Process planning support (smart sensors and transmitters). Support for decisions by limiting errors in the product flow (Business Intelligence)	Faster reaction to production errors — predictive maintenance (IoT/M2M) Acceleration of reaction to market changes — just-in-time manufacturing (Business Intelligence)			Distribution decision support based on real-time sales data (IoT/M2M)		Marketing decisions based on precise sales data (M2M/IoT). Support for decisions on sales forecasting, customer segmentation and offer personalisation (Big Data/Business Intelligence)
FURNITURE	ZETA	Designing prototypes and creating an offer for customers in a short time (3D printing/scanning)	Facilitating decisions on the flexible adaptation of the offer to market needs (3D printing/scanning)			Increasing the flexibility of production decisions — personalisation of products (3D printing)					
	ETA	Designing prototypes and creating an offer for customers in a short time (3D printing/scanning)	Facilitating decisions on the flexible adaptation of the offer to market needs (3D printing/scanning)			Shortening and automation of production decisions (automation & robotisation)					Support for decisions on offer personalisation and customer relationships (smart apps/virtual solutions)
	KAPPA	Designing prototypes and creating an offer for customers in a short time (3D printing/scanning)		Support for decisions on warehousing — autonomous storage (automation & robotisation)		Faster production decisions based on a smooth information flow (Business Intelligence).					Support for decisions on sales forecasting, customer segmentation (Business Intelligence)

Value chain		Project/design		Inbound logistics (e.g. supplier management, warehousing)		Manufacturing		Outbound logistics (warehousing, distribution)		Sales and marketing	
Industry	Firm	Speed	Quality	Speed	Quality	Speed	Quality	Speed	Quality	Speed	Quality
						Automation of production decisions — full integration of the production system (M2M)					
Automotive	Lambda	Designing prototypes and creating an offer for customers in a short time, faster adaptation of a product to customer requirements & faster decision to accept the order (3D scanning)					Elimination of production errors resulting from wrong decisions (automation & robotisation)			Acceleration of the sales cycle and customer service time (Business Intelligence)	Support for decisions on sales forecasting, customer segmentation, promotional activities (Business Intelligence)
	Sigma	Designing prototypes and creating an offer for customers in a short time; faster verification of product concepts (3D printing/scanning)	Facilitating decisions on designer review — evaluation and verification of projects (virtual solutions)	Accelerating logistics decisions in terms of supplier management (Big Data)		Faster decision-making based on quick access to data and reports (cloud computing)	Elimination of production errors resulting from wrong decisions (IoT)		Estimating logistics parameters — simplification of decisions at the board level (Business Intelligence)		Facilitating decisions on customer relationship management (Business Intelligence)
	Omega	Designing prototypes and their verification in products in a short time (3D printing)	Facilitating decisions on the flexible adaptation of the offer to market needs (3D printing)		Facilitating decisions on warehouse management - pursuing rights with component suppliers. (Big Data)	Autonomation of production decisions			Facilitating analysis and decisions on the evaluation of the logistics process (Business Intelligence)		

ing concepts that we cannot directly implement with the use of final products, due to the cost and time of production" (Sigma), and in particular it allows for faster adaptation of a product to a customer's requirements: "We have 3D printers to build bottle prototypes to show the customer a visualisation of what it might look like in the future (...). The customer expects it to be implemented quickly" (Beta).

Although the respondents focused on the decision-making speed as a positive effect of 3D printing, it can also be linked at least partly to the quality of these decisions. Being able to quickly test a concept or visualise an idea allows for the avoidance of errors at the stage of creating a project and product concept. As one of the managers points out: "We use 3D printing at the level of furniture design because it is quite simple; you can imagine things and implement projects quite quickly" (Eta). This is especially important in the case of products tailored to individual needs (e.g., custom-made furniture), where the use of 3D printing at this stage allows for more effective cooperation with the customer, thus avoiding wrong decisions and reducing unnecessary costs ("Now, we model the first models in 3D and ship them to the customer. If the customer intends to make some changes, we introduce changes to the virtual model" (Zeta). This quality of decisions in terms of innovations introduced to products is also facilitated by Big Data analysis, which is described as "a concept trigger" (Gamma).

The decisions within the next stage of the value chain, namely, Inbound Logistics, tend to be speeded up thanks to the robotisation and automation applied in warehouses, and thus, the introduction of autonomous storage decisions: "We have high storage systems, where everything is automatically placed and then picked, thanks to which the completion of shipments is automatic" (Gamma). At the same time, this automation of warehouses not only speeds up or rather eliminates managerial decisions but also leads to cost-effectiveness ("it accelerates everything, it also increases our bargaining power during discussions with suppliers" (Kappa)). As far as the quality of decisions at the stage of Inbound Logistics is concerned, the respondents tended to underline the influence of I4.0 technologies on limiting errors and facilitating quality control. In particular, this concerns collecting data and, thus, controlling the quality of components and raw materials thanks to Big Data analysis, eliminating errors in deliveries and product flow obtained via Business Intelligence, and the quality control of supplies in comparison to a 3D template.

Manufacturing in the value chain concerns the transformation of input into the final product. The speed of managerial decisions concerning manufacturing is facilitated by the diversity of I4.0 technologies. First, robotisation and automation allow for the autonomation of production decisions and even eliminate the involvement of managers in some production processes, as one of the respondents exemplified: "We have made a system that makes automatic decisions. It is about the process of access control and making decisions about how to classify the finished product after testing. The system makes this decision and analyses all the samples, assigns the appropriate class and inserts it into the system and marks this batch. (…). In this way, the human has been completely eliminated from the process" (Alpha). The aim to limit the involvement of people at the production stage and, thus, their decisions was underlined by several respondents (Zeta, Omega). The automation and speed of production decisions are also facilitated by 3D printing and scanning, which allows for fast validation of materials and finished products, while Business Intelligence and cloud computing provide a smooth flow of information and quick access to data and reports, as well as M2M and full integration of the production system.

I4.0 technologies enable managers to react quickly to emerging changes and eliminate errors, which is linked to the quality of decisions. The IoT and M2M allow for so-called predictive maintenance, meaning managers react faster to production errors ("The use of the Internet of Things and M2M communication as part of predictive maintenance and failure prevention, makes employees react earlier and does not result in major repairs" (Gamma)). These errors are also mitigated by 3D printing and scanning, robotisation and automation, and the use of sensors and IoT.

Regarding Outbound Logistics, including warehousing and distribution of finished products, the respondents focused on the supportive role of I4.0 technologies in terms of decision quality. Mostly, this concerned Outbound Logistics evaluation and control facilitated by Business Intelligence, IoT and M2M and was linked with the identification and elimination of errors in logistics provided by robotisation and automation. As one of the managers described: "We use the Internet of Things, e.g., in logistics to track transports, shipments (…) because we have noticed that in many cases strange things happen to the shipment, and then there is confusion about the reasons. So, we install special sensors that collect this data and, at the same time, send information that is analysed on an ongoing basis. (...) Wireless transmitters in conjunction with Big Data, Business Intelligence, and the Internet of Things and machine communication play an important role here" (Sigma). The same technologies, i.e., IoT and M2M, facilitate the distribution of products based on real-time sales data. The same respondent added: "M2M communication with external systems allows us to determine the consumption of warehouse demand, which affects the operation of these warehouses and stock levels. Business Intelligence, through the use of intelligent sensors in transport, allows us to estimate delivery times, delivery costs, the current location of given components and the demand for them and optimises the entire logistics process" (Sigma).

Sales and Marketing, the final analysed value chain stage, is linked with advertising, promotion, and pricing. In this regard, the facilitating role of Business Intelligence in the quality of managers' decisions was underlined in particular by the respondents. Business Intelligence supports decisions on promotional activities, allowing for the creation of marketing materials based on collected data, sales forecasting and customer segmentation, as well as customer relationship management. As one of the managers summarised, "Access to historical data shows us what impact the customer has on the company's operations (turnover, costs of manufacturing, new products). We can analyse this, select clients to complete or develop

Tab. 3. Support of I4.0 technologies in companies from analysed industries across the value chain — the summary

Value chain	Project/Design		Inbound Logistics (e.g., supplier management, warehousing)		Manufacturing		Outbound Logistics (warehousing, distribution)		Sales and Marketing	
Industry	Speed	Quality	Speed	Quality	Speed	Quality	Speed	Quality	Speed	Quality
Food	3D printing, Business Intelligence	3D printing, Big Data	Automation & robotisation	Smart sensors and transmitters, Business Intelligence	3D scanning, IoT/M2M, Business Intelligence	3D scanning, smart sensors IoT/M2M	Automation & robotisation	Automation & robotisation IoT/M2M		Business Intelligence M2M/IoT, Big Data
Furniture	3D printing/ scanning,	3D printing/ scanning,	Automation & robotisation		3D printing, automation & robotisation Business Intelligence, M2M					Business Intelligence, smart apps/virtual solutions
Automotive	3D scanning/printing	Virtual solutions, 3D printing	Big Data	Big Data	Cloud computing, automation & robotisation	Automation & robotisation, IoT		Business Intelligence	Business Intelligence	Business Intelligence

cooperation with, and quickly compare clients in terms of certain indicators and issue them a score on a points scale" (Kappa).

Table 3 summarises the support of I4.0 technologies in companies representing analysed manufacturing industries.

The most similarities, when comparing the three examined industries, could be observed in the Project/Design stage, dominated by 3D printing/scanning. Additionally, in the sales and marketing stage, Business Intelligence support for decision quality was noted in all industries.

Greater differences in support of implemented technologies could be noticed at the Inbound Logistics stage. Automation and robotisation support decision speed in the food and furniture industries, while Big Data provides support for both speed and quality of managerial decisions in the automotive industry.

At the manufacturing stage, differences are evident between the food industry and the other examined industries. In the food industry, 3D scanning and IoT/M2M dominate, providing support for both speed and quality of decisions. On the other hand, in the furniture and automotive industries, robotisation and automation were mainly indicated, offering support for decision-making in the production process.

An interesting observation can be made regarding the Outbound Logistics stage, where technological support is minimal. Only in the food industry respondents identified robotisation and automation as valuable for decision-making, and in the context of improving decision quality, additional support from IoT/M2M was noted. Business Intelligence proved to be helpful in improving decision quality in the automotive industry.

4. Discussion

Managers from the manufacturing industry are mostly aware of the benefits resulting from the application of I4.0 technologies. They also emphasise that such technologies facilitate their decisions. Thanks to I4.0 technologies, managers can make decisions faster, and as they are based on more accurate data, often obtained in real-time, these decisions have higher quality. Thus, this research aligns with previous studies exemplifying the need for detailed, accurate and timely information for fast high-quality decisions (Darwish et al., 2014). This paper showed that obtaining real-time information and the fast analysis of a large amount of data is facilitated by I4.0 technologies, especially Business Intelligence and Big Data analysis. This confirms the findings by Neziraj and Shaqiri (2018) that real-time, up-to-date information supports the decision-making process. In a similar vein, this research showed results similar to those by Janssen et al. (2017), that as data becomes larger, more complex and more inexplicable, the limited mental capacities of people pose difficulties in interpreting the data and information, and this is where advanced Big Data technologies are greatly needed. This complexity and the limited capacity of people is also one of the reasons why in some decisions, the involvement of managers is eliminated, and decisions are automated. Of course, this may raise questions about the future of managers and human involvement within companies, but as one of the respondents underlined, "This creates an attractive working environment. Access to data is faster, easier and more attractive, so that's a plus. It can be said that our young employees cannot imagine working without these tools" (Gamma). Thus, the authors agree with de Sousa Jabbour (2018), Pozzi et al. (2023) and Ribeiro et al. (2021) that the manager's role will not be changed by Industry 4.0; however, the tools and techniques will be different.

Although the analysis was carried out within particular stages of the value chain, it must be emphasised that the same technologies can simultaneously support decisions within several stages. For instance, Business Intelligence may facilitate managerial decisions at each value chain stage. Similarly, 3D printing and scanning are used within several stages. This application of the same I4.0 technologies simultaneously within several value chain stages may be linked, first, with the specifics of the technology. This is the case of Business Intelligence that, by definition, allows managers to make better decisions based on technology and data analysis (Kašparová, 2022). As a technology-supported process, BI has universal application as it gathers and transforms the fragmented data of companies and markets into information or knowledge about a company's objectives, opportunities and positions (Wieder & Ossimitz, 2015).

Second, the reason for applying the same I4.0 technology may be linked to the specificity of the value chain itself. As Porter and Heppelmann (2014) argued, it is necessary to reconsider the skills and processes used across the entire value chain due to industrial digitisation. In this context, this research results suggest that the project/design stage creates crucial input for manufacturing; thus, 3D printing and scanning technology can facilitate decisions when designing prototypes and creating an offer for customers, and the subsequent support for decisions during production when products are personalised, or there is a need for validation of materials and finished products (Candi & Beltagui, 2019). Financial efficiency must be mentioned as an additional reason for the wider application of the same technology. When investing in more expensive technology aimed at decision support, there is a need to use its full potential.

Although the same technology may be applied across the value chain, technologies that tend to be more specific to a particular stage can still be identified. This is important, as particular stages of the value chain have at least a partly different specificity and, thus, require different decisions affecting the value created and competitive advantage. In the case of Project/Design, 3D printing and scanning facilitate decisions on prototypes and product design. Inbound and Outbound Logistics decisions tend to be supported by Big Data, Business Intelligence, M2M and robotisation and automation. Similarly, automation and robotisation, along with M2M, are helpful when making decisions on production processes (manufacturing) (Cui et al., 2021). Finally, for sales and marketing, Business Intelligence tends to be most helpful. The impact of BI was identified, but Big Data, which serves to strengthen Business Intelligence, can be assumed to be similarly important (Sun et al., 2018). It should also be emphasised that different technologies are often not used separately. Often, at one stage of the value chain, several I4.0 technologies are used to support decisions and, by synergy, achieve the same positive effect. This is particularly the case when Business Intelligence and Big Data analysis are applied together, for instance, with IoT, M2M or robotisation.

The Industry 4.0 technologies indicated in the study belong to the group of mature technologies (i.e., they are more widely implemented) (Kearney, 2020). At the same time, it is difficult to estimate the potential impact that emerging technologies based on advanced AI/machine learning algorithms will have. However, it can be expected that the scope of their influence, especially on decision-making speed, will be significant, sometimes eliminating the need for "physical" manager involvement.

Conclusions

In contrast to earlier studies that have addressed the impact of Industry 4.0 technologies on supporting managerial decision-making, the research presented in this paper focused on individual value chain stages and the support provided by advanced I4.0 technologies for managers' decision-making within these particular stages. Thanks to this approach, it was possible to provide a theoretical contribution by identifying I4.0 technologies that facilitate the quality and speed of the decision-making process at individual value chain stages, which is an important contribution to making managerial decisions and effective value chain management. The most important technologies in this regard include Business Intelligence, 3D printing, robotisation and automation, and M2M.

The research results are also important from the point of view of identifying the sources of competitive advantage of manufacturing companies. The research results indicated that I4.0 technologies generally positively impact the speed and quality of managerial decisions in the manufacturing industry across most value chain stages. For the Design stage, 3D printing and scanning technologies play a crucial role, allowing for faster prototyping and customisation. The speed of decision-making at this stage is positively impacted, and errors can be avoided. The use of Big Data analysis also facilitates the introduction of product innovations. In the case of Inbound Logistics, robotisation and automation in warehouses lead to automatic decision-making and cost-effectiveness. Big Data analysis is useful for quality control of components and raw materials, and Business Intelligence can help eliminate errors in deliveries and product flow. During the Manufacturing stage, robotisation, automation, 3D printing, scanning, Business Intelligence, cloud computing, and M2M integration enable quick decision-making and speed up production. Predictive maintenance through IoT and M2M communication can help managers react faster to emerging changes and prevent major repairs. I4.0 technologies can also support Outbound Logistics through sensors and IoT to optimise distribution. Finally, BI supports decisions on sales forecasting and customer segmentation at the Sales and Marketing stage. To sum up, although the authors expected greater differences between the use of individual technologies at subsequent stages of the value chain and their support for decision-making processes, some similarities could still be noticed.

The specific technologies and their impact vary across different stages of the value chain, emphasising the need for tailored approaches based on the industry's characteristics and requirements. Industry 4.0 technologies can provide more accurate and up-to-date information for analysis and evaluation, enabling managers to make decisions quickly and accurately. However, the scope of decisions made by managers within the value chain depends on whether a stage in the value chain is managed within the company's structures or outsourced. Managers need to be aware of the potential of I4.0 technologies for each value chain stage and adopt them accordingly to improve their decision-making speed and quality. By leveraging I4.0 technologies, managers can optimise their production processes, reduce costs, avoid errors and improve customer satisfaction. At the same time, I4.0 technologies facilitate predictive analytics for forecasting and anticipating future demand, quality issues and potential risks. This can allow organisations to make better decisions and take proactive measures to prevent problems before they occur. However, managers must also be cautious and ensure that their workforce is trained and equipped to handle the changes brought about by these technologies.

This research had certain limitations. The analysis and conclusions are based on a qualitative study and a purposeful selection of a sample of companies characterised by a rather high level of application of I4.0 technologies. Therefore, when compared to the average company, these analysed entities and their managers may be more aware of the benefits resulting from I4.0 technologies. Similarly, it should also be considered that only selected manufacturing industries were studied, while other industries may show different tendencies with regard to technology support for decision-making process across different value chain stages. Finally, the list of technologies is still open due to various industries systematically spending funds on research and development, and, therefore, the list certainly does not exhaust all the available technologies used.

The limitations mentioned above provide perspectives for directions of further research, i.e., the need for extensive quantitative research that will enable diagnosis of the level of application of I4.0 technologies among companies in general and, above all, identify the general perceived impact of these technologies on managerial decisions. Furthermore, while the authors focused on the quality and speed of the decision-making process, it is important to study the consequences of these processes and to identify how they affect companies' financial and market performance.

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Literature

Abdelmajied, F. Y. (2022). Industry 4.0 and Its Implications: Concept, Opportunities, and Future Dirctions. In T. Bányai, A. Bányai, & I. Kaczmar (Eds.), *Supply Chain – Recent Advances and New Perspectives in the Industry 4.0 Era*. London, UK: Intechopen.

Alvesson, M., & Ashcraft, L. K. (2012). Interviews. In G. Symon, & C. Cassell (Eds.), *Qualitative Organizational Research. Core Methods and Current Challenges*. Los Angeles: Sage.

Bartodziej, C. J. (2017). The concept Industry 4.0. In: *The Concept Industry 4.0.*Wiesbaden: BestMasters. Springer Gabler.

Bastug, S., Arabelen, G., Vural, C. A., & Deveci, D. A. (2020). A value chain analysis of a seaport from the perspective of Industry 4.0. *International Journal of Shipping and Transport Logistics*, *12*(4), 367-397.

Cañas, H., Mula, J., Díaz-Madroñero, M., & Campuzano-Bolarín, F. (2021). Implementing Industry 4.0 principles. *Computers and Industrial Engineering, 158*. doi: 10.1016/j.cie.2021.107379

Candi, M., & Beltagui, A. (2019). Effective use of 3D printing in the innovation process. *Technovation*, *80-81*, 63-73.

Castelo-Branco, I., Oliveira, T., Simões-Coelho, P., Portugal, J., & Filipe, I. (2022). Measuring the fourth industrial revolution through the Industry 4.0 lens: The relevance of resources, capabilities and the value chain. *Computers in Industry*, *138*.

Curasi, C. F. (2001). A Critical Exploration of Face-to Face Interviewing vs. Computer-Mediated Interviewing. *International Journal of Market Research*, *43*(4), 1-13. doi: 10.1177/147078530104300402

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

Darioshi, R., & Lahav, E. (2021) The impact of technology on the human decision-making process. *Human Behavior and Emerging Technologies*, *3*, 391-400.

Darwish, H., Saki, N., Sahraei, M., Zakrifar, F., & Talebi, S. M. (2014). Effects of Automated Office Systems (Automation) on Improve Decision- Making of Staff Managers (At the Airports Company of Country*). Journal of Educational and Management Studies*, *4*(3), 554-564.

de Sousa Jabbour, A. B. L., Jabbour, C. J. C., Foropon, C., & Godinho Filho, M. (2018). When Titans Meet–Can Industry 4.0 Revolutionise the Environmentally-Sustainable Manufacturing Wave? The Role of Critical Success Factors. *Technological Forecasting and Social Change*, *132*, 18-25.

Gomes, K., Guenther, E., Morris, J., Miggelbrink, J., & Caucci, S. (2022). Resource nexus oriented decision making along the textile value chain: The case of wastewater management. *Current Research in Environmental Sustainability*, *4*. doi: 10.1016/j.crsust.2022.100153

Hermann, M., Pentek, T., & Otto, B. (2016), Design Principles for Industrie 4.0 Scenarios: A Literature Review. *49th Hawaii International Conference on System Sciences (HICSS),* 3928-3937.

Hofmann, E., & Rüsch, M. (2017). Industry 4.0 and the current status as well as future prospects on logistics. *Computers in Industry*, *89*, 23-34. doi: 10.1016/j.technovation.2018.05.002

Janssen, M., van der Voort, H., & Wahyudi, A. (2017). Factors influencing big data decision-making quality. *Journal of Business Research*, *70*, 338-345. doi: 10.1016/j.jbusres.2016.08.007

Kašparová, P. (2022). Intention to use business intelligence tools in decision making processes: applying a UTAUT 2 model. *Central European Journal of Operations Research, 31*, 991-1008. doi: 10.1007/s10100-022-00827-z

Kaya, I., & Kahraman, C. (2010). Development of fuzzy process accuracy index for decision making problems. *Information Sciences*, *180*(6), 861-872. doi: 10.1016/j.ins.2009.05.019

Kearney. (2021). *A brave new world for manufacturing.* Retrieved from https://www.kearney.com/service/operations-performance-transformation/

Koc, T., & Bozdag, E. (2017). Measuring the degree of novelty of innovation based on Porter's value chain approach. *European Journal of Operational Research*, *257*(2), 559-567. doi: 10.1016/j.ejor.2016.07.049.

Konur, S., Lan, Y., Thakker, D., Morkyani, G., Polovina, N., & Sharp, J. (2021). Towards design and implementation of Industry 4.0 for food manufacturing. *Neural Computing and Applications*. doi: 10.1007/s00521-021-05726-z

Liao, Y., Deschamps, F., Loures, E., de, F. R., & Ramos, L. F. P. (2017). Past, present and future of Industry 4.0 – a systematic literature review and research agenda proposal. *International Journal of Production Research*, *55*(12), 3609-3629.

Loderer, K., Pekrun, R., & Lester, J. C. (2020). Beyond cold technology: A systematic review and meta-analysis on emotions in technology-based learning environments. *Learning and Instruction*, *70*.

Lucianetti, L., Chiappetta Jabbour, Ch. J., Gunasekaran, A., & H. Latan, H. (2018). Contingency Factors and Complementary Effects of Adopting Advanced Manufacturing Tools and Managerial Practices: Effects on Organizational Measurement Systems and Firms' Performance. *International Journal of Production Economics*, *200*, 318-328.

Lunenburg, F. (2010). The Decision-Making Procedure. *National Forum of Educational Administration and Supervision Journal*, 27(4), 179-258. doi: 10.1007/978-3-030-69441-8_6

Marschan-Piekkari, R., & Welch, C. (2004). Qualitative research methods in international business: the state of the art", In R. Marschan-Piekkari, & C. Welch (Eds.), *Handbook of Qualitative Research Methods for International Business* (pp. 5-24). Northhampton: Edward Elgar.

Mehta, P., Butkewitsch-Choze, S., & Seaman, C. (2018). Smart manufacturing analytics application for semi-continuous manufacturing process – A use case'. *Procedia Manufacturing*, *26*, 1041-1052. doi: 10.1016/j.promfg.2018.07.138.

Müller, F., Jaeger, D., & Hanewinkel, M. (2019). Digitization in wood supply – A review on how Industry 4.0 will change the forest value chain. *Computers and Electronics in Agriculture, 162*, 206-218.

Nauhria, Y., Kulkarni, M. S., & Pandey, S. (2018). Development of Strategic Value Chain Framework for Indian Car Manufacturing Industry. *Global Journal of Flex-*

ible Systems Management, 19(1), 21-40. doi: 10.1007/s40171-017-0179-z

Neziraj, E. Q., & Shaqiri, A. B. (2018). The impact of information technology in decision making process of companies in Kosovo. *Informatologia*, *51*(1–2), 13-23. doi: 10.32914/i.51.1-2.2

Núñez-Merino, M., Maqueira-Marín, J. M., Moyano-Fuentes, J., & Martínez-Jurado, P. J. (2020). Information and digital technologies of Industry 4.0 and Lean supply chain management: a systematic literature review. *International Journal of Production Research*, *58*(16), 5034-5061. doi: 10.1080/00207543.2020.1743896

Oláh, J., Aburumman, N., Popp, J., Khan, M. A., Haddad, H., & Kitukutha, N. (2020). Impact of industry 4.0 on environmental sustainability. *Sustainability*, *12*, 4674.

Porter, M. E., & Heppelmann, J. E. (2014). How smart, connected products are transforming competition. *Harvard Business Review*, *92*, 64-88.

Pozzi, R., Rossi, T., & Secchi, R. (2023). Industry 4.0 technologies: critical success factors for implementation and improvements in manufacturing companies. *Production Planning & Control*, *34*(2), 139-158.

Raghunathan, S. (1999). Impact of information quality and decision-maker quality on decision quality: A theoretical model and simulation analysis. *Decision Support Systems*, *26*(4), 275-286. doi: 10.1016/S0167-9236(99)00060-3

Ribeiro, A., Amaral, A., & Barros, T. (2021). Project Manager Competencies in the context of the Industry 4.0. *Procedia Computer Science*, *181*, 803-810.

Robert, M., Giuliani, P., & Gurau, C. (2020). Implementing Industry 4.0 real-time performance management systems: the case of Schneider Electric. *Production Planning and Control*, *33*, 1-17.

Savastano, M., & Amendola, C. (2018). How Digital Transformation is Reshaping the Manufacturing Industry Value Chain: The New Digital Manufacturing Ecosystem Applied to a Case Study from the Food Industry. *Network, Smart and Open*, *24*, 127-142. doi: 10.1007/978-3-319-62636-9

Schumacher, A., Erol, S., & Sihn, W. (2016). A maturity model for assessing industry 4.0 readiness and maturity of manufacturing enterprises, *Procedia CIRP*, *52*, 161-166.

Shepherd, N. G., Mooi, E. A., Elbanna, S., & Rudd, J. M. (2021). Deciding Fast: Examining the Relationship between Strategic Decision Speed and Decision Quality across Multiple Environmental Contexts. *European Management Review*, *18*(2), 119-140. doi: 10.1111/emre.12430

Simatupang, T., Ginardy, R., & Handayati, Y. (2018). New framework for value chain thinking. *International Journal of Value Chain Management, 9*(3), 289-309.

Stouthuysen, K. A. (2020). Perspective on "The building of online trust in e-business relationships". *Electronic Commerce Research and Applications*, *40*.

Sun, Z., Sun, L., & Strang, K. (2018). Big Data Analytics Services for Enhancing Business Intelligence. *Journal of Computer Information Systems*, *58*(2), 162-169. doi: 10.1080/08874417.2016.1220239

The Smart Industry Readiness Index (SIRI). (2020). *Manufacturing transformation. Insight report*. EDB Singapore.

Toušek, Z., Hinke, J., Gregor, B., Prokop, M., & Streimikiene, D. (2022). Shareholder value creation within the supply chain – working capital perspective. *Polish Journal of Management Studies*, *26*(1), 310-324. doi: 10.17512/pjms.2022.26.1.19

Unhelkar, B., Joshi, S., Sharma M., Prakash, S., Krishna Mani, A., & Prasad, M. (2022). Enhancing supply chain performance using RFID technology and decision support systems in the industry 4.0 – A systematic literature review. *International Journal of Information Management Data Insights, 2*(2), 100084. doi: 10.1016/j.jjimei.2022.100084

Villalobos, J. R., Soto-Silva, W. E., González-Araya, M. C., & González-Ramirez, R. G. (2019). Research directions in technology development to support real-time decisions of fresh produce logistics: A review and research agenda. *Computers and Electronics in Agriculture*, *167*, 105092. doi: 10.1016/j.compag.2019.105092

Wieder, B., & Ossimitz, M. L. (2015). The Impact of Business Intelligence on the Quality of Decision Making – A Mediation Model. *Procedia Computer Science*, *64*, 1163-1171. doi: 10.1016/j.procs.2015.08.599

Yasin, E. T., Hamadamen, N., Loganathan, G. B., & Ganesan, M. (2021). Recent Scope for AI in the Food Production Industry Leading to the Fourth Industrial Revolution. *Webology, 18*(2), 1066-1080. doi: 10.14704/web/v18i2/web18375

Zehir, C., & Özşahin, M. (2008). A field research on the relationship between strategic decision-making speed and innovation performance in the case of Turkish large-scale firms. *Management Decision, 46*(5), 709-724. doi: 10.1108/00251740810873473