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Content

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Exploring the Implementation of Industry 4.0: A Pilot Study on Assessing Readiness in Czech Food Enterprises

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Abstract

Purpose: The aim of the paper is to define the concept of Industry 4.0 and to create a pilot study of the implemented research - to propose a methodological approach to assess the readiness of food enterprises in the Czech Republic for Industry 4.0.

Methodology: The results are based on research that focused on the readiness of 102 companies in the areas of strategy, leadership, customers, product, culture, employees and technology. The research focused on food companies in the Czech Republic.

Findings: Based on the results of our own research, a factor analysis was used to create an index of the readiness of food enterprises in the Czech Republic for innovation. The absolute highest representation was found at the readiness level of 60-65%. On the contrary, there is no representation of enterprises in the range of 0-25% readiness.

Research Limitation: Limitations of the paper include the time period in which the research was conducted. The COVID-19 pandemic certainly affected data and corporate approaches to innovation, with many firms being the first to curtail development projects. The empirical part is the first, i.e. pilot output of the research.

Originality: The paper analyses the determinants of innovation activities in relation to Industry 4.0, focusing exclusively on companies in the food industry.

Keywords: Industry 4.0, Technology, Food Industry, Management, Knowledge economy, Innovation

JEL Classification: O32, O33, M11, M21

Introduction

The world's advanced economics are now an integral part of a globalised world. Businesses find themselves in a highly competitive environment in which education and technological progress combine to create both a competitive advantage and a source of economic growth. It is in the era of globalisation that labour and goods are becoming freely tradable commodities and knowledge forms the basis of competitive advantage. The support of education, science and research, lifelong learning or the development of technology form the basis of the possibilities to secure the necessary resources, and where possible achieve economic growth. Human capital is the main resource of the knowledge economy, the new industrial revolution creates the technological basis and economic growth is behind many economic theories. A key factor for success in a competitive environment is the ability of organisations to exploit their knowledge and innovation potential. This trend stems from the development of the knowledge economy, which emphasises the creation, sharing and use of knowledge as a strategic asset.

The knowledge economy represents a driving force of innovation and growth in all sectors and industries. Within this context, it is essential that organisations operate in an innovation environment that fosters creativity and the development of new ideas. The innovation environment is a key factor in achieving competitive advantage and therefore organisations need to adapt their management and governance approaches to make effective use of new technologies and processes.

Industry 4.0 has been an important concept in recent years, bringing a new era in trans-industrial production. In terms of social change and the world economy, new industrial technologies play a key role and are an important factor in economic performance. The advanced structure of information systems and technologies is a condition for modern effective management. The changes associated with the paradigm shift from an industrial to a knowledge-based society affect all important aspects of the functioning of enterprises. Industry 4.0 is based on the interconnection of digital technologies, automation, the Internet of Things and artificial intelligence, which together are transforming the way organisations produce and deliver products and services. Industry 4.0 technologies open new opportunities and challenges for organisations seeking to improve their competitiveness and efficiency.

In addition to technological innovation, the emphasis on environmental, social and governance (ESG) aspects of business is increasing significantly. Businesses are increasingly focusing on sustainability, ethical principles, and social responsibility. ESG management is becoming an integral part of organisations' strategies and a key factor in their long-term sustainability and success. ESG management is the first of many reasons to address the Industry 4.0 phenomenon in the food industry. Industry 4.0 is intended to bring businesses in this sector increased efficiency and speed in logistics processes, reduced transportation costs, food quality monitoring and more. Research on the implementation of Industry 4.0 in the food industry has several specifics - quality control and food safety, variability of raw materials, seasonality, size of enterprises. Overall, although the basic principles of Industry 4.0 are similar across sectors, the food industry has its own specific challenges and requirements. The above reasons give room for research on corporate governance in Industry 4.0 conditions with a focus on the food industry. The main objective of the paper is to define the concept of Industry 4.0 and to create a pilot study of the research carried out - to propose a methodological approach to assessing the readiness of food enterprises in the Czech Republic for Industry 4.0.

1 Theoretical background

1.1 Knowledge economy

After the Second World War, changes took place that support the concept of the knowledge economy. There has been a rich body of economic theory that tends to integrate science, technology, and economics. These theories include theories of economic growth (which, however, does not by itself offer any practical solutions for converting knowledge into innovation) Solow (1956), the theory of catching up Warriner (1964), and theories of technological capability and technological accumulation. These theories view scientific research that has been converted into co-variant viable innovations as the main driving forces that produce the accumulated technological progress that constitutes economic growth. The breakthrough came with the discovery of changes in Solow's exogenous growth model, which considers immaterial factors of production, such as science and research or education, as the main source of economic growth. This growth theory shows that deliberate investment in human capital converts knowledge into products that enable unlimited economic growth, and that the theory can be a useful frame of reference for exploring the knowledge economy (Švarc and Dabić, 2017).

Key components of the knowledge economy include a greater reliance on intellectual capabilities than on natural and physical inputs. Efforts to integrate improvements into all stages of the production process are reflected in the increasing gross domestic product attributable to this intangible capital. Powell and Snellman (2004) criticize overly general definitions that cover everything and nothing at the same time, since all economies are knowledge-based in some way, and it is hard to imagine that some businesses are not directly knowledge-based if a knowledge economy means the distribution of knowledge and information. Beyond the general definitions, however, we find four basic perspectives on the meaning of knowledge:

1. Many economists believe that knowledge is a quantitatively, and in some sense qualitatively, more important concept than to think of it as a simple input. Peter Drucker emphasizes knowledge as a factor of production over labour and capital. Similarly, the OECD recognises that the role of knowledge is becoming increasingly important compared to natural resources, physical capital, and low skills. Although the pace may vary, all economies are moving towards a knowledge-based economy.
2. There are also theories that put forward the idea that knowledge is somehow more important as a product than it was before. We are witnessing the rise of new forms of activity based on the trade in knowledge products.

3. The third view of the meaning of knowledge deals with explicit and tacit knowledge. It can be concluded that explicit knowledge is in some ways more significant as part of knowledge bases than implicit knowledge. One of the most prominent characteristics of economic growth is the increasing explicit knowledge as a basis for the economic activities of the enterprise.
4. The final importance of knowledge lies in the technological changes in ICT, as innovations in computing technology are changing both the physical constraints and costs of information gathering and dissemination.

1.1.1 Definition of the term

The knowledge economy can be defined as production and services based on knowledge-intensive activities that contribute to an accelerated pace of scientific and technological progress. The idea of a knowledge economy is not simply a description of a high-technology sector, but a set of new sources of competitive advantage that can be exploited in all sectors, societies, and regions (Brinkley, 2006). A more specific definition describes the knowledge economy as a principle of value creation based on knowledge capitalisation. In this definition, the importance of education and the use of scientific knowledge in terms of a country's overall competitiveness is growing. The knowledge economy is characterised by the fact that it has no fixed boundaries. Acquired knowledge transcends sub-enterprise, sectoral and national boundaries (Bureš, 2007). Structural changes based on dynamic technological change are leading to increasing integration of national economies into the global economy. These changes are then further translated at the macroeconomic level into stable economic growth, low unemployment rates and the ability of economies to minimise short-term fluctuations in real output.

According to Kislingerová (2011) above-mentioned integration of national economies into the world economy can undoubtedly be described as a globalisation phenomenon. Globalisation is closely linked to the building and development of international networks - corporations and, finally, to the use of knowledge and information in these processes. Education and knowledge are not just key factors of production, since, like other inputs, they can be exported, either in the form of services or products. Comparing other factors of production with knowledge, knowledge achieves high export efficiency.

Hadad (2017) states differences in the approaches of traditional and knowledge-based economies:

A knowledge economy means abundance rather than scarcity. So, if in the past resources were diminishing, in a knowledge economy knowledge and information are not diminishing – on the contrary, they can be shared and increased. If appropriate technologies and methods are used, time and location are not major obstacles. Products or services with low knowledge intensity are not competitive, but price and value may vary by time period. Identical information and knowledge may have different value in different situations. There are difficulties in applying the rules at national level. There is a need to enforce global regulations, given that the flow of knowledge and information is consistent with high demand and low barriers.

1.1.2 Knowledge economy and growth theory

The need for specialisation in industry to support high global competitiveness has initiated a process of industrialisation of economic systems and restructuring of economies of different countries in the direction of increasing the share of the service sector. According to Sukhodolov (2019), the subsequent economic crisis gave rise to a rethinking of the concept of post-industrialization – traditional factors of production are increasingly being replaced by a single factor, namely knowledge (Dean & Kretschmer, 2007). This process, according to Sukhodolov (2019), gave rise to the concept of the knowledge economy.

Carlsson et al. (2009) present a historical evolution of the use of knowledge for economic growth, showing that contemporary economies are increasingly dependent on the ability to convert human capital into economic growth. Whereas in the late 19th century knowledge creation was associated with the growth of university-educated people, in the late 19th and early 20th centuries economic growth was driven primarily by science and engineering-based industries (chemicals, electronics, telecommunications). World War II then led to a massive expansion of research and development, which was immediately converted into economic activities. The 1960s were influenced by the declining impact of R&D from the previous years, but by the increase in R&D spending in the 1980s, together with the development of biotechnology and microprocessors. The efficiency with which knowledge is translated into economic activity changes over time, as does the mechanism for translating economically useful knowledge into economic growth.

The modern approach to economic growth has several basic features. A new economic order, sometimes called the new economy, is emerging. This is nothing less than an industrial-hunting revolution, a revolution in the explosion of information and knowledge capital. Sengupta (2011) goes on to list three key elements of this revolution:

1. increasing the efficiency of microprocessors and telecommunications
2. interdisciplinary knowledge enhancement
3. new innovations in the sense of global trade expansion through market externalities

Modern growth theory emphasises two main channels for inducing growth through R&D expenditure, which include knowledge capital and the knowledge component of innovation. The second channel is then called learning-by-doing. The role of R&D investment in improving the productivity of emerging countries is irreplaceable and has the following two effects: a market size effect, where access to a larger global market increases the likelihood of finding different activities and brands. The competitive effect is the second consequence of investment in science and research. In the short term, companies' profits may be affected as a result of entering new markets, but public competition may induce domestic technological leaders in the field to open up new challenges that will make the country show high growth rates.

According to Sengupta (2011) knowledge capital is an integral component of economic growth as it is described today. The basic components of knowledge capital are research and development, workplace learning, research in applied and basic forms, in public institutions and the general level of education in the economy from primary to tertiary levels. The concept of knowledge capital is most relevant to economic growth because of its, already mentioned, 'learning-by-doing' effect. The learning process has two effects. One is that it increases the total stock of knowledge by increasing its efficiency. The second is that the human capital "employed" in the R&D division of private industry generates an expansion of the stock of knowledge. It is generally subject to increasing returns and complements all other inputs. It should be stressed that the productivity of human capital in basic and applied research is an increasing function of accumulated knowledge capital. As a result, the cost of producing new goods decreases over time.

Furthermore, Ramani (2014) claims modern growth theories cannot do without innovation. The relationship between innovation ecosystems and co-existing economies is seen in three main points. The first is the fact that, with increasing participation in global markets, companies recognise that, in addition to the technical skills of staff and the quality of local knowledge, an entrepreneurial, collaborative and leadership mindset is also essential to enhance competitiveness. Second, firms in both emerging and developed economies are cooperating more with academic institutions in terms of R&D and knowledge exchange due to increased competition, shortened product life cycles and rising costs.

A third feature is that although knowledge generation has so far been largely concentrated within companies, market leaders are increasingly sourcing knowledge from external sources through joint ventures, alliances and hybrid relationships with other organisations, including universities, key resource institutions.

Avkopashvili et al. (2019) compares post-industrial economics with knowledge-based economics. He characterises the post-industrial economy as a service-oriented economy, with technology being the most valuable type of capital, and considers the Second Industrial Revolution as the main impetus for the post-industrial economy. In the case of knowledge-based economics, he identifies human capital as the key resource and identifies the third industrial revolution as the key moment.

Note that in this case, the author again indirectly claims that the knowledge economy is a much older concept than Industry 4.0. A distinction should be made between the new and knowledge economy Kislingerová (2008) confirms that knowledge-based economics is a historically older concept of neoclassical theory. New economics is a historically younger term and should not be confused with knowledge economics. This is even though the emphasis of the new economics is on structural changes that are closely related to technological progress. There is no consensus among economists to define the term new eco-nomics. However, four typical features can be defined. The first is the high added value brought by goods and services related to education and knowledge. The second is the efficient and rapid implementation of change in the context of ICT development. ICT itself is then the third common feature that limits geographical distance. Finally, the fourth feature of the new economy is the significant reduction of service intermediaries. The new economy can thus be seen as a particular historical period when the effects of the knowledge economy have been positively manifested (Kislingerová, 2011).

Avkopashvili et al. (2019) add that the knowledge economy seeks to overcome the effects of the economic downturn to avoid a relapse in the medium term. If we think of the knowledge economy as an economic system, it has a high level of economic development and a sustainable trajectory. The followers of the evolutionary approach believe that the new modern economy is a new modern phase in advanced economic systems and offers tools for solving existing problems.

1.2 Innovation environment

In the last century, the concept of innovation has become established mainly in the economic but also in the social spheres. Innovation can be thought of as a cognitive tool that allows the importance of technical, marketing and process knowledge to be explored while simultaneously improving these areas (Müller, 2017). Innovation can be defined as the expansion and renewal of product offerings and associated markets, the creation of new methods of production, distribution, or delivery. The broad definition of innovation also includes the introduction of changes in management, working conditions, work organisation and the qualification of the workforce (Novák, 2017). Given such a general concept as innovation, the understanding of innovation found in the current literature varies considerably. Dziallas and Blind (2019) understands innovation as the implementation of a new or significantly redesigned product, process or service and notes that the term refers both to innovative ideas that have the potential for commercialization in the marketplace and to ideas that have already been successfully commercialized. Thayer et al. (2018) define innovation as the introduction and application of new practices, processes and products that are intended to significantly benefit a group, wider society or an individual. The concept of innovation is not synonymous with the concept of creativity, which is based on the generation of ideas, however novel and useful they may be. Innovation builds on creativity through the implementation of new and unique ideas and is thus more of a non-linear and dynamic process. The above definitions, like much of the literature from the previous decade, neglect environmental innovation. In fact, innovation can play an absolutely crucial role in the efforts of companies, individuals, and society as a whole to move towards sustainable growth. Environmental innovation in relation to sustainability requires radical changes in services and products, and not only throughout the product life cycle. Environmental innovation often fails for two main reasons. The first is that they require a comprehensive and interdisciplinary approach. The second reason is the many externalities that enter the whole innovation process. We thus find two types of failure, the first originating in an imperfect market environment, the second being purely systematic (Working Group on Innovation and Technology Policy, 2000).

The initial phase of the innovation process requires a quality innovation environment - a society where barriers to innovation are not found. A suitable society is a dynamically developing socio-economic system, which nowadays bears various names - knowledge society, knowledge economy, modern society, collectively a society or enterprise based on knowledge

(Karpov, 2017). According to Ramani (2014); Arocena et al. (2018) relationship between innovation systems and contemporary - knowledge economies is seen in three main points. The first is the fact that, with increasing participation in global markets, companies recognise that, in addition to the technical skills of staff and the quality of local knowledge, an entrepreneurial, collaborative and leadership mindset is also essential to enhance competitiveness. Second, firms in both emerging and developed economies are cooperating more with academic institutions in terms of R&D and knowledge exchange due to increased competition, shortened product life cycles and rising costs. A third feature is that although knowledge generation has so far been largely concentrated within companies, market leaders are increasingly sourcing knowledge from external sources through joint ventures, alliances and hybrid relationships with other organisations, including universities, key institutions when it comes to sourcing. Ahmi et al. (2019) they add, the knowledge economy seeks to overcome the effects of the economic downturn so as to avoid a relapse in the medium term. If we think of the knowledge economy as an economic system, then it has a high level of economic development and a sustainable trajectory. The followers of the evolutionary approach believe that the new modern economy is a new modern phase in advanced economic systems and offers tools for solving existing problems, while it is generally accepted that innovation and innovation strategies improve the competitiveness of enterprises (Qershi et al. 2020).

1.2.1 Innovation models

According to Sengupta (2014) innovation models generally emphasise the endogenous nature of growth. How does a given enterprise grow? How does industry growth affect it? What role does the market environment play. These questions have recently been central to the formulation of innovation models. Innovation models differ according to the types of innovation and the way they affect industry growth. However, most innovations have common characteristics - features that are as follows: Innovations involve new and productive ways of growing an industry through production, dis-tribution, communication or organisation. Investment in R&D is a major component of most innovations and may include both theoretical and applied research. However, theoretical research does not produce direct cross-cutting results until it is applied through the dissemination of knowledge across enterprises and sectors on a commercial basis. Techno-technological change and the diffusion of human capital play a central dynamic role in most industrial innovations, although building a new enterprise or a new organisation can be equally important for launching an innovative activity. All endogenous innovation is driven by market incentives of profit and economic efficiency in a dynamic competitive environment.

Berkhout et al. (2006) claim innovation models can be divided into three historical stages. In the traditional innovation model (first generation), innovation is represented by a sequence of processes that start with research and development and end with the deployment of the product on the market. The biggest shortcoming of the first-generation innovation models was the lack of identifying market needs, which is why they were not always accepted by customers. The second-generation innovation models, unlike the earlier models, drew information directly from the market and are the opposite of the earlier models in terms of information flow. The disadvantage of the newer models was too much emphasis on optimising existing projects, this led to many short-term projects.

According to Léger & Swaminathan (2007) companies have been using third-generation models that exhibit less linearity due to feedback loops in the chain. Investments in innovation are closely linked to the long-term strategy of the enterprise and can be described as open R&D models. Modern innovation models focus mainly on technical innovation (product, process) and less on non-technical innovation. Thus, the third generation of innovation models focuses on new technological capabilities of the firm more than on institutional constraints. characterizes the evolution of innovation models and confirms the linear nature of earlier innovation models, where each aspect of the process was considered modular and unrelated to other parts of the innovation process. The author describes two approaches to innovation, namely the linear model pushed by techno-logic (technology push) and the linear model pushed by market needs (demand pull). In the first approach, innovation is seen as exogenous and driven solely by scientific progress. The second approach describes innovation as a response to demand for new products and processes. As already indicated, neither approach has succeeded because it has not respected the fact that there are feedback loops and a linear sequence of processes in the innovation process.

The innovations that competitive companies have been implementing in the last decade have the following characteristics: Innovation is synonymous with partnership, we speak of so-called open innovation. Attention is paid to the interaction between science and business. Hard knowledge of new technologies is complemented by soft knowledge of new markets. Partnerships play a crucial (Léger & Swaminathan, 2007)

A summary of the historical development of innovation models is provided by Žižlavský (2011) and is shown in Table 1.

Table 1:Development of innovative models

innovation model	Year	Author
Linear pushed by technology	50s - 60s of the 20th century.	Rothwell
Linear pushed by the market	60s – 70s of the 20th century.	Described by Myersem and Marquisem
Interconnected (interactive)	70. – 80. of the 20th century.	Movery and Rosenberg
Integrated (chained)	90. – 90. of the 20th century.	Kline and Rosenberg
Network	Early 90s of the 20th century	Rothwell

Source: Žižlavský (2011)

1.2.2 The linear models

Chronologically, the first innovative model is the aforementioned **technology-driven model**. Shavinina (2003) likens this model to a black box. The reason for the designation is that the innovation process itself was not important at that time, the only things of interest to the organisation were the inputs and outputs of the innovation process. The funds invested in R&D generated new technological products, but the actual model of transforming inputs into outputs stood in the background. The model recognises innovation as an important economic activity of firms, although it does not explain the characteristics of R&D, it does draw attention to the fact that firms and industries that spend relatively large amounts on R&D may tend to have a relational outlook on the future. Thus, it is the first linear model whose sub-essence is R&D discoveries that eventually lead to technological development, resulting in the flow of new products to the market, regardless of market attractiveness, and the application of the developed technologies to new (Caetano & Amaral, 2011). A graphical sequence of the innovation sub-processes of the linear model is provided in Figure 1.

Figure 1: Linear innovation model pushed by technology

Source: own processing according to Shavinina (2003)

The linear model driven by market needs is the second innovation model in chronological order. The post-World War II economic crisis and the trend towards consolidation, control and cost reduction contributed to the emergence of the model. Market-driven innovation arises as a result of perceived and articulated customer needs and wants (Geum et al. 2016). The approach usually stems from unmet customer needs or previously identified existing problems in the market. It is primarily driven by the sales or marketing department, which seeks to demonstrate potential markets for new products or products that should be (Maier et al. 2016). A diagram of the innovation process is shown in Figure 2.

Figure 2: Linear innovation model pushed by the market

Source: own processing according to Shavinina (2003)

One of the conclusions of this innovation model is that fluctuations in investment are better explained by external events (e.g. demand) than trends in research activity. A number of authors have compared the two innovation models mentioned above, for example Shavinina (2003) states that the predominant model of innovation for a long time historically has been just linear models, according to which innovation is a sequence of phases based either on scientific research or on some perception of demand. Schumpeter and Schmookler were among the first to recognise innovation as the main engine of growth. For both, albeit in very different ways, innovation was a very important component of economic development. The debate on whether a technology-driven model could be distinguished from a market-driven model, and if so, which was more important, was somewhat lengthy and did not have a clear outcome. The selected studies suggest that the demand-driven model is the most important determinant of the inovation process. The findings are confirmed, for example, by Langrish (1972) and Gheorghiou (1986), who argue that very few innovations were the result of scientific discovery. Table 2 provides a summary of the differences between the two innovation models.

Table 2: Comparison of linear innovation models

Model pushed by technology	Model pushed by the market
The innovation process begins with invention and ends with application	The starting point is the customer needs identified in the market or identified by the company's management.
The growth of new industries is based on technology and the technological renewal of existing industries.	Capacity and demand are more or less in balance, with an increasing strategic emphasis on marketing.
Technical breakthroughs are invented by scientists and engineers; the target market may not yet exist or the current market may be transformed.	Market potential - one that already exists but is not fulfilled, or one that could be created.
All activities are focused on development, there is no interest in market attractiveness and application.	Improvement of existing products in line with market requirements.
New products are driven by new technologies.	Driven by previously unrecognized customer wants and needs for new products.
Commercialisation of a specific technology	Strong link to incremental innovation

Source: own processing according to Maier et al. (2016)

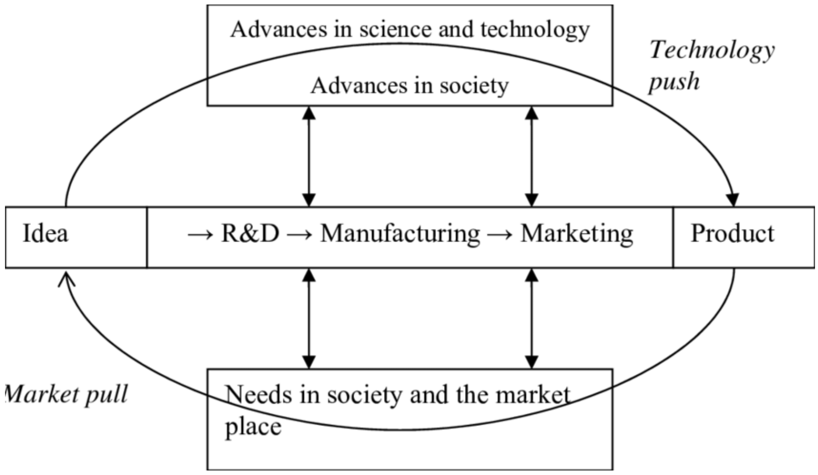
According to Di Stefano et al. (2012) we find authors who referred to the so-called technology-push perspective, emphasizing the key role that science and technology play in the development of technological innovation and adaptation to the changing characteristics of the industrial structure. On the other hand, scholars taking a demand or market approach have identified a broader set of market characteristics, including characteristics of the final market and the economy as a whole, that affect innovation performance. The comparison of these two approaches to innovation sparked a fruitful debate that culminated in the 1970s. These years saw an acknowledgement of the role of science and technology in generating innovation and a growing scepticism about a purely demand-side.

1.2.3 Non-linear models

Müller (2001) claims, both linear models were a very simplified picture of the generally complex interactions between science, technology and the market. A deeper understanding and a more thorough description of all aspects as well as actors in the innovation process was needed. The linear post-balance of innovation began to be questioned and the process was broken down into discrete phases, each interacting with the others – thus creating an **interactive innovation model**. The interactive model is based on the theoretical assumptions of evolutionary economic theory and insights derived from new theories of economic growth. In the interactive model, R&D activities are not seen as the primary innovation-generating processes, but rather as part of a larger system of relationships between different elements: market contact, design, financial capabilities, opportunities for linking the firm to external knowledge systems, use of information and communication technologies (ICT), managerial skills, corporate culture, network activities, and regional and national innovation systems. Manley (2003) adds that the interactive model goes beyond the conventional model by integrating feedback loops and emphasizing the interactive nature of innovation processes. Compared to the innovation models presented so far, the interactive model approach encompasses the widest range of relationships, addressing not only the relationships between companies, but also focusing on technical support providers, relationships with different market actors.

Johannessen (2019) describes an interactive innovation model, the basic idea of which is to connect different types of knowledge. Another important feature of this innovation model is the emphasis on collaboration as opposed to competition. The interactive innovation model also emphasises the link between internal, external, and technological factors. A simplified outline of the difference between the linear and interactive innovation models can be explained as follows. In the linear model, innovation is a function of investment in private and public R&D. In the interactive model, innovation is a function of investment in private and public R&D, plus knowledge spillovers from the various intermediary links between R&D and practice. A schematic of the interactive innovation model is provided in Figure 3.

Figure 3: Interactive innovation model

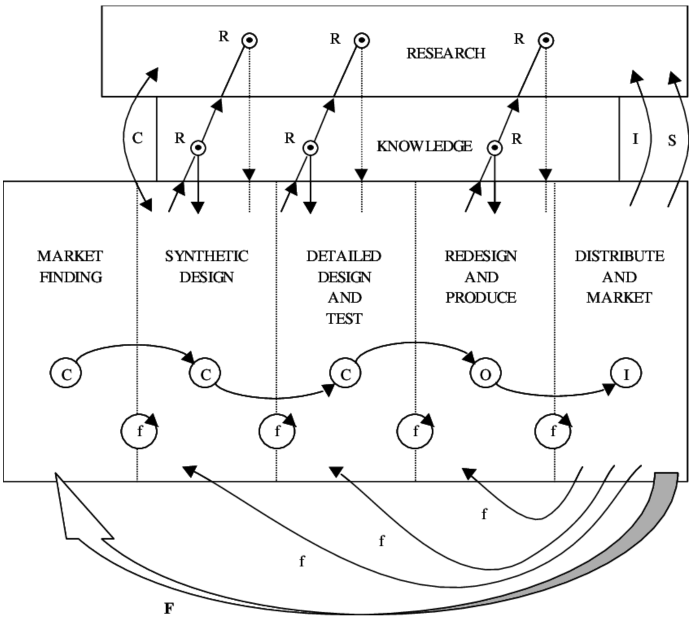


Source: according to Rothwell (1994)

The second non-linear model is **the chain-linked innovation model.** This model recognises interaction as a central element of the process of technological innovation. Two types of interactions are found - the first refers to intra-company interaction processes, i.e. in - company networks that link R&D to production and that connect different work groups within R&D.

These links can be complemented by inter-enterprise networks, a second type of interaction involving other enterprises and institutions in the wider S&T environment in which the enterprise is located (Kline & Rosenberg, 2009). A diagram of the chained innovation process is shown in Figure 4.

Figure 4: The chained innovation model



Source: according to Kline (1995)

Figure 4 presents an interactive (chained) model of the innovation process. As Fischer (2013) describes the innovation process is shown here as a set of activities that are interconnected by complex loops and feedback loops. The process is visualized as a chain that starts with the perception of a new market opportunity or an invention based on new scientific and technological knowledge. This is followed by detailed design and testing, redesign, production, distribution, and marketing. Initial design is essential for knowledge generation to create inventions and innovations, while redesign is important for their ultimate success. Problems most often arise during the processes of designing and testing new products. Caraça et al. (2007) summarise the findings of the chained innovation model with a distance. The more changes are introduced, the greater the uncertainty; Technical infrastructure and nature can be a barrier to innovation; Commercial success requires the optimization of many factors; Getting the timing of an innovation right can be critical; Responding to user feedback is an important part of innovation; Economically significant innovation does not necessarily mean sophisticated technology; Sophisticated technologies are not themselves valued in the market; Novelty alone is not an economic advantage.

The last model in Table 1 is the network innovation model. According to Žižlavský (2011) the core of this model is system integration and resource constraints. Other characteristics are mainly information systems, enterprise ecosystems and open innovation, which are created by system integration and collaboration between enterprises. In the face of increasing competition and shortening product life cycles, the network model refers to a time-based strategy. Although it was not necessarily necessary to be the first enterprise to innovate in the market, it meant a big pay-off in the form of timely and elastic supply. Time is a central motive in the innovation model, also with regard to the costs involved in developing new products.

1.2.4 Contemporary models

The network model described at the end of the previous chapter is logically the closest to the current manage of innovation, with technology playing a crucial role as in many other fields, and innovation ecosystems being today's reality. Nevertheless, we find more or less described in recent research and academic articles new/emerging innovation models. Keiningham et al. (2020) describe a "data-driven innovation model" i.e. an innovation model pushed by data and state that the innovation strategy does not have to be designed based on product innovation, nor does it have to be disruptive. It should simply aim at a change in the value creation, value appropriation or value delivery function of the firm that will lead to a significant improvement in the value proposition of the company. The innovation model should be designed around a process of collecting, organizing, and summarizing external data to simplify the market research process and thus increase the likelihood of identifying unmet customer needs.

The term "business model innovation" resonates in relatively recently published papers. Verma and Bashir (2017) states that researchers, scholars, and senior managers unanimously agree that business model innovation is a completely new form of innovation, distinct from product or process innovation. The benefits associated with business model innovations outweigh other forms of innovation beyond any doubt. Taran et al. (2015) notes that the business model concept lacks theoretical foundations in economics and management, including organizational, strategic, and marketing stu- dents. Innovation research has produced a wealth of theoretical knowledge, especially on radical product and incremental process innovation, but has not addressed business model innovation. Business model innovation has been described as a process of finding a new way of doing business that leads to a reconfiguration of the mechanisms of value creation and capture of the firm. The principle of open innovation allows for the penetration of new technologies, products or market areas that go beyond the firms' own core activities and that would be difficult for individual organisations to discover. Emerging business models are about sharing the work of innovation.

Gay (2014) claims, that rapid digitalisation of the business world is breaking down traditional industry barriers and many academics and practitioners are highlighting the need to rethink existing business models. However, recent research focuses primarily on technological developments and less on the new business models that are emerging from the integration of these technological innovations. However, this new industrial para-digma is changing current modes of value creation, as it involves changes in technical and production developments, providing a more cooperative environment, better customer relationships or new product offerings.

According to Ben-Daya et al. (2019) information and communication technologies have been and continue to be a prerequisite for effective management and play a vital role in the ability to integrate suppliers and customers to improve the performance of the entire supply chain. Advanced manufacturing systems, in collaboration with ICT analytical tools, are transforming manufacturing into a new form of ICT called the Internet of Things IoT (Hamzeh et al. 2018). IoT is a new era of computing that is completely outside the realm of traditional desktop computing. Radio frequency identification (RFID) technologies in the new industrial revolution should meet the premise of identifiable objects that are present in a computer network in each form, in which ICT elements are invisibly embedded in the environment around us. The massive expansion of these and other information technologies has given rise to the now well-established term Industry 4.0, which in essence is further made up of several elements - auto-nomic robots, horizontal and vertical integration, the aforementioned IoT, cloud computing, big data and additive manufacturing (Ahmi et al. 2019; Gubbi et al. 2017)

1.3 Industry 4.0

1.3.1 Historical development

The twentieth and twenty-first centuries are the age of industry. The desire of businesses to find a balance between supply and demand is the motive behind the industrial revolutions (Yin et al. 2018). The first industrial revolution was marked by the introduction of machines into manufacturing, in the late 18th century in Great Britain. At this time, manual production was replaced by steam-powered machines. Products that were commonly made on spinning wheels, the mechanised version reached an eight-room volume at the same time. The Industrial Revolution first developed industries such as textiles, iron, steam power, machine tools, chemicals, cement, glass, agriculture, paper, transportation, mining, (canals and improved waterways, railroads, roads), and other (Morya and Shankar, 2020).

According to Lamoreaux at al. (2006) the Second Industrial Revolution refers to the period of industrialisation from the late 19th century to the early 20th century. The focus of the revolution is mass production regarding the development of machine tools. The Second Industrial Revolution adopts new technologies such as electricity, tele-phones, internal combustion engines, the railway network, telegraph, sewage, and water supply. Industrial technologies develop in various sectors, - electrification, steel, railways, machine tools, paper making, chemical industry, petroleum industry, rubber industry, bicycles, automobile industry, applied science, fertilizers, telecommunications, engines, turbines and others. Further states that the US economy, for example, has benefited from a legal, economic, and cultural environment that has strongly encouraged technological innovation. Yet, over time, there have been significant changes in the way new technological ideas have been generated and exploited. Although in the early nineteenth century the practice of inventors commercialising their ideas themselves was prevalent, during the two quarters of the nineteenth century an increasing division of labour emerged between those who invented and those who commercialised inventions. Most new inventions in this period involved mechanical technologies, and as a result the amount of capital and formal education an inventor needed to set up a business was relatively low. Innovative firms eagerly sought patent rights for cutting-edge technologies, and many creative individuals learned to make a living as independent inventors by selling their intellectual property in the marketplace. By the end of the century, however, the more scientifically demanding technologies associated with the Second Industrial Revolution greatly increased the capital requirements (both human and physical) for effective inventions, and inventors found it increasingly difficult to maintain their independence. Roberts (2015) adds the following to the first two industrial revolutions - the industrial revolutions had a profound effect on the way we produce, the place we live and our progress towards a more just and prosperous society. The first and second industrial revolutions were the driving forces in the formation of a modern society. These revolutions witnessed significant changes over the course of two and a half centuries - in ideology, social hierarchy, production and distribution, international relations, trade links, and above all, technological advances.

According to Fotr and Souček (2005) With the end of the 20th century, after the world wars and the economic crisis, came the third industrial revolution. The main symbol is the involvement of computers in production; we speak of the information and digital age precisely because of the development of information and digital technologies. Automated processes and a revolutionary way of accessing information in the form of the Internet are coming. It is noticeably easier to obtain information and the competitive strength of enterprises is increasing. The key technology of the Internet and the whole electronics industry is experiencing exponential growth. Changes have to be implemented at shorter intervals, both in traditional and especially new sectors. Robotics is entering manufacturing; personal computers are emerging. We are talking about globalisation bringing to the surface the environmental impacts of human activity that are causing climate change. Tetřevová et al. (2022) add, that corporate social responsibility is becoming a tool for promoting sustainable development.

According to Piccarozzi et al. (2018) market development, internationalisation and increasing competitiveness have led to the emergence of the so-called fourth industrial revolution and the parallel development of both industry and commerce. the concept of Industry 4.0 and its study area. Industry 4.0 builds on three previous techno-logical transformations: steam power, which was the transformative force of the nineteenth century, electricity, which transformed much of the twentieth century, and the computer era, which began in the first half of the twenty-first century.

As Klingenberg (2017) continues, in 2011 the German government is presenting a strategy for the computerisation of the manufacturing industry and the fourth industrial revolution - Industry 4.0 - is being discussed. The value chain is undergoing a process of intense change, to the extent that organisations are having to question everything they do and the industry they operate in. The core technology of Industry 4.0 is the cyber-physical system (CPS), which is defined as a combination of physical and cyber systems. Both systems behave as if they were one - everything that happens in the physical, virtual and vice versa.

1.3.2 Definition of terms

According to Nosalska et al. (2019) despite the enduring popularity of the term Industry 4.0, researchers and practitioners regularly point to the unclear meaning of Industry 4.0 and the different contexts in which it is used. Researchers often explain the concept by listing its characteristic elements. Creating a concise definition that encompasses all relevant aspects of Industry 4.0 thus remains difficult, as the concept covers a wide range of issues. The basic differences between scientific and business descriptions of Industry 4.0 can be seen in the approach to changes in business models: business studies emphasise this issue much more often than scientific publications. This is confirmed by the results of an analysis of the co-occurrence of technical and business topics in the scientific literature, as well as by the types of journals that most frequently publish.

An example of a scientific definition might be the definition according to Piccarozzi et al. (2018), where he describes Industry 4.0 as a revolution based on the development of fully automated and inter-intelligent production that is able to interact autonomously with major corporate entities. Industry 4.0 is based on the horizontal and vertical integration of production systems driven by real-time data exchange and flexible manufacturing, allowing for 'made-to-measure' production. Important elements are the automation and digitisation of processes, the use of electronics and information technology (IT) in production and services. This is the age of "cyber-physical systems" - systems that integrate computing, networking and physical processes and encompass a myriad of technologies that include mobile devices, the Internet of Things (IoT), artificial intelligence (AI), robotics, cybersecurity and 3D printing.

The second category of definitions focuses on value creation and the structure of the value chain. The value chain can be understood as a description of "the full range of activities that are required to take a product or service from conception through the various stages of production. An example of such a definition is the following from Robert et al. (2022) „Industry 4.0 will bring greater flexibility and robustness to the value chains associated with Industry 4.0, which will be made up of flexible and adaptable corporate structures, with a sustained capacity for internal evolution to cope with the changing business pro-centre."

The literature offers countless explanatory definitions of Industry 4.0. The definitions below illustrate the variety of definitions of Industry 4.0: Industry 4.0 addresses the fourth industrial revolution in manufacturing, in which technological trends such as digitalization, automation and artificial intelligence are changing production processes (Madsen, 2019). Industry 4.0 aims to increase the competitiveness and efficiency of manufacturers by bridging the gap between industrial production and information technology (Hahn, 2020). Industry 4.0 is the era of digitalisation - everything is digital: business models, environments, production systems, machines, operators, products and services (Alcácer and Cruz-Machado, 2019). Industry 4.0 enables an environment in which all elements are connected seamlessly and effortlessly. All devices and functions are designed as services that communicate with each other non-stop to achieve a high level of coordination (Zambon et al. 2019). Industry 4.0 is intelligent manufacturing that improves long-term competitiveness by optimising labour, energy and materials to produce a high quality product and respond quickly to market fluctuations and lead times (Mehrpouya et al. 2019). Industry 4.0 connects the supply chain and ERP system directly to the production line, creating integrated, automated and potentially autonomous manufacturing processes that make better use of capital, raw materials and human resources (Li et al. 2019).

The Fourth Industrial Revolution, also known as Industry 4.0, is bringing a number of changes to organisations in terms of organisational processes, working methods and employee structure (Pejic-Bach et al. 2020). Industry 4.0 requires certain technologies, such as artificial intelligence, which is programmed to make intelligent and autonomous problem-solving decisions based on the situation and to remember adaptive decisions that will be implemented in the future (Jena et al. 2020). Industry 4.0 can be described as an increasing level of digitalization and automation of the production environment and the creation of a digital value chain that enables the communication of products and their environment with business partners (Lasi et al. 2014). Industry 4.0 is revolutionizing manufacturing and bringing a whole new perspective to the industry on how manufacturing can work with new technologies to get maximum performance with mini-low resource use (Kamble et al. 2018). Industry 4.0 is an emerging concept in the field of manufacturing systems and is described as encompassing technologies such as the Internet of Things, big data, cyber-physical systems and smart objects (Gobbo et al. 2018).Industry 4.0 enables the emergence of an intelligent network within the enterprise, connecting employees, customers, suppliers, products, machines and production facilities (Cugno et al. 2022).

Based on a lot of research that mentions Vrchota et al. (2020), Industry 4.0 can be understood as a revolutionary concept of the production process, oriented towards new technologies that interconnect machines and equipment with digital data into automated, intelligent systems.

1.3.3 Barriers and risks of implementation

According to Chauhan et al. (2021) the implementation of Industry 4.0 is of interest not only to scientists but also to companies directly affected by the industrial revolution. The aforementioned digitalisation, decentralised systems, service orientation and modular production - these principles, together with the increasing influence and pace of technology development, have the potential to improve the performance of businesses. The changes that Industry 4.0 brings with it are necessarily accompanied by a certain degree of uncertainty. Among the often-mentioned barriers to implementation are the following:

The need for organisational and procedural adjustments. The introduction of digital technologies requires process and organisational changes in companies. The emergence of decentralised organisations, the use of autonomous robotics is leading to organisational changes and IoT solutions that pose challenges to the integration itself (Fantini et al. 2020; Karadayi-Usta, 2020).Lack of skilled labour. Workforce skills, higher education requirements and special qualifications are essential for working with Industry 4.0 technologies, both during the implementation phase and beyond. Full technology integration depends on a multi-disciplinary workforce with highly developed soft and hard skills (Stentoft and Rajkumar, 2020).

Lack of knowledge and data management systems. Existing systems are not capable of processing data in real time and therefore more robust knowledge management systems need to be put in place. These embedded systems store and retrieve knowledge, can search for knowledge sources through storage offloading, thus improving processes, and are capable of integrating with embedded IoT components (Stentoft and Rajkumar, 2020). Lack of understanding of the benefits of IoT. IoT devices, when fully implemented, should theoretically bring potential profits to businesses. However, a lack of understanding of IoT opportunities leads to financial losses (Fantini et al. 2020).

Insufficient communication and IT infrastructure. The deployment of I4.0 technologies requires a robust IT and communication infrastructure as it relies on real-time data collection, analysis and dissemination (Karadayi-Usta, 2020; Kiraz et al. 2020). Security and privacy issues. Cyber-attacks can be expected to be an increasing concern given the data generated and distributed between companies through CPS and IoT, especially in relation to communications:

identity authentication, authoring procedures and protocols, privacy and system access (Dalmarco et al. 2019).

Lack of standardisation efforts. To support the production and implementation of Industry 4.0-enabled components, standards need to be comprehensive and widespread among equipment manufacturers. This shortcoming is particularly relevant for SMEs, as it is costly to support the upgrading and integration of smart machines without standardised approaches (Schroeder et al. 2019; Stentoft and Rajkumar, 2020). Lack of a digital strategy. There is an increasing need to develop and implement digital strategies that consider both vertical and horizontal aspects of the value chain. This means that digital strategies must take into account integration with different IT systems, where compatibility and interoperability are key aspects (Ghadge et al. 2020).

Lack of ready-made solutions. Current digital technologies still lack further development for full deployment in the form of ready-made solutions. To achieve this approach, solutions need to be fully integrated with legacy systems, achieve real-time information management and enable full interoperability with data analytics systems and services (Barros et al. 2017). The need for a high volume of investment. Businesses need to make high capital expenditures to develop Industry 4.0 infrastructure. Investments are particularly relevant for small and medium-sized enterprises. New technologies entail increased risk due to potential financial losses and unrealised returns on investment. (Kamble et al. 2018). The need for adaptive modernisation. The widespread implementation of Industry 4.0 raises the need to convert existing equipment into CPS-enabled machines, the so-called modernisation process. The pro- mix of I4.0-related technologies with current organisational hierarchies, architectures, structures, production and logistics systems entails a high level of complexity and investment that prevents companies from achieving full digital transformation (Stock andSeliger, 2016).

The barriers that stand between businesses and successful implementation certainly do not end with the above list. For example, Attiany et al. (2023) staff resistance to adopting new technologies is compounded by low levels of technology maturity or lack of staff competence. Elhusseiny and Crispim (2022) adds a general fear of change to the list and the skills and competencies aimed at managers, lack of R&D activities, lack of experience.

Türkeș et al. (2019) describe a purely human obstacle, i.e. the ability of machines and computers to keep an eye on working people, thus depriving them of intimacy. Dependence on robots arises and people become more apathetic, more introverted, more sad, more connected to virtual life. Demography is the new limit in the development of Industry 4.0, because we are facing a negative natural population growth, i.e. an ageing population. Young people are the people of the future. Another barrier to Industry 4.0 is the lack of expertise (lack of culture, vision or in-house training in the digital field, as well as lack of experts are barriers to the accelerated development of Industry 4.0). Barriers to the development of Industry 4.0 are caused by the lack of regulations and working practices in developing countries, the lack of legislation for the development of cloud computing, cybersecurity, augmented reality, artificial intelligence, especially in developing countries.

According to Sima et al. (2020) industrial robots will gradually take over some occupations over the next decades, affecting a large number of jobs. Traditional roles in manufacturing, agriculture and public services will disappear, but new jobs will be created in health, education and service delivery. However, these new jobs will require employees to acquire new skills, especially digital skills. At present, employees whose formal education is insecure are most concerned about job automation. Continuous retraining of employees is the most commonly used method to reduce the skills gap. Miranda et al. (2021) claims, that businesses need to engage in and support lifelong learning. Similarly, governments need to support continuing education programmes. Industry 4.0 needs Education 4.0. To meet the needs of the future economy, Education 4.0 needs to be seen from a four-dimensional perspective: vocational education, business education, financial education and digital education. In Education 4.0, traditional learning methods need to be adapted to include strategies, technologies and activities that enable students to access appropriate education and training programmes. As Education 4.0 seeks to deliver more effective, accessible and flexible learning programmes, new teaching and learning methods are emerging that take into account the use of technology and the best principles, strategies, styles and pedagogies that are increasingly being used in higher education.

1.3.4 Benefits of Industry 4.0

The previous chapter focused on the barriers to the implementation of Industry 4.0, the following chapters will focus more on the values that the implementation brings to enterprises. Waibel et al. (2017) in his work, he mentions the benefits of the fourth industrial revolution, especially in the area of ESG: Reducing overproduction and waste, reducing waste in the product development phase,saving natural resources, ecological dimension of existing production plants.

Nunes et al. (2017) complements the other benefits of Industry 4.0: Reduction of logistics costs in the form of transport, storage, stock transport and administration, improving delivery times and lead times, reduction of inventory volumes, more accurate demand estimation.

Kayikci (2018) lists the following benefits of Industry 4.0: Decentralised and digitalised production, where production elements can be independently controlled. Products become more modular and configurable, this will support mass customisation to meet specific customer requirements, new innovative business models: value chains become more responsive, increasing competitiveness by removing barriers between information and physical structures, digitisation is about the convergence between the physical and virtual worlds and will have a wide-ranging impact in every economic sector. It is a driver of innovation that will play a decisive role in productivity and competitiveness, Transforming jobs and the skills required, i.e. redefining existing jobs and taking measures to adapt the workforce to the new jobs that will be created.

Last but not least Hammer et al. (2017) who refers following benefits: Workers will be much more involved in their daily work in complex and indirect tasks such as working with machines, workers will have to solve unstructured problems, work with new information and perform a range of non-routine manual tasks, strengthening physical skills such as strength or fine motor skills, and reducing the physical strain of working with exoskeletons, positioning devices, robots or automation of monotonous tasks, reducing short-term memory effort by visualising detailed information and information on demand (users get relevant information when they need it and in a way they can understand it), reducing the number of errors that occur on the shop floor by real-time observation of the process and skill/ability-based work instructions.

1.4 Technology of Industry 4.0

Industry 4.0 is characterised by the use of a wide range of interconnected technologies that enable automation, digitisation, big data analysis and artificial intelligence. The literature offers a number of technologies that can be classified as part of the new industrial revolution, such as: the Internet of Things, artificial intelligence, robotics, cloud computing, simulation and virtual reality, Big Data and data analytics, additive manufacturing, cyber-physical systems or Blockchain (Zheng et al. 2021). Selected technologies are discussed in more detail in the following subsections.

1.4.1 IoT

According to Tawalbeh et al. (2020) the Internet of Things (IoT) refers to the concept of connected objects and devices of all types via wired or wireless internet. The popularity of IoT has experienced a significant increase in recent years as these technologies are used for a variety of purposes including communication, transportation, education and business development. The IoT has introduced the concept of hyper-connectivity, meaning that businesses and individuals can communicate with each other seamlessly from remote locations. Kevin Ashton coined the term "IoT" in 1999 to promote radio frequency identification (RFID), which involves embedded sensors and actuators. Enterprise IoT deployment is all about working with the data that IoT generates. IoT can be characterised by three words: big, open and connected. Brous et al. (2020) claims the IoT generates large amounts of data that are often of higher quality than data generated through traditional means, no-go: are often more accurate, they're more heterogeneous, they come from many different sources, more timely than traditional data - often in real or near real time,have a much larger volume.

Brous et al. (2020) claim, that IoT-enabled devices are used in industrial applications and for various business purposes. IoT is helping businesses achieve competitive advantage, but with the proliferation of a wide range of smart devices with data sharing and integration, privacy and data breaches are becoming a significant concern for most businesses as they disrupt the flow of work, activities and network services. Leloglu (2017); Liu et al. (2017) believe that despite the huge benefits businesses gain from the IoT, there are issues that need to be addressed. Cybersecurity and privacy risks are the main concerns mentioned by the authors. These two factors apply not only to businesses but also to other organisations and households. To overcome these threats, it is essential to have IT experts at your disposal and to develop comprehensive security measures and policies to protect your business assets and ensure continuity and stability of services. Shafique et al. 2020) states that every new technology brings with it certain challenges, and IoT is no exception. IoT cannot exist on its own, the solution is usually made up of multiple technologies and hardware, and this is what creates a difficult environment. The main challenges he sees are investment, security, integration of disparate data and sufficient skilled personnel.

The IoT architecture is based on three components/layer: Hardware that consists of many sensor nodes including communication and interconnection circuits. Middleware, the data storage layer, as well as analysis and big data processing tools. The imaging layer, which consists of powerful visualization tools and is designed for the end-user. Data is presented in an understandable form across platforms.

Shafique et al. (2020) also claim, that parameters affecting IoT architecture are diverse. Thus, efforts are currently being made by stakeholder groups to design the most optimal architecture that solves problems such as scalability, security, addressability and energy efficiency. The future IoT architecture must therefore meet these requirements.

Khanna and Kaur (2020) states, that IoT has great potential for social, environmental and economic impact. Smart grids, smart homes/buildings, public safety, environmental monitoring, healthcare, agriculture and livestock are some of the IoT-based concepts. All these areas are connected to human activities in one way or another. A key reason for IoT adoption by manufacturers, utilities, agricultural producers and healthcare providers is to increase productivity and efficiency through intelligent and remote management.

As stated in Selvanathan et al. (2020) Thames Water, the UK's largest provider of drinking water and wastewater services, uses sensors to collect and analyse real-time data to respond to equipment breakdowns and critical situations such as leaks or adverse weather events. Another area is agriculture - by using IoT, farmers can better measure monitored variables such as nutrients in the soil, fertiliser used, temperature and soil moisture. With a sufficient density of sensors deployed, agricultural yields can almost double. In healthcare, the implementation of IoT primarily brings rapid responses to changes and accurate information. However, industry is far from the only area where IoT can be used. Servida and Casey (2019) states that IoT devices have sensors or actuators that generate data, - auto-nomically, or in response to human action (motion detection, door opening). Because the devices are always active and always generating data, they are excellent digital witnesses that capture traces of activities potentially useful in investigations. IoT devices can be a neo-valuable source of evidence, provided that digital investigators can manage the amount of data generated and the number and variety of devices.

1.4.2 Big Data

According to Unhelkar (2018) today's world is literally saturated with data. It is one of the most important resources for businesses, just like electricity or oil. Businesses that have learned, or will learn, to harness the potential of data resources have an undeniable advantage in a competitive environment. Effective data acquisition, storage, sharing, security and presentation is not just a hallmark of the modern enterprise, but an integral part of the journey towards a learning organization.

Hendl (2021) adds, that while in the past, enterprises defined a way of storing data, where data was stored in databases and elaborate structures, and this way of storing and organizing data has served businesses for decades, today's enterprise reality is different. Data flows to users from many different sources and also in many different formats. When we talk about Big Data, it is not only about the amount of data processed with respect to the applications that work with it, but also about the mix of different types of data. Big Data or big data can be classified in many aspects - data sources, content formats, processing or storage methods. A diagram of the different perspectives is shown in the following list: Data sources (IoT, machines, transactions, sensors), format (structured, unstructured or semi-structured data) preprocessing (normalization, cleaning, transformation), storage and organization (by key, columnar ordering, document orientation), processing (real-time, batch).

The first property of big data, namely heterogeneity, is mentioned in the previous text. Koseleva & Ropaite (2017) state that, diversity refers to the different types of data collected through sensors, smart phones or social network data. It is not only data in the sense of text, but also images, sounds and documents. Diversity, as the first characteristic of big data, lies in the aforementioned data format - structured data (e.g. energy consumption data), semi-structured data (e.g. data exchange between smart energy systems) and also unstructured data (e.g. email communication, social network interactions).

The second characteristic of big data is the volume offered - the bulkiness. This is the main characteristic of Big Data with regard to the increasing amount of data generated, yet it does not bring any major difficulties to enterprises. The advantage of data voluminosity, or its collection and processing, is undoubtedly the acquisition of valuable knowledge, both for the enterprise and for the whole company. The last characteristic is speed - the speed of data transfer. The content of the data generated is constantly changing as enterprises implement additional data collections - from new data generators, but also by introducing older data collections into intelligent systems. Unlike traditional business intelligence type of post-processing and data mining, the collection and processing of, for example, energy big data needs surprising speed, so that it can support near real-time data processing, with decision making and data collection and processing speeds in the order of seconds.

Lamba and Singh (2016) shares already mentioned, the sheer volume of data does not pose a major problem in the adoption of this part of the Industry 4.0 concept. The process setup together with the modern infrastructure built on modern ICT technologies - RFID, IoT or Cloud

Computing - has made it very easy to collect a significant amount of data that exhibit the aforementioned 3V characteristics - volume, velocity and variety. Lu et al. (2014) report that the rise of big data depends not only on the promised solutions to the 3V challenges, but also on the security and privacy challenges of big data analytics. It is likely that unless the security and privacy challenges are well addressed, the concept of big data cannot be widely adopted.

According to Unhelkar (2018) Big Data processing technologies allow enterprises not only to sample data for analytical purposes, but also to use the entire available set. As a result, business analytics driven by Big Data technologies have a much greater chance of success in accurately understanding the meaning of data and predicting trends. Such analytics are therefore also able to provide businesses with a greater opportunity to make precise changes - in other words, to be more agile. This requires that the business strategy contributes to a positive impact on the agility of the business. Understanding agility in the context of the business is important for dealing strategically with big data. Big Data enables the enterprise to be agile, and agility provides the enterprise with opportunities to formulate successful Big Data stra-egies. Such strategic integration of technology and Big Data analytics requires holistic considerations of people, processes, technology and economics.

Piecemeal approaches to incorporating Industry 4.0 technologies to provide businesses with a rapid response can lead to inaccurate or even harmful consequences, while the ability to respond to change can be a critical factor in the success or failure of a business. Embracing new and disruptive technology such as Big Data requires consideration of all dimensions - the processes, the underlying data, and the analytical applications that work with the data. Therefore, agile management methods depend on systems agility and, in the context of Big Data, the way Big Data is incorporated into systems.

1.4.3 The additive manufacturing

According to Gibson et al. (2015) the development of industries depends on innovative and cutting-edge research activities related to manufacturing processes, materials and product design. In addition to the usual requirements for low price and best quality, market competition in today's manufacturing industries is associated with demands for products that are complex, have shorter life cycles, have shorter lead times, involve customisation and require relatively less skilled workers. In fact, the current type of products is very complex and demanding to design. Therefore, there is a strong incentive to design, develop and implement new and sophisticated manufacturing processes.

The use of conventional production methods is usually limited primarily by the size of the production run and the geometric complexity of the products, which forces companies to use processes and tools that increase the final cost of the product produced. Additive manufacturing techniques provide significant competitive advantages by adapting to the geometric complexity and indivi-dual design of the component being manufactured. Depending on the field of application Jiménez et al. (2019) to achieve the following results: Lighter products, multi-material products, ergonomic products, efficient short production runs, fewer assembly errors and therefore lower associated costs, lower tooling investment costs, combination of different production processes, optimised use of materials and a more sustainable production process.

Jiménez et al. (2019) claims, that additive manufacturing can be described as a technique of mixing materials by melting, bonding, or non-solidifying materials. In this technique, the part is manufactured in layers using 3D CAD modelling. Terms such as 3D printing, rapid prototyping, direct digital manufacturing and solid freeform (SFF) manufacturing can be used to describe additive manufacturing processes. Salmi (2021) adds that the term additive manufacturing can be understood in a non-technical context as a 3D printing process in which physical parts are produced using computer-aided design and objects are built up layer by layer. Other technologies, such as laser-assisted forming, also intervene in this process, but such processes do not fall under additive manufacturing, even though they are involved in the production process. The reason is that they do not add material to the product, but form.

As Abdulhameed et al. (2019) describes, additive manufacturing processes produce components using 3D computer data or files that contain information about the geometry of the object. Additive manufacturing is very useful in cases where low production volumes, high design complexity and frequent design changes are required, offering the possibility to produce complex parts by overcoming the design limitations of traditional technologies. Currently, additive manufacturing is being exploited and investigated for applications in areas such as healthcare, automotive, aerospace and marine, as well as industrial spare parts.

1.4.4 AI

According to Zhang and Lu (2021) artificial Intelligence looks at how to get computers to perform intelligent tasks that in the past could only be done by humans. In recent years, artificial intelligence has been developing rapidly and changing people's lifestyles. The development of AI has become an important development strategy for countries around the world to increase national competitiveness and maintain security - many countries have introduced preferential policies and strengthened the deployment of key technologies to take the lead in the new round of international competition.

Aggarwal (2022) claims, that concepts of artificial intelligence and robotics have become so pervasive that people fear machines will take over their lives and the role of humans will be relatively diminished in many areas. Humans distinguish themselves by exercising talents, skills and abilities that other creatures cannot. Humans are also distinguished by creativity and skill, and those who excel possess intelligence. Human intelligence is then understood as the ability and skill to solve problems. The main reason for the development of artificial intelligence is to simulate the human mind by studying the behavior of human intelligence using computer programs that are capable of understanding human behavior. This fact na-signs that computer and human intelligence will have a huge and obvious impact on humans. Artificial intelligence is described as the ability of machines and programs to simulate human mental experiences and their practical patterns, such as the ability to learn, judge and respond to situations. Taulli (2019) describes artificial intelligence as neural networks - essentially very simple mathematical algorithms that mimic the activities of biological neural networks. The emergence of these networks was motivated by a desire to model and understand the workings of the human brain.

Charlwood et al. (2022) claims that artificial intelligence is penetrating into a wide range of areas of our lives. One of these areas is human resources (HR), where AI can sift through thousands of job applications faster and more efficiently, free from unconscious bias. With the ability to identify key characteristics of successful employees, AI can increase the likelihood of hiring the best candidates, which in turn leads to increased productivity and reduced employee turnover. Additionally, AI can relieve human workers from routine administrative work and providing answers to common questions, as well as contribute to diversity and inclusion in organizations. Another area that AI is entering is manufacturing and industry, where it brings many benefits. For example, it enables real-time monitoring and maintenance of equipment and virtual designing. Generative design can be used within manufacturing processes, where software explores all possible design alternatives and allows them to be tested for feasibility. Thus, AI brings increased efficiency and accuracy to manufacturing processes.

According to Wang and Siau (2019) the healthcare sector is opening up a wide field of application for artificial intelligence. AI-based applications have the potential to improve the health of patients and the elderly and enhance their quality of life. There are several major applications of AI in the healthcare sector, including medical monitoring, chronic disease treatment, disease diagnosis and surgery support. AI-based applications have achieved many successes in the healthcare field. These include the use of social media to infer health risks, machine learning to predict at-risk patients, and robotics to support surgical procedures. Artificial intelligence can also help predict and identify patients with the most urgent palliative care needs. Algorithms using AI are characterised by high accuracy and speed, both in diagnosing symptoms and supporting clinical decisions.

Rui and Badarch (2022) states that artificial Intelligence conjures up the idea of a supercomputer, a computer with vast computational capabilities, including adaptive behaviours such as sensor engagement, and other capabilities that allow it to have human-like cognitive and functional abilities that actually enhance the supercomputer's interactions with humans. For example, we observe AI capabilities in intelligent buildings, such as the ability to control the air quality of a building, the temperature, or the playing of music depending on the detected mood of the occupants of a space. In the field of education, there has been a greater application of AI beyond the common understanding of AI as a supercomputer. According to Chen et al. (2020) artificial intelligence cannot completely replace the teacher, nor can it be used as the main teaching method. However, assuming that AI applications can be integrated by teachers into learning activities while working within the traditional teaching method, it can bring a whole new edge to teaching and provide substantial assistance in effective teaching.

Hwang et al. (2020) states that challenge in developing intelligent tutoring and adaptive learning systems is not only programming skills, but also techniques for simulating the intelligence of human experts. These incorporate the knowledge and experience of human teachers to make judgments and decisions based on the best available evidence to help solve problems for individual students and help them learn better. These challenges arise because AI is a highly technology-dependent and interdisciplinary field. Without an understanding of the roles of AI in education and the workings of AI technologies, researchers and educators may not be able to effectively implement AI applications and activities.

According to Shaji et al. (2023) every few decades, an innovation comes along that completely changes the world. That is, innovations that play a major role in raising living standards, such as the internet or airplanes. A historic milestone is the introduction of artificial intelligence to the general public in the form of ChatGPT. As Lund and Wang (2023) describes ChatGPT is a public tool developed by OpenAI that is based on the GPT language model technology. It is a highly sophisticated chatbot that is capable of fulfilling a wide range of text requests, including answering simple questions and performing more advanced tasks such as generating thank-you letters and guiding individuals through challenging discussions about productivity issues. ChatGPT is able to do this by leveraging its extensive data stores and efficient design to understand and interpret user requests and then generate appropriate responses in near-natural human language. Beyond its practical applications, ChatGPT's ability to generate human-like language and perform complex tasks makes it a significant innovation in natural language processing and artificial intelligence.

1.4.5 Other elements of the Industry 4.0

The above technologies and basic elements of the new industrial revolution are not an exhaustive list. According to Zonta et al. (2020) Industry 4.0 technologies are inevitably part of the ongoing revolution. Machines and managers and other employees are confronted daily with decision-making processes involving massive data input and production process adaptation. The ability to anticipate the need to maintain assets at a specific future point in time is one of the major challenges as well as opportunities. The ability to perform predictive maintenance contributes to increased machine downtime, cost, control and production quality.

Paolanti et al. (2018) claims that predictive maintenance, or on-line monitoring, refers to the intelligent monitoring of machines and other equipment. Like other areas affected by Industry 4.0, predictive maintenance has evolved from visual inspection, to automated methods using advanced signal processing techniques based on pattern recognition and machine learning, to the use of neural networks. According to Sang et al. (2020) the performance and condition of the production equipment are critical to the entire production process. In particular, these are areas that require absolute reliability, such as power plants, utilities, do-it-yourself systems and emergency services. Forecasting information is usually necessary for long-range planning and for planning various operational activities (maintenance, production, inventory, etc.). Any unplanned failure or inefficient process of a component of a production facility can have a negative economic impact on the entire production line, leading to unplanned downtime and costs. Traditional approaches to maintenance, such as manual maintenance, are inefficient and cumbersome in collecting equipment data due to general credibility concerns, discrete support, and limited data available from competing equipment manufacturers. Technologies such as RFID make it possible to collect data, but the process is complex and the huge volumes of data are impossible for traditional data processing and tools to generate meaningful information. Pech et al. (2021) defines predictive maintenance as a set of tools used to determine when specific maintenance is needed. This tool is based on continuous monitoring of the machine or process, allowing maintenance to be carried out only when necessary. A secondary, equally important function of predictive maintenance is the possibility of early detection of faults thanks to tools based on historical data - machine learning, and also on visual aspects of faults - wear, shape, colour.

According to Goel and Gupta (2020) businesses are automating many processes, making them more efficient, and this leads to collaboration between people and machines. Competitiveness in today's business environment is growing every day. It is important to make smart and timely decisions, thus meeting the need for smarter decision-making systems. Machines in the form of robots have been used for decades to perform specialised tasks in manufacturing processes, while humans are collaboratively assigned predefined tasks such as quality control and scrapping a product that has some defects. In modern industry, robots play an important role, capable of performing their tasks intelligently and, if required, autonomously and with an emphasis on safety, flexibility or collaboration. The main technologies are artificial intelligence and, of course, robotics. Robotics and industrial automation are completely changing the production and processing phases. There are countless uses to be found – Javaid et al. (2021) states that the robots are suitable for disassembly processes such as trimming and cutting due to their high precision and repeatability. This can take the form of cutting materials, plastic mouldings, etc. Thangam and Sathish (2018) in their study, they present many other areas of application of robots in conjunction with artificial intelligence, such as healthcare, agriculture, banking, education, energy and national security.

Collaborative robots or cobots are increasingly entering industrial production. Cobot technology can, according to Knudsen and KaiVo-Oja (2020) to change the game and become the dominant robotics technology in the coming decades, with collaborative robotics already becoming one of the fastest growing sectors of the robotics market. The development of robots, especially cobots, has been so advanced in the last decade that collaborative robots mark a departure from traditional industrial robots that operate separately from their human collaborators. Cobots, on the other hand, are designed to interact directly with human workers, to handle shared payloads, and to operate safely without conventional safety cages or similar protective measures.

Robotic technology and its evolution according to Bayram and İnce (2018) depends not only on the cost of materials, but also on the advancement of technological components for building robots that lower their purchase price, have better sensors, faster and cheaper processors, depend on open-source software and robot applications, consume less power, and are connected everywhere. However, there are still many challenges in robotics, such as dealing with uncertainty, perception of the real environment, real-time cognitive decision making, problems of slow and inefficient decision making by auto-nomic robots, difficulty in using robots, introducing robots into the manufacturing process, etc.

1.5 Sustainability and Industry 4.0

In 2023, the Intergovernmental Panel on Climate Change IPCC (2022) published its Sixth Assessment Report. The abridged version of the assessment report, "Summary for Policymakers", states that *"Human activities, mainly through greenhouse gas emissions, have clearly caused global warming, with global surface temperatures 1.1 °C higher between 2011 and 2020 than between 1850 and 1900… (high confidence). “*

According to Bag and Pretorius (2022) ever-increasing consumer demand translates into increased production of goods. This system can result in serious environmental damage, mainly due to the use of non-renewable inputs. Moreover, these are being consumed at a faster rate that is not sustainable. There are increased emissions from the production process and non-environmental disposal of products at the end of their life cycle. The only way to eliminate these problems is to follow the path of sustainable development. Changing consumption and production patterns can thus help to protect natural resources. Sustainable production and the circular economy as a recent paradigm that is essential for manufacturers to achieve the Sustainable Development Goals. The key challenges according to Jaeger and Upadhyay (2020) are: High initial set-up costs, complexity of the supply chain, lack of cooperation between companies, insufficient information for product and process design, lack of skills, quality concessions, long lead times for disassembly and high costs associated with these processes.

As Carvalho et al. (2019); Yan et al. (2021) claims these challenges can be overcome by implementing Industry 4.0 technologies. The use of cyber-physical system in smart manufacturing can be beneficial in proper planning and production itself. This leads to resource and cost savings, increases the adaptability and availability of natural resources and minimises the negative impact on the environment. Smaller production batches allow more accurate response to demand curves and reduce waste. Key principles of Industry 4.0 include decentralisation, virtualisation, real-time capability, modularity and service orientation. Virtualisation enables the reduction of industrial waste, facilitates the implementation of modern environmental practices, increases recycling opportunities and allows flexible response to demand curves and changes in energy supply. Modularity brings greater utilisation of industrial resources and extends the lifetime of machines. A service orientation can improve end product recovery, increase recycling and reuse opportunities.

According to Liu and De Giovanni (2019); Vrchota et al. (2020) sustainability can be seen as an opportunity for new industries that bring a competitive advantage in environmental protection. Businesses should use environmental and technological innovation in their processes, products and awareness to improve their financial performance. Green process innovations refer to all efforts related to in-investment in Industry 4.0 technologies and which have an impact on the production process. Examples of such investments include robotics, a key process innovation technology that enables companies to increase the efficiency of the production process by reducing the amount of resources used and consequently waste, and by reducing energy consumption and error rates. Green manufacturing differs from the traditional manufacturing approach in that it emphasises the natural impact of environmental guidelines that actually reduce costs, increase profitability and make companies more competitive. The concept of green processes and technologies was popularised by the introduction of the Kyoto Protocol and the climate change conferences in Kodan and Paris. Industrial production is a major source of environmental pollution.

Mubarak and Petraite (2020); Yadav et al. (2020) claims thath ssustainability-focused innovations that meet environmental safety criteria are used to improve environmental management. These innovations fall into two categories: process innovation and green product innovation. Process innovation focuses on the implementation of environmentally friendly technologies such as cleaning processes, emission control, pollution prevention, environmental performance and recirculation. Green product innovations then concern the substance or purpose of a company's products and services that are new or significantly improved in terms of environmental impact. Currently, green innovation is gaining increasing attention in the manufacturing industry. It is therefore essential to make a significant effort to minimise waste and pollution in the production process and to maximise the use of resources through the implementation of

Industry 4.0 technologies. The role of stakeholders is important in the effort to decarbonise industry. There is a need for a strong commitment and commitment to sustainability from business leadership. Understanding the key benefits and long-term implications is necessary to meet sustainability goals - managers need to be aware of policies that support sustainability.

1.6 Maturity models

Caiado et al. (2021) claims that many businesses have the goal of developing Industry 4.0, but are often unclear about what exactly this goal means or how to approach it - or both. Businesses that are actively seeking to move towards full adoption of Industry 4.0 should start by acknowledging their current level of maturity. Using appropriate maturity assessment methods will help them to better understand their current resource and technology.

According to Akdil et al. (2018) readiness or maturity models represent a systematic approach to the assessment of pro-processes and organisations in different business areas, which divides maturity into discrete levels. These models serve as a valuable tool for assessing and evaluating processes and organisations from different perspectives. Maturity frameworks are of great importance in evaluating organizations because they provide a structured approach to describe the ideal process for achieving desired change through sequential stages or levels. Maturity frameworks allow organisations to audit and benchmark assessment results, monitor progress towards the desired level and assess different elements of the organisation, such as its strengths, weaknesses or opportunities. The process is carried out by moving through a sequence of maturity levels, starting at a basic level and gradually moving to more advanced stages.

Voß and Pawlowski (2019) distinguish between the concepts of "readiness" and "maturity" in their work. The term 'readiness' refers to a state in which someone is fully prepared or willing to do something. It conveys the ability to be un-mediated, quick or prompt. It can be said to describe a forward-looking state, something that is to come, or a situation that is almost present. Conversely, the term "maturity" describes a state where something is finished, perfect, or ready. It means that there has been concrete progress in development. "Mature systems" (e.g. biological, organisational or technological) develop more and more over time and improve their capabilities in order to reach a certain desired state in the future. Maturity can be expressed qualitatively or quantitatively, in either a discrete or continuous manner.

The main evaluation pillars of models that focus on the adoption of Industry 4.0 can be seen in Table 3:

Table 3: Main evaluation pillars of maturity models

Strategies	• Existence of an Industry 4.0 implementation plan • Use of available resources for digitalization and intelligent automation • Adaptation of business models
Customers	• Use of customer data • Digitisation of sales and services • Customer competence in digital media
Products	• Product personalisation/mass customisation • Product digitalization (product as a service) • Integration of products into other systems
Leadership	• Management's willingness to undergo transformation • Managing digital competencies • Existence of a central strategy for Industry 4.0
Operations	• Decentralisation of processes • Modelling and simulation • Interdisciplinary collaboration
Employees	• ICT competences of employees • Employee openness to new technologies. • Employee autonomy
Culture	• Sharing knowledge • Open innovation and collaboration between businesses • The value of ICT in society
Administration and management	• Suitability of technological standards • Working regulations for Industry 4.0. • Protection of intellectual property
Technology	• The existence of modern information and communication technologies • The use of mobile devices • Use of machine-to-machine (M2M) communication

Processed according to Schumacher et al. (2016)

As Facchini et al. (2022) discuss, specific models that assess enterprise readiness for implementation include Accenture's Digital Capability Assessment (DCA), which explores the digital capabilities needed to compete in current and future markets. The tool considers five main dimensions: strategy and leadership, people and culture, product and services, customer experience and business support. It provides a framework for a basic diagnosis of seven capabilities and forty-one sub-capabilities that are considered key to digital maturity.

Another example is the Smart Grid Maturity Model (SGMM) Kapustina et al. (2020), which comprises five phases (exploration and initiation; functional investment; integration - across functions; op-timisation - enterprise-wide; innovation - the next wave of improvement), which are applied to eight areas (strategy, governance and regulation; organisation; technology; society and environment; pro-networking; work and asset management; customer management and experience; value chain integration). As Weber (2019) describes, digital Maturity model developed by Deloitte. This is the first cross-enterprise maturity model used to assess the digital capabilities of enterprises. Five core business dimensions, such as customer, strategy, technology, operations, organisation and culture, and 28 sub-dimensions, such as customer experience and security, are used for this assessment. The details of the different levels of the model are not publicly available.

Hizam-Hanafiah et al. (2020) analysed a total of thirty existing models, identifying the six most common evaluation dimensions - technology, employees, strategy, processes, leadership and innovation. The research also shows that SMEs typically do not have the resources to implement large-scale solutions and can therefore use models with these six key dimensions to comprehensively assess their readiness for Industry 4.0. Further, that research on future models for small and large organisations can be extended to include these six most common dimensions. Readiness models containing these six most common dimensions require minimal customization in different sectors in terms of implementation and practicality, thus saving costs for companies.

1.7 Food industry in terms of Industry 4.0

Náglová et al. (2022) state that food production in the Czech Republic is one of the traditional sectors of the manufacturing industry. This sector is of strategic importance in ensuring the food supply of the population with emphasis on the quantity and quality of the food produced. According to the CZ-NACE classification, the food processing industry is classified in Division 10, which is further divided into nine subgroups. In a food industry that is full of companies competing with each other, competition is consistently high. This is further accentuated by imports of food from abroad, especially from European countries. Measures aimed at eliminating unfair commercial practices, which are spreading both from European structures and at national level, should help to improve the rules on the market. The legislative process is under way, and is aimed particularly at protecting small and medium-sized enterprises.

According to Godfray et al. (2010) innovation in the food industry has its roots deep in history, several centuries ago. The original use of simple tools was gradually transformed into the use of large and advanced machines. The agriculture and food industry is one of the most important sectors, generating almost 64% of the world's food production, using different types of technological innovations. Over time, innovative practices have been implemented in every segment of the food industry, with the aim of increasing production efficiency and reducing losses and waste of raw materials. Oltra-Mestre et al. (2021) in their study compares two Spanish agri-food companies that use the same categories of Industry 4.0 technologies, but the innovation outputs are already different.

The food industry faces a number of challenges in relation to Industry 4.0 technologies. As Bigliardi (2021) claims the food industry has historically primarily prioritized reducing production costs without much consideration for consumer needs. However, there has been a significant shift wherein the food chain has been inverted, transitioning from a supply-based model to one driven by demand. This means that consumers now dictate to producers what they desire to eat. As a result of this trend, modern food companies are implementing innovations in diverse ways. Augusto (2020) highlights the distinctiveness of the food industry in relation to Industry 4.0, in order to attain optimization within an Industry 4.0 framework, it remains imperative for us to enhance our comprehension and characterization of the phenomena occurring during processing, across multiple scales, while considering the intricate complexities inherent in food products.

1.8 Research gap

The research area, i.e. the topic of Industry 4.0, has grown in popularity over the last decade, as evidenced by the contributions of Majiwala and Kant (2023); Sierra-Henao et al. (2020); Sikandar et al. (2021). All these studies confirm the increasing trend in the number of papers on Industry 4.0 The systematic literature review describes a comprehensive concept of Industry 4.0, but as Ortt et al. (2020) state in their study - the implementation of Industry 4.0 varies by industry and type of company. These results encourage the formulation of specific implementation processes for different companies. The fact that it makes sense to examine implementation depending on the industry is also confirmed by Zheng et al. (2019) who conclude in their study that the level of knowledge of each technology does not automatically lead to its adoption. Some technologies are well known but less applicable in specific companies. In this case, a high level of knowledge may be associated with a low level of adoption.

Bartoš (2017) lists the challenges facing the food industry as opposed to other industries. The food industry is currently striving for a fully automated production process, similar to that found, for example, in the automotive industry. However, there are several important differences. In the food industry, systems need to ensure not only tracking of individual ingredients, but also expiry monitoring, sample management, batching, environmental monitoring and HACCP compliance. Production lines should be able to self-manage and control the availability of raw materials for a specific product. However, in the food industry, raw materials are often a problem, as many of them are bulk or liquid and difficult to identify using RFID chips. In some cases, however, these difficulties are solved by using containers that can be easily equipped with the aforementioned chips. Bigliardi (2021) states that the food industry is increasingly customer-oriented and raises the need for a faster response in order to deal with dynamic and collaborative supply chains.

Based on the systematic literature review, the following research questions can be formulated for the pilot study:

What is the general readiness of food industry enterprises to implement Industry 4.0?

What are the main areas in which food industry enterprises show some readiness in relation to Industry 4.0?

2 Methodology

2.1 Objectives of the paper

The main objective of the paper is to define the concept of Industry 4.0 and to create a pilot study of the research carried out - to propose a methodological approach to assessing the readiness of food enterprises in the Czech Republic for Industry 4.0. The systematic literature review fulfils the first part of the main objective of the paper by defining the concept of Industry 4.0 using adequate and up-to-date sources. In relation to the research part, the systematic literature review results in a research gap as described, for example, by Tranfield et al. (2003)

The research focused on the area of food businesses in the Czech Republic. The paper works with data from 102 food industry enterprises. The data collection took place in the autumn of 2020. In order to answer especially the first research question, the results use the statistical methods of Pearson and Spearman correlation with null hypothesis H_0: $\rho=0$, to assess the relationships between the domains, as well as the suitability of the data for factor analysis (Child, 2006) using Bartlett's test of sphericity (He et al. 2010) and sample size using the Kaiser-Meyer-Olkin measure of sampling adequacy (Cohen, 2013). The Mann-Whitney U Test is used to examine differences between two independent groups (Milenović, 2011), and mainly descriptive statistics is used for the second research question. On the basis of the data obtained, a methodology will be developed and possible procedures for the effective implementation of Industry 4.0 will be proposed.

2.2 Methodological approach

The first step is to compile a literature review. A systematic review allows for a greater degree of knowledge on the topic, gives scope for linkage and ex-pertise, and also provides some scope for eliminating bias (Pittaway et al. 2005). A systematic literature search, according to Pittaway at al. (2004), is characterized by fairness - not favoring one source over another; accessibility - the literature search is compiled using available databases; and transparency or obviousness, where the steps are clearly presented for possible revision of the steps taken with reference to the reference list and other sources. The literature review will be based on a study of the scientific literature using world scientific databases, consultations or findings from scientific conferences. The main objective of the literature review is to define the concept of Industry 4.0 and to establish a theoretical basis, a starting point for the research part of the thesis.

The second step is data collection, which is being addressed within GAJU 047/2019/S using quantitative research. According to Pavlica (2000), quantitative research has the following selected parts: formulation of the scientific problem, formulation of hypotheses, sampling, pre-survey, data collection and analysis, and conclusion. The above methodological procedure is the starting point for the research to be conducted, including the pre-survey, which will be conducted on a sample of 8-10 enterprises, on the basis of which the methodological procedure will be refined and applied to the final 102 enterprises. A questionnaire will be used as a written formalised interview method to obtain relevant data. The questionnaire consists of a total of twenty-one questions and contains all possible forms of questions - i.e. closed, open and scaled. Part of the results come from research that focused on the readiness of the company in the areas of strategy, leadership, customers, product, culture, employees and technology. These evaluation dimensions were chosen following Schumacher et al. (2016) who identified nine main dimensions in their research. After the pre-testing of the questionnaire itself, the dimensions were reduced in order to reduce the content of the questionnaire to the final twenty-one questions. Thus, the dimension "Governance" is not taken into account in the conducted research and the dimension "Operations" was decomposed into the dimensions "Leadership and Product".

Januardy et al. (2023) states that the ethical aspects of Industry 4.0 research are essential to ensure appropriate and sustainable operations. Salamanca et al. (2023) adds that the introduction of Industry 4.0 technologies such as automated digital systems and cyber-physical systems raises ethical dilemmas related to data misuse, stress, social interaction and human surveillance. It is important to analyse and evaluate the implementation of these systems. Iqbal and Rahim (2021) adds that ethics is a key aspect of Industry 4.0 and factors such as better software/hardware, reduction of e-waste and production costs, and awareness of government policies and support contribute to ethical sustainable manufacturing in the digital era. Jimenez et al. (2022) claims that incorporating ethics into industry performance management is essential to address potential risks related to improper data privacy management, surveillance policies, discrimination and automated assessments in the context of Industry 4.0.

We hereby declare that the research conducted in this study has been carried out in accordance with ethical principles and research standards. Collected data have been properly protected in accordance with applicable laws. We ensure all results are presented with fairness and objectivity. We are available to provide further information and explanations of procedures if needed.

2.3 Sample characteristics

As already mentioned, the basic sample consists of 102 enterprises of the food industry and all sizes of enterprises are represented. All companies operate in the Czech Republic, and 82% of companies also have foreign sales. The average number of employees of the company in the sample is 165, and the distribution of the main economic activity can be seen in Figure No. 5.

Figure 5 – Data distribution research/CZ-NACE

Respondents were approached through a direct link to the questionnaire, while the questionnaire was addressed to managers responsible for the operation or business of the company, or close equivalents of these positions. Out of a total of 229 businesses approached, 102 responses were obtained. With regard to the focus of the research, companies falling into category C, specifically companies of section 10 of the CZ-NACE classification, were approached. In order to achieve a stratified sample, the main advantage of which is according to Acharya et al. (2013) to ensure the representation of all necessary groups in the population, the research sample was deliberately approached in such a way as to best represent the actual representation of food businesses in the Czech Republic. Figure 7 shows the distribution of data, specifically the representation of categories of the food industry in the Czech Republic according to the methodology of CZ-NACE Náglová et al. (2021), as well as the representation of businesses in the conducted research. The data shows that the biggest difference in the representation of individual subgroups of section 10 can be found in the groups labelled Manufacture of bakery, confectionery and other farinaceous products, Manufacture of industrial feeds and Processing and preserving of meat and manufacture of meat products.

2.4 Questionnaire design

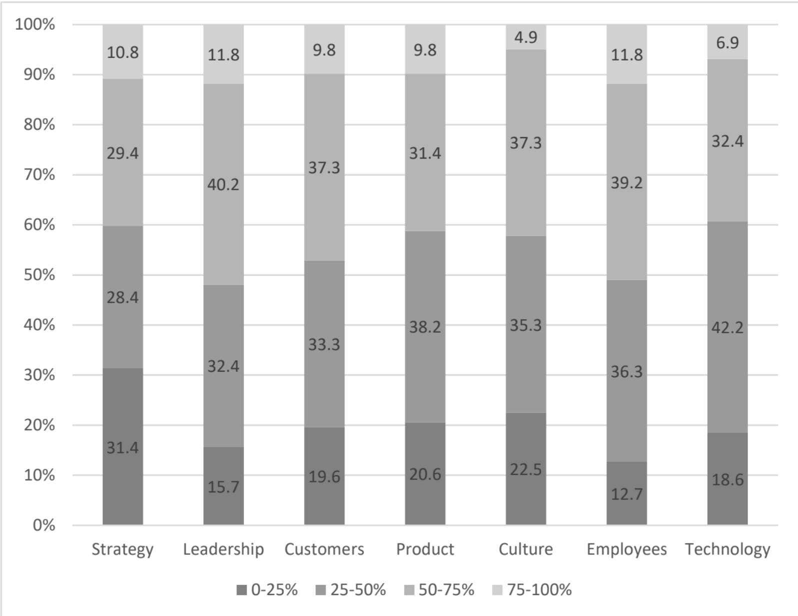
The questionnaire consists of 21 questions and is appended to this thesis. The first part of the questions (5) is an integral part of questioning, as they enable the validation of the obtained inputs for research and at the same time there is an elementary distinction between companies, whether for descriptive statistics or other statistical methods. An example can be a question about the prevailing economic activity, which clearly defines the distribution of the sample according to the CZ-NACE methodology, or a question about the number of employees, which is necessary for research in the field of management. The second part of the formulated questions is based on the following researches: Gurjanov et al. (2018); Schumacher et al. (2016); Schmidt et al. (2015); Stojkic et al. (2016); Armengaud et al. (2017); Wang et al. (2017); Xu & Duan (2019); Frank et al. (2019); Santos et al. (2017); Sony & Naik (2019); Zawadzki &

Żywicki (2016); Müller & Däschle (2018); Lorenz et al. (2018); Trstenjak & Cosic (2017); Ibarra et al. (2018); Gunasekaran et al. (2019); Prifti et al. (2017); Bolisani & Bratianu (2018); Santoro et al. (2018) excluding question about covid situation. The question regarding the impact of the pandemic is used in the paper in the form of quotations, in the sense of the variety of impacts on food industry enterprises and is not part of a detailed analysis. A detailed description of the questionnaire, including links to the assessed dimensions or the types of questions used, is part of the appendix. Questions used in pilot research and methodology are marked*.

3 Results

The literature review highlights that evaluating enterprise readiness for Industry 4.0 implementation involves considering multiple criteria or factors. It also outlines the dimensions through which enterprises assess their preparedness for embracing Industry 4.0. Analysis of descriptive statistics reveals that food businesses demonstrate the highest levels of preparedness in areas such as "employees" and "leadership". Conversely, the lowest readiness is evident in the domain of "strategy", indicating whether Industry 4.0 integration is strategically embedded within corporate strategies. These findings are graphically represented in Figure 6.

Figure 6 – Readiness by dimensions



According to Majumdar et al. (2021), robust leadership and management support are imperative for embracing radical innovations such as digitalization and automation. Their study indicates that over 68% of respondents positively rated the stance of business owners towards investing in modernization. This suggests that managers perceive strong support from both owners and employees in companies surveyed. Conversely, more than 11% of enterprises seem to overlook the significance of investing in enterprise upgrading. The results from descriptive statistics serve as the foundation for further statistical analysis. In the case of the Pearson correlation coefficient, the hypothesis is formulated as follows: H_0: $\rho=0$ (null hypothesis) and H_a: $\rho\neq0$ (alternative hypothesis). At a chosen significance level of $\alpha=0.05$, the null hypothesis is rejected in favor of the alternative hypothesis. This indicates a significant relationship between enterprises' owners willingness towards innovation and the size of the enterprise, measured in terms of the number of employees ($p=0.00$).

The correlation coefficient value stands at 0.610, suggesting a moderate to strong positive correlation. Thus, it can be inferred that the willingness of management to invest in enterprise modernization tends to increase with the size of the enterprise.

According to Benitez et al. (2020), enterprise strategies play a pivotal role in the successful adoption of Industry 4.0. When surveyed, enterprises were asked about the development of strategies and whether they encompassed the implementation of Industry 4.0. Over 25% of enterprises reported incorporating elements of the new industrial revolution into their strategies. However, it's essential for all companies' objectives to be measurable. Therefore, further statistical analysis was conducted in terms of the identified key performance indicators (KPIs).

For the analysis of two independent samples, the Mann-Whitney U-test (MWU) was employed with the following hypotheses: H_0= There is no difference in whether businesses have applied KPIs between different sized businesses (expressed by number of employees); H_a=non H_0. Based on the available data and at a chosen significance level of α=0.05, the null hypothesis (p=0.00) was rejected in favor of the alternative hypothesis. Consequently, it can be inferred that there exists a significant difference between the size of the enterprise, as expressed in terms of the number of employees, and the determination of KPIs in Industry 4.0.

The results also show a high interdependence of the individual areas (Strategy, Leadership, Customers, Product, Culture, Employees and Technology), which is evidenced by the correlation matrix created using Pearson and Spearman correlation, where both correlation coefficients came out very similar. For the purposes of this paper, we present only the Spearman correlation matrix in the Table 4 below. All coefficients listed are marked ** as they are significant and their p-value is always close to zero. As can be seen from the Table 4, the highest correlation is between Strategy and Leadership (0.684), which is due to the strong interdependence of these two levels in practice, where it is the managers (leaders) who shape the strategies of the company. On the other hand, the lowest level of correlation is between Customers and Technology (0.482), where often the company's technologies are planned precisely on the basis of the customers' needs in the final product.

In general, all relationships are characterized by a correlation at the sign level of α= 0.05, where the p-value is close to zero and correlations are at a medium to strong level according to Evans (1996) between 0.482-0684. The factor that has the strongest relationships with the others is strategy, which is the common link also in the work between the selected areas, its importance is also highlighted by Švárová and Vrchota (2013)

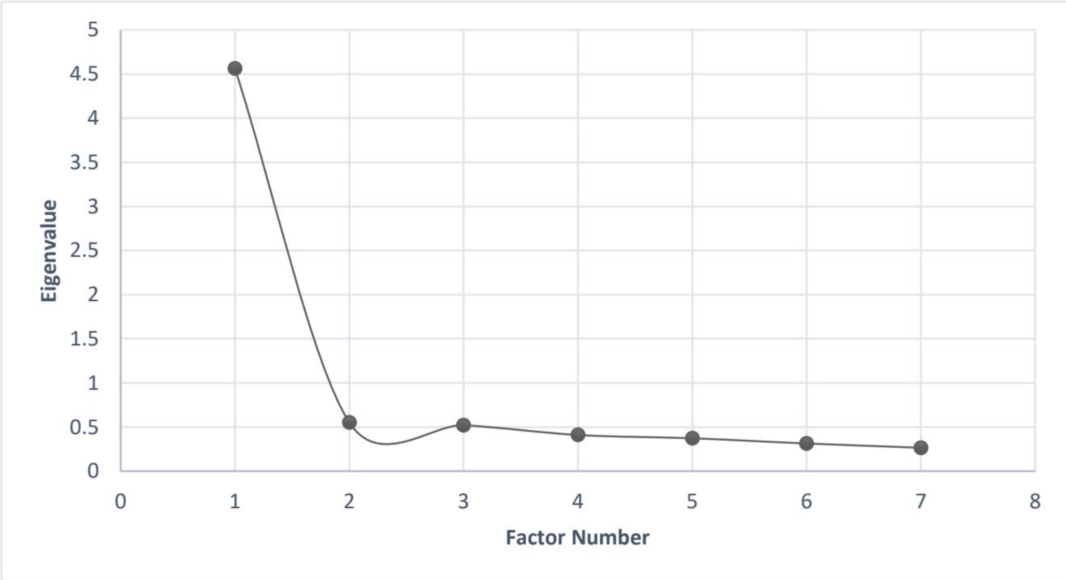
Table 4 – Correlation matrix - Spearmann

	Strat-egy	Leader-ship	Cus-tomers	Prod-uct	Cul-ture	Employ-ees	Technol-ogy
Strategy	1	.684**	.600**	.649**	.676**	.615**	.658**
Leadership	.684**	1	.590**	.583**	.576**	.618**	.541**
Customers	.600**	.590**	1	.567**	.640**	.503**	.482**
Product	.649**	.583**	.567**	1	.637**	.535**	.611**
Culture	.676**	.576**	.640**	.637**	1	.592**	.586**
Employees	.615**	.618**	.503**	.535**	.592**	1	.501**
Technology	.658**	.541**	.482**	.611**	.586**	.501**	1

Due to the moderate and strong correlation of all factors, the logical outcome of the research was to try to characterize all variables using one dimension. For this purpose, factor analysis was used, the suitability of which to the chosen data is demonstrated by Bartlett's Test of Sphericity, whose null hypothesis was rejected at a significance level close to zero. The appropriateness of the sample range is also supported by the high Kaiser-Meyer-Olkin Measure of Sampling Adequacy (0.920), whereby the appropriateness according to (Hutcheson and Sofroniou, 1999) can be considered above the 0.5 level, and above 0.9 is considered excellent for this method.

The relationship between dimensions and variables is illustrated by the scree plot – Figure 7 below, which is created by connecting points whose coordinates are given by the ordinal number of the dimension and the corresponding eigenvalue corresponding to that factor. In the plot, the two general rules for determining the number of dimensions are in agreement, where one can follow the rule of elbow or also use values above 1.

Figure 7 – Scree plot



For this reason, all 7 components can be captured by one dimension, whose values are shown in the Table 5 below, where it can be seen that this dimension captures 65% of all cases, while adding another dimension would extend the variance to 73% and 81% of cases of three factor solution. All other dimensions have % representation less than 8% and also their eigenvalues are less than 1 therefore are not considered.

Table 5 – Dimensions according to Factor Analysis

Dimension	Total	% of Variance	Cumulative %
1	4.563	65.191	65.191
2	0.553	7.901	73.092
3	0.521	7.441	80.533
4	0.410	5.861	86.394
5	0.373	5.326	91.719
6	0.314	4.486	96.205
7	0.266	3.795	100.000

During variable extraction, factor loadings were calculated for each item to represent the correlations between the dimension and the variables. They can be used to interpret the chosen dimension, which can also be seen as a complete characteristic of the firm's readiness to innovate. The Table 6 shows the values of the factor loadings of the unrotated factors. Thus, by processing the data, one dimension was extracted when the values of the individual components are above the level of 0.75, with the strongest association for the Strategy and Culture variables.

Table 6 – Dimensions according to Factor Analysis

Components	Dimension
Strategy	0.874
Culture	0.829
Leadership	0.826
Product	0.822
Customers	0.788
Employees	0.781
Technology	0.775

On the basis of the obtained data, the data of each enterprise was recalculated for this dimension, which expresses a certain index of the readiness of food enterprises for innovation, taking into account all seven components. As can be seen from the distribution of the data in the Figure 8 below, no enterprise falls into the 0-25% category in terms of the innovation readiness index which can be seen as positive from the perspective of the food industry, interestingly there is also a slight drop in the 45-55% range which is then offset by the 60-65% level which has the largest representation of enterprises. A very good result above 90% in terms of readiness was recorded by 3 enterprises, where the common feature of these enterprises is their size. All of them fall into the category of large enterprises with over 250 employees and also have a very high share of exports abroad, where in all cases it is over 60% and at the same time there are always enterprises that are already introducing elements of Industry 4.0 into production.

Figure 8 – Distribution of the innovation readiness index

The reasons for innovation are also a common factor for these companies, with the creation of new business models and cost savings consistently selected as reasons. At the same time, in terms of human resources, these enterprises value IT knowledge the most compared to, for example, professional knowledge or soft skills. On the other hand, the contradiction for these enterprises is evident in terms of the impact of the COVID-19 crisis, where managers answered this question as follows: 'The pandemic increased the demand for our products, people cooked more at home...'; 'The pandemic did not seriously affect…; 'The pandemic brought a significant reduction in sales. Our products are mainly used as food supplements for athletes and sportsmen. With the reduction in sports venues and the overall reduction in the sports industry, our sales have dropped significantly and production has been reduced." The responses show a very different impact for all three companies in terms of the pandemic. For this reason, it will certainly be stimulating in the future to follow the approaches of all these companies, how this crisis has affected their approaches to innovation and their readiness.

3.1 Discussion

Finding the appropriate determinants of innovation activities of enterprises is crucial not only for researchers, but especially for the enterprises themselves. Capitanio, Coppola and Pascucci (2010) assess the innovation activities of food firms in Italy, with firms focusing more on process than product innovation, and the same conclusions are reached by Traill and Meulenberg (2002), where strategy culture saturates a given index more than product-related innovation, similarly to performed research. Polish food companies, on the other hand, do not follow this trend (Krzysztof et al. 2017). Fortuin and Omta (2009) emphasize the role of customers as possible drivers of innovation activities, which are not given enough attention by enterprises, similarly, in the presented readiness index, the customer dimension is only fifth in the ranking.

In assessing enterprise readiness, it's evident that food industry enterprises exhibit a notable preparedness, particularly in the realms of employee readiness and strong leadership. Notably, there's a positive inclination from management towards investing in new technologies. However, it's emphasized by Schumacher et al. (2016) that this willingness shouldn't solely rest with management. They highlight the pivotal role of employees and stress the importance of effectively communicating change across the entire enterprise.

Further statistical analysis has revealed a correlation between firm size and the propensity to innovate, indicating that the willingness of managers to invest in new technologies tends to increase with the size of the firm. Additionally, subsequent testing has demonstrated that larger enterprises are more inclined to implement elements of Industry 4.0, as evidenced by the establishment of key performance indicators within the framework of Industry 4.0 implementation. The impact of firm size on innovation activities is corroborated by studies conducted by Acosta et al. (2016), Soto-Acosta et al. (2018), as well as Traill & Meulenberg (2002). Collectively, these findings underline the significant influence of firm size on the adoption of innovative practices and the implementation of Industry 4.0 elements within enterprises.

Focusing on answering the previously posed research questions, then the answer to the first of them can be found primarily in the output of the factor analysis, from which the fact can be highlighted that each company in the examined sample is more or less ready for implementation from the point of view of the evaluated dimensions, no we will not find the company in the range of 0-25%. The largest representation of companies on the readiness scale can be found in the range of 60-65%. At the level of descriptive statistics, it can be further stated that the main areas in which food industry enterprises show a certain readiness are mainly "Leadership" and "Employees", the opposite is the "Strategy" dimension. Subsequent statistical testing highlighted that the size of the company plays a key role when it comes to the implementation of Industry 4.0.

From the point of view of theoretical contributions, the study mainly brings a modified framework for evaluating the readiness of enterprises on the basis of individual dimensions.

The practical contribution of the study is the conducted research, which enters this study in pilot form, yet at the beginning of the research it defines the areas that are important for companies when it comes to the implementation of Industry 4.0. The research is specific in that it focuses exclusively on food businesses.

The limitations of the paper certainly include the time when the research was conducted, when the COVID-19 pandemic certainly impacted data and corporate approaches to innovation, when many companies were the first to start scaling back development projects. Other limits certainly include variance at the 65% level, but it should be noted that variance above 65% on a single dimension is very rare. The empirical part is the first, i.e. pilot output of the research, and so only part of the data was examined so far. In the future, we would like to extend our research abroad, where it would be very useful to compare Czech food companies with, for example, Slovak or Austrian ones, and at the same time to obtain data for these companies over several periods, so that we would be able to define the impact of the COVID-19 crisis.

3.2 Conclusion

The main objective of the paper was to define the concept of Industry 4.0 and to create a pilot study of the research carried out - to propose a methodological approach to assessing the readiness of food enterprises in the Czech Republic for Industry 4.0. This paper focused in depth on a complex set of topics that play a key role in the modern economic environment and have a major impact on the business sphere and economic development. The literature review illustrates that in today's knowledge economy, where information, innovation and technology are of fundamental value, it is essential that businesses and economies actively exploit these elements to achieve competitive advantage and sustainable economic growth. The knowledge economy shows us that the key to success is the creation, collection and effective use of knowledge. Businesses that can develop their learning systems, foster innovation and improve the ability to share and transfer knowledge between employees and departments will be better equipped to respond more quickly to market changes and new opportunities.

The innovation environment plays a critical role in supporting and facilitating innovation in organisations. The space for creativity and experimentation needs to be firmly embedded in the corporate culture through active leadership and engagement of management and employees. Collaboration with external partners, including universities, research institutions, can bring new perspectives and innovative solutions to many businesses. Industry 4.0 represents a new era of the industrial revolution, where digital technologies, automation and artificial intelligence are merging with established industrial post-ps. The transformation of the digital industry offers not only increased efficiency and productivity, but also new opportunities for innovation and the creation of new business models. Businesses that are able to adapt their processes and implement modern technologies will be better equipped to achieve competitive advantage.

In the era of Industry 4.0, it is crucial that companies apply appropriate implementation practices - readiness models and are able to assess the implementation stage - maturity. These models allow to assess an organisation's ability to successfully implement Industry 4.0 and leverage modern technologies. Readiness includes technological, organisational, human and cultural aspects. The organisation must have a strategy for change that includes not only technological aspects but also training of employees who will need to use modern technologies effectively.

In conclusion, the combination of knowledge economy, innovation environment, governance, Industry 4.0 and its technologies represents a strategic direction for businesses and economies that want to achieve sustainable growth and competitive advantage. The implementation of modern technologies and innovative processes requires not only technical knowledge, but also the ability to respond to constantly changing conditions and to effectively manage change in enterprises. Those that dare to innovate, invest in new technologies and move readiness towards full implementation of Industry 4.0 will be able to become pioneers in a new era of industrial development and achieve a long-term sustainable competitive advantage.

Attachment

The text of the questionnaire

Question n.	Question	Question type	Specific type	Dimension
1	Do you consider implementation of Industry 4.0 in your business?	close-ended	dichotomous	Strategy
2	Please provide the company's ID number.	open-ended	numerical	N/A
3*	Indicate the predominant economic activity.	close-ended	multiple choice	N/A
4*	Indicate the number of employees.	open-ended	numerical	N/A
5*	What percentage of your sales is exported abroad?	open-ended	numerical	N/A
6*	How would you estimate the percentage of readiness of your enterprise to implement Industry 4.0?	close-ended	matrix	All
7	Radical change is required to meet technical readiness requirements.	close-ended	likert scale (5-point)	Technology
8	What barriers have you encountered during implementation?	close-ended (other)	matrix	N/A
9	What are the main reasons for implementing Industry 4.0 in your enterprise?	close-ended (other)	multiple choice	Customers
10	To what extent are employees in your enterprise familiar with digital technologies?	close-ended	matrix	Employees
11*	In what position is the owner in relation to investments in the modernization of the enterprise?	close-ended	likert scale	Leadership
12	Approximately what % of your employees are IT workers?	open-ended	numerical	Culture
13	What knowledge and skills are key for you when it comes to Industry 4.0?	close-ended (other)	matrix	Employees
14	Does your company have a corporate strategy?	close-ended	multiple choice	Strategy
15*	Do you have set KPIs within the company in the area of Industry 4.0?	close-ended	dichotomous	Leadership
16	How do you collect data in your enterprise?	close-ended	multiple choice	Customers
17	Do you use cloud-based data storage in your enterprise?	close-ended	dichotomous	Technology
18	To what extent is production robotized?	close-ended	likert scale	Product
19	What is the level of digitalization of processes in your enterprise?	close-ended	likert scale	Product
20	What is the level of digitalisation in the areas mentioned?	close-ended	matrix	Culture
21*	How has the pandemic related to COVID-19 affected your enterprise?	open-ended	open-ended	N/A

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