Kaunas University of Technology
School of Economics and Business

Performance Measurement of Supply Chains in the Context of Digitalisation

Master's Final Degree Project

Tadas Danušis
Project author

assoc. prof. Viktorija Varaniūtė
Supervisor

Kaunas, 2023

Kaunas University of Technology
School of Economics and Business

Performance Measurement of Supply Chains in the Context of Digitalisation

Master's Final Degree Project

Accounting and Auditing (6211LX037)

Tadas Danušis
Project author

assoc. prof. Viktorija Varaniūtė
Supervisor

assoc. prof. Kristina Kundelienė
Reviewer

Kaunas, 2023

Kaunas University of Technology

School of Economics and Business

Tadas Danušis

Performance Measurement of Supply Chains in the Context of Digitalisation

Declaration of Academic Integrity

I confirm the following:

1. I have prepared the final degree project independently and honestly without any violations of the copyrights or other rights of others, following the provisions of the Law on Copyrights and Related Rights of the Republic of Lithuania, the Regulations on the Management and Transfer of Intellectual Property of Kaunas University of Technology (hereinafter – University) and the ethical requirements stipulated by the Code of Academic Ethics of the University;

2. All the data and research results provided in the final degree project are correct and obtained legally; none of the parts of this project are plagiarised from any printed or electronic sources; all the quotations and references provided in the text of the final degree project are indicated in the list of references;

3. I have not paid anyone any monetary funds for the final degree project or the parts thereof unless required by the law;

4. I understand that in the case of any discovery of the fact of dishonesty or violation of any rights of others, the academic penalties will be imposed on me under the procedure applied at the University; I will be expelled from the University and my final degree project can be submitted to the Office of the Ombudsperson for Academic Ethics and Procedures in the examination of a possible violation of academic ethics.

Tadas Danušis

Confirmed electronically

Danušis, Tadas. Performance Measurement of Supply Chains in the Context of Digitalisation. Master's Final Degree Project / supervisor assoc. prof. Viktorija Varaniūtė; School of Economics and Business, Kaunas University of Technology.

Study field and area (study field group): Accounting, Business and Public Management.

Keywords: performance measurement, digitalisation, Industry 4.0, Industry 5.0.

Kaunas, 2023. 73 p.

Summary

The relevance of supply chain's performance measurement in the context of digitalisation is based on both performance measurement's importance and the expectations that the digitalisation will bring significant changes to the supply chains. As performance measurement is highly depended on the organisational environment, there is a need for the change of performance measurement practices and frameworks in order to be aligned with the environment of organisations performing in the context of digitalisation. Currently the performance measurement frameworks tend to encompass the supply chain as a whole rather than be limited to organisational boundaries. The frameworks are becoming more complex and consider not only financial, but also non-financial measures as well. With regard to the digitalisation, the concept is expected to bring both benefits and challenges. The expected benefits would include higher efficiency, lower costs and increased levels of flexibility, resilience, sustainability and customisation, while currently observed barriers are considered to be the following: higher vulnerability of the systems, aggravated business ethics, theoretical discrepancies, scarcity of research, high implementation costs, etc. However, it is still unknown how digitalisation-related technologies will effect the organisational environment as well as supply chains as current effect of digitalisation is still scarce and underresearched. This creates significant difficulties aligning performance measurement with the expected changes. Considering the aforementioned, this thesis aims to propose and empirically test the conceptual model of the performance measurement of supply chains in the context of digitalisation. The conceptual model shall align the performance measurement and contemporary environment of organisations performing in the context of digitalisation. In order to achieve this aim, the following objectives are undertaken:

1. To reveal currently researched topics in performance measurement and digitalisation disciplines and to analyse relations of them according to supply chain;

2. To propose a conceptual model for assessing the performance measurement of supply chains in the context of digitalisation;

3. To develop an empirical research methodology in order to test the proposed conceptual model in practice;

4. To perform empirical research of the proposed model for the performance measurement of supply chains in the context of digitalisation solutions and make suggestions for improvement of this model.

The result of the thesis is an aligned performance measurement model as well as a recommendation on proactive performance measurement with regard to implementation of digitalisation-related technologies. The results of the research also provide that although companies employ digitalisation-related technologies minimally, their performance is still significantly influenced by these technologies. It has been discovered that the impact of digitalisation on the performance of the companies is complex and involves both financial and non-financial benefits and issues. Complexity of technology, higher idle time, a lack of human capital, a longer mean time to repair, and weaker resilience have been identified as the primary and most prevalent problems among the investigated organisations.

Danušis, Tadas. Tiekimo grandinių veiklos vertinimas skaitmenizacijos kontekste. Magistro baigiamasis projektas / vadovė Doc. Viktorija Varaniūtė; Kauno technologijos universitetas, Ekonomikos ir verslo fakultetas.

Studijų kryptis ir sritis (studijų krypčių grupė): Apskaita, Verslas ir viešoji vadyba.

Reikšminiai žodžiai: veiklos vertinimas, skaitmeninimas, Pramonė 4.0, Pramonė 5.0.

Kaunas, 2023. 73 p.

Santrauka

Tiekimo grandinių veiklos vertinimo aktualumas skaitmenizacijos kontekste yra grindžiamas tiek veiklos vertinimo svarba, tiek lūkesčiais, kad skaitmeninimas atneš reikšmingų pokyčių tiekimo grandinėms. Kadangi veiklos rezultatų matavimas labai priklauso nuo organizacinės aplinkos, atsiranda poreikis veiklos vertinimo praktikų bei metodų pokyčiams, kurie lemtų organizacijų, veikiančių skaitmeninimo kontekste, aplinkos bei veiklos vertinimos metodų suderinamumą. Šiuo metu yra pastebima tendencija, jog veiklos vertinimo metodai peržengia organizacines ribas ir apima visą tiekimo grandinę. Metodai tampa sudėtingesni ir apima ne tik finansinius, bet ir nefinansinius rodiklius. Kalbant apie skaitmeninimą, tikimasi, kad ši koncepcija duos ir naudos, ir iššūkių. Tikėtina skaitmeninimo nauda būtų didesnis efektyvumas, mažesnės sąnaudos ir didesnis lankstumas, atsparumas, tvarumas bei pritaikymas individualiems poreikiams, o šiuo metu pastebimos kliūtys yra šios: didesnis sistemų pažeidžiamumas, papildomi iššūkiai verslo etikai, susiję teoriniai neatitikimai, mokslinių tyrimų trūkumas, didelės įgyvendinimo išlaidos ir kt. Vis dėlto vis dar nėra žinoma, kaip su skaitmeninimu susijusios technologijos paveiks organizacinę aplinką bei tiekimo grandines, nes dabartinis skaitmeninimo poveikis vis dar yra menkas ir nepakankamai ištirtas. Tai sukelia didelių sunkumų siekiant suderinti veiklos vertinimą su numatomais pokyčiais. Atsižvelgiant į minėtą problemą, teze siekiama pasiūlyti ir empiriškai išbandyti konceptualų tiekimo grandinių veiklos vertinimo modelį skaitmeninimo kontekste. Konceptualus modelis suderina veiklos vertinimą ir šiuolaikinę organizacijų, veikiančių skaitmeninimo kontekste. Norint pasiekti šį tikslą, yra išsikeliami šie tikslai:

1. Atskleisti šiuo metu tiriamas veiklos vertinimo ir skaitmeninimo disciplinų temas ir išanalizuoti jų ryšius pagal tiekimo grandinę;

2. Pasiūlyti koncepcinį modelį tiekimo grandinių veiklos vertinimo skaitmeninimo kontekste įvertinimui;

3. Parengti empirinio tyrimo metodiką, siekiant išbandyti siūlomą konceptualų modelį praktikoje;

4. Atlikti siūlomo tiekimo grandinių efektyvumo matavimo modelio skaitmenizacijos sprendimų kontekste modelio empirinį tyrimą ir pateikti siūlymus šiam modeliui tobulinti.

Tezės rezultatas yra suderintas veiklos vertinimo modelis bei rekomendacija dėl iniciatyvaus veiklos vertinimo, susijusio su skaitmeninių technologijų įgyvendinimu. Tyrimo rezultatai taip pat rodo, kad nors įmonėse su skaitmenizacija susijusios technologijos yra naudojamos minimaliai, jų veiklai šios technologijos vis tiek daro didelę įtaką. Nustatyta, kad skaitmeninimo įtaka įmonių veiklai apima tiek finansinę, tiek nefinansinę naudą bei iššūkius. Technologijų sudėtingumas, ilgesnis neveiklumo laikas, žmogiškojo kapitalo trūkumas, ilgesnis vidutinis remonto laikas ir silpnesnis atsparumas buvo įvardytos kaip pagrindinės ir labiausiai paplitusios tirtų organizacijų problemos.

Table of Contents

List of figures

List of tables

Introduction

The relevance of the topic. The performance measurement in the context of digitalisation has become a significantly relevant field. Performance measurement is considered to be an essential element in the process of organisation's management aiding in decision making (Shahbaz et al., 2018) and is vital to organisational growth, success and competitiveness (Rahim et al., 2018; Galankashi et al., 2021). The scope of performance measurement is undoubtedly extensive and it is evident that the concept has become a common practice in the most of the sectors (Bititci et al., 2018). Regarding digitalisation, the emerging concepts related to the concept have created enormous amounts of digital data (Xie et al., 2020). In 2018 there were 25 million terrabites of digital data generated daily (Hariri et al., 2019) and it is estimated that by 2024 there will be 149 billion terrabites of digital data (Fleming, 2021). This tendency is considered to be creating an abundance of opportunities and many are keen to employ them for their benefit (Iqbal et al., 2018). The opportunities include capabilities enabling such benefits as higher efficiency, lower costs and increased levels of flexibility, resilience, sustainability and customisation (Mohamed, 2018; Frank et al., 2019; Maddikunta et al., 2022; European Commission et al., 2021; Patil et al., 2022; Haleem & Javaid, 2019), all of which are expected to bring significant changes (Bienhaus & Haddud, 2018).

The problem of the topic. Digitalisation is considered to cover the concepts of Industry 4.0 and 5.0 (Queiroz et al., 2019; Haipeter, 2020; Meindl et al., 2021; Maddikunta et al., 2022). Recently both Industry 4.0 and Industry 5.0 have been attracting attention from researchers and practitioners from all over the world. Industry 4.0 embodies trend of digitalisation and automation which includes such emerging concepts as artificial intelligence, cloud computing, cognitive computing, big data Analytics, and cyber-physical systems, as well as Internet of Things and the Industrial Internet of Things (Frederico et al., 2020; Pilloni, 2018; Queiroz et al., 2019; Kunkel et al., 2022; Frank et al., 2019; Maddikunta et al., 2022; Tay et al., 2018; Trentesaux & Caillaud 2020). Industry 5.0, on the other hand, undertakes to align the concepts related to Industry 4.0 with the interests of society (Longo et al., 2020; Maddikunta et al., 2022). Both concepts are believed to bring significant changes to various areas (Bienhaus & Haddud, 2018), including supply chains (Frederico et al., 2020). Furthermore, these changes render the need to change various related methodologies and frameworks accordingly. One of such is performance measurement. The latter, having substantial dependence on organisational context (Frederico et al., 2020; Simniškytė, 2020), will need to change as Industry 4.0 and 5.0 are bringing significant changes to the organisational environment (Bienhaus & Haddud, 2018). However, although there is a growing need to align performance measurement methods with the upcoming changes in the supply chain, the knowledge gap regarding the supply chain's performance measurement in the context of Industry 4.0 and 5.0 still persists (Frederico et al., 2020). Therefore, the following problem question requires to be answererd: "how can performance of supply chains be measured in the context of digitalisation?".

Due to this, the **aim** of this thesis is to propose conceptual model of the performance measurement of supply chains in the context of digitalisation as well as empirically test it.

Research object – the performance measurement of supply chains in the context of digitalisation.

In order to fulfil the aforementioned aim, the following **objectives** are considered:

1. To reveal currently researched topics in performance measurement and digitalisation disciplines and to analyse relations of them according to supply chain.
2. To propose a conceptual model for assessing the performance measurement of supply chains in the context of digitalisation.
3. To develop an empirical research methodology in order to test the proposed conceptual model in practice.
4. To perform empirical research of the proposed model for the performance measurement of supply chains in the context of digitalisation solutions and make suggestions for improvement of this model.

1 Problem Analysis of Performance Measurement of Supply Chains in the Context of Digitalisation

In this part of the thesis, it will be undertaken to analyse the relevance of supply chain's performance measurement in the context of digitalisation. The analysis will be conducted in three main steps:

- Analysis of supply chains' performance measurement relevance, considering the concept's role in the organisations, recent tendencies including their impact, and contemporary approaches;
- Analysis of digitalisation relevance including the current characteristics of Industry 4.0 and 5.0, recent tendencies, what areas and how they currently effect, and how this effect is expected to change over time;
- The combined analysis of the latter two concepts, their current relationship, what performance measurement changes are mandated by the digitalisation, and what solutions addressing the latter currently are established.

1.1 The Relevance of Supply Chain Performance Measurement

Performance measurement is a concept of great importance in the management of supply chains (Galankashi et al., 2021). The growth and success of companies are based on their level of performance (Rahim et al., 2018). In the processes of decision-making, it is considered to be essential for an organisation (Shahbaz et al., 2018). Therefore, performance measurement has become an important concept which is recognised by practitioners as means of assuring the growth and competitiveness of the business companies in supply chains (Rahim et al., 2018; Galankashi et al., 2021). In the last two decades, factors such as increasing global competition, shorter product life cycles, technological advancement, and shifting consumer preferences have made performance measurement even more relevant (Rahim et al., 2018; Shahbaz et al., 2018) and have shifted the concept from internal organisational point of view to the focus on the entire supply chain (Ka et al. 2019), thus enabling numerous performance measurement models to be developed and employed (Rahim et al., 2018; Shahbaz et al., 2018; Frederico et al., 2020). Even though performance measurement has gained a lot of attention, researchers note that there are cases where performance measurement approaches are subjected to failure (Fisher, 2021) and are considered to be counterproductive (Bititci et al., 2018). Some of the failures are considered to be the result of faulty implementation of the methods (Fadel et al., 2021), while others are considered to be caused by the shortcomings of the methods themselves (Shahbaz et al., 2018; Fisher, 2021; Kumar et al., 2022; Aryani & Setiawan, 2020). Furthermore, as performance measurement depends on the organisational context which varies significantly, currently there is no universal performance measurement method which would fit all or the majority of organisations, and each measurement method should be tailored individually for each organisation (Frederico et al., 2020; Simniškytė, 2020). Currently, studies tend to distinguish two categories of performance measures: financial and non-financial (Rahim et al., 2018; Galankashi et al., 2021; Rahim et al., 2018). The financial measures are considered to be traditional measures and for a long time have acted as a fundamental of performance evaluation and only recently the non-financial measures have been employed as additives to already used financial measures (Rahim et al., 2018; Shahbaz et al., 2018; Fisher, 2021). The rationale for this change has been increased competitiveness alongside changing external demands (Asiaei & Bontis, 2019) and the emerging perception that performance measurement fulfilled on financial measures alone does not fully capture performance (Rahim et al., 2018) and it is believed that the use of non-financial measures may fill this gap (Shahbaz et al., 2018). Furthermore, Martini & Suardana (2019) provide the following reasons why financial measures alone are insufficient for successful employment of performance measurement:

- it could promote quick decisions that are not in the best interests of the organisation in the long run;
- may encourage managers to pursue short-term profits rather than look into the actions helpful for long-term benefits;
- use of short-term profits as the only purpose may negatively impact the communication between different level managers in the organisation;
- may motivate managers to manipulate data.

Shahbaz et al. (2018) also provide a comprehensive list of conventional performance measurement drawbacks established by various researchers and scholars. These drawbacks include:

- the lack or absence of a connection between the measurement system and organisational strategy;
- inconsistencies and incompleteness in metrics;
- a large number of measures with an inability to identify critical few;
- an abundance of scattered, incompatible and isolated nature of measures;
- too many inward-looking measurement practices which tend to have biased focus on financial metrics;
- total or partial absence of supply chain context, including lack of focus on competitors and customers.

The aforementioned flaws do provide the need for the improvement of the conventional performance measurement models. However, research on this topic is still scarce and, according to Shahbaz et al. (2018), current research on performance measurement is rather narrow and limited. As stated by Maestrini et al. (2017), the latter limitation is enabled by the following:

- most of the research is narrowed to the performance measurement at the operational level and does not consider it in the supply chain context;
- the majority of studies concentrate on the performance measurement design phase, with a special emphasis on the identification and description of metrics;
- the articles included are usually limited and the criteria of selection are sometimes unclear;
- the approach for developing performance measurement matrices is not specified.

Currently the most used performance measurement approach is balanced scorecard (Ka et al. 2019). The balanced scorecard has been designed with the intention to provide managers better control and quick access to information about how the organisations are performing, enhance managers' understanding of current performance, enable managers to make operational adjustments faster and more successfully, and eventually enhance the efficiency with which strategies are implemented and overall financial performance (Tawse & Tabesh, 2022). The concept considers that organisations are acting in complex environments and, therefore, it is crucial to clearly understand organisational goals and methods undertaken to achieve them (Frederico et al., 2020). According to Kaplan & Norton (1996), four perspectives are used by the balanced scorecard to measure performance: financial, customer, business processes, and learning and growth. As stated by Tawse & Tabesh (2022), balanced scorecard, even though its adoption rate is decreasing, remains to be a crucial performance measurement tool despite the appearance of other performance measurement methods many of which are based on balanced scorecard itself. Furthermore, according to Aryani & Setiawan (2020), balanced scorecard is considered to be a dominant framework in the area of performance measurement.

To conclude, performance measurement is a vital part of organisation management. However, the way it is undertaken is highly dependent on organisational environment and, therefore, there is no universal performance measurement method. Current performance measurement methods are individually tailored to each organisation and tend to be inconsistent, biased, and unaligned with the context of organisation and its environment. Furthermore, it is also noted that there is a lack of studies which would address the aforementioned issues while existing studies are insufficient.

1.2 Contemporary changes in supply chains in the context of digitalisation

For several years, the concept of Industry 4.0, also known as the fourth industrial revolution or sometimes referred to as digitalisation in general, has been the object of massive attention and discussion. According to Rupp et al. (2021) although the concept of Industry 4.0 at first was initially used with the focus on the production and engineering processes of the manufacturing industry, it has evolved and now covers a wide range of areas such as logistics, medicine, food industry, etc. The concept is driven by rapid technological advancement (Ghobakhloo, 2020; Frederico et al., 2020; Bienhaus & Haddud, 2018) and increased competitiveness (Bienhaus & Haddud, 2018). Studies tend to address the core basis of the concept differently. Some state that the basis of Industry 4.0 are Internet of Things and cyber-physical systems while big data analytics, artificial intelligence and other disruptive technologies are only enablers of the former (Ghobakhloo, 2020; Queiroz et al. 2019; Pereira et al., 2020). Others consider all of the aforementioned technologies as a basis for Industry 4.0 (Frederico et al., 2020; Bienhaus & Haddud, 2018; Kunkel et al., 2022) while some also include organisational changes driven by these technologies (Bienhaus & Haddud, 2018; Xie et al., 2020). In general, the researchers consider that the core basis of Industry 4.0 is emerging disruptive technologies which are considered to cause significant impact and changes on business models and supply chains (Frederico et al., 2020; Queiroz et al. 2019; Kunkel et al., 2022; Sørensen, 2018; Xie et al., 2020; Mohamed, 2018). This change is evident in various parts of supply chains. In manufacturing, due to the digitalisation of industrial processes, particularly through the use of big data and predictive analytics, businesses are now able to better foresee demand, use assets more efficiently and maximise the usefulness of their resources (Abou-Foul et al., 2021). The Internet of Things provides a higher level of automatisation to processes such as product development and manufacturing, lowering costs and increasing efficiency (Gurjanov et al., 2018; Olsen & Tomlin, 2020). Furthermore, these technologies provide enterprises with the ability to track raw materials, intermediate and final goods in real-time (Xie et al., 2020). Instantly available data about the manufacturing status may increase productivity, decrease mistake rates, and improve product quality control and tracking (Xie et al., 2020). In logistics, Industry 4.0 is considered to be bringing radical changes (Wang & Sarkis, 2021). Distributed Ledger Technology, also known as Blockchain, is considered to great potential, and researchers note that it will bring such benefits to the area as improved tracing and visibility processes, lower number of the middlemen in the supply chain, tokenization incentives promoting green behaviour and advantages of safe data management (Wang & Sarkis, 2021). According to Wang & Sarkis (2021), Distributed Ledger Technology not only aims to remove time and financial costs from the supply chain, but also tends to cause fundamental changes to the organisations and supply chains in the logistics area. Furthermore, it is expected that digitalisation will provide logistics with the ability to see, learn, reason, and solve logistical problems on its own and thus will increase the effectiveness of contemporary logistics, lower logistics costs and help to meet the requirements needed for fast response (Xie et al., 2020). In the area of retail, digitalisation is also prominent. (Protega, 2021). Protega (2021) provides statistics which show that retailers are embracing digitalisation and already more than a third of the retailers have digital shops. These changes are believed to significantly impact the efficiency and results of the retailers (Protega, 2021) by providing them with new methods to (Xie et al., 2020):

- fully comprehend customer behaviour, their purchase preferences and frequency;
- better establish and implement pricing strategies;
- plan and manage shelf and storage capacities.

Furthermore, in the case of the Coronavirus disease 2019 (COVID-19) followed by various restrictions on retailers, digitalisation has proven to be helpful (Bartik et al., 2020).

Taking the supply chain as a whole, disruptive technologies are known to smoothly integrate into every step of the supply chain, improving quality and efficiency in the process (Xie et al., 2020). The case study, conducted by Klovienė & Uosytė (2019), provides that these technological advances have an indirect impact on changes in business models, firm strategies, planning, measuring, controlling, and decision-making functions. According to Xie et al. (2020), it is expected that further development of these technologies may reduce or eliminate heterogeneity of information systems, increase efficiency as well as create an intelligent, networked, and automated supply chain system, which means that the changes will transform traditional supply chains into the intelligent supply chain which is an ecosystem that would be transparent to all participants. However, it is noted that the impact of Industry 4.0 on supply chains is currently still, for the most part, scarce (Frederico et al., 2020) and there is a lack of empirical studies and results on how the adoption of technologies related to Industry 4.0 could be adopted in manufacturing companies (Frank et al., 2019).

Although the concept of Industry 4.0 is still not fully embraced, a new concept of Industry 5.0 has already appeared. The concept of Industry 5.0 is fairly new and is addressed differently by researchers: some consider Industry 5.0 to be a stand-alone concept (Aslam et al., 2020), while others state that Industry 5.0 is a part of Industry 4.0 and emphasise that it could be referred to as Industry 4.0 Plus or Industry 4.0 Symmetrical (Özdemir & Hekim, 2018). Some researchers also tend to consider Industry 5.0 as an enhanced version of Industry 4.0 (Patil et al., 2022; Maddikunta et al., 2022; Alves et al., 2023). Nevertheless, the concept is considered to be very relevant among the researchers. According to Longo et al. (2020) and Patil et al. (2022), Industry 4.0, although beneficial, is in nature technology-oriented, and newly established concepts of industrial systems and work processes do not consider human factors sufficiently. Furthermore, as stated by Maddikunta et al. (2022), it also has a negative impact on employment of human resources. Özdemir & Hekim (2018) provide the following as shortcomings of Industry 4.0: excessive integration in the absence of a "safe escape method" through networks, filter bubbles and understudy of Industry 4.0 impacts on society compared to related technical research. Philbeck et al. (2018) state that the technologies which minimise the distinction between technological and human capabilities tend to aggravate the decisions related to the development as there is evident lack of understanding about the moral role of these technologies in the society.

In order to fill this gap, the concept of Industry 5.0 has been established and undertakes to emphasize how cognitive computing and human intelligence may work together, and to view automation as a way to further improve physical, sensory, and cognitive abilities in people (Longo et al., 2020; Maddikunta et al., 2022). According to Maddikunta et al. (2022), the main feature of Industry 5.0 is mass customisation which would focus on enhancing product or service consumer satisfaction in an environment where Industry 4.0 has already been embraced. Other researchers tend to include a human-centric approach as a core feature where, unlike in Industry 4.0, the attention is directed toward how technologies could serve the human and society needs as well as interests rather than the opposite (Özdemir & Hekim, 2018; European Commission et al., 2021). Some researchers also tend to include focus on creating environmentally sustainable manufacturing processes, lessening hazardous impacts on nature and creating a pollution-free environment as the integral feature of Industry 5.0 (Maddikunta et al., 2022; European Commission et al., 2021; Patil et al., 2022). Furthermore, Industry 5.0 is also expected to address resilience which refers to the need of making industrial production more robust and better prepared to adapt to changing situations, withstand interruptions and, in case of emergencies, be capable of supporting society and maintaining essential infrastructure (European Commission et al., 2021; Patil et al., 2022). According to Patil et al. (2022), Industry 5.0 also promotes various ideas of social sustainability such as elimination of “9-5” work culture, reducing human performed tedious and repetitive tasks in order to direct more of human work into the betterment of society, and providing people with the opportunity to explore their innovativeness and creativity that contribute to society’s well-being.

Özdemir & Hekim (2018) suggests that Industry 5.0 offers three-dimensional symmetry to Industry 4.0 environment. This symmetry would consist of these dimensions:

- Innovation accelerators and brakes;
- Research on Next-Generation Technology and Society that explicitly states opportunity costs and conceptual frameworks;
- Constructing orthogonal safe exits independent of hyperconnected systems automating production and manufacturing.

The aforementioned dimensions are believed to support Industry 4.0 enabling it to achieve its technical goals safely with innovative technology policy and responsible implementation science (Özdemir & Hekim, 2018). As concluded by European Commission et al. (2021; p. 16): “Industry

5.0 recognises the power of industry to achieve societal goals beyond jobs and growth to become a resilient provider of prosperity, by making production respect the boundaries of our planet and placing the well-being of the industry worker at the centre of the production process “.

Although researchers state that it is unclear how and to what extent Industry 5.0 will affect environment of industries (European Commission et al., 2021), some examples of possible changes are already presented. For example, according to Haleem & Javaid (2019), mass personalisation brought by Industry 5.0 has the potential in the healthcare industry to enable such products as implants which would be based on patient compatibility and can be customised to match requirements of each patient’s treatment. It is believed that, for example, in the industry of orthopaedics, where high-quality, individualised implants are needed, Industry 5.0 would help to address and solve such problems as excessive production, a lack of transparency and poor tool choice (Haleem & Javaid, 2019). Furthermore, it is suggested that these technologies related to Industry 5.0 would also be useful in ensuring more precise surgery performance and aiding medical students by enhancing learning, teaching and research methods (Haleem & Javaid, 2019). Other researchers also tend to consider the impact of Industry 5.0 in contactless treatment of patients which is relevant in case of viral deceases such as Covid-19 (Maddikunta et al., 2022).

Researchers tend to consider that both Industry 4.0 and 5.0 are going to bring significant changes to supply chains (Bienhaus & Haddud, 2018), however, some of them note that both concepts are still in their infancy (Frederico et al., 2020; European Commission et al., 2021). Some researchers also tend to question whether projected technological innovations will materialise as expected and state that the presentation of new scientific techniques and technologies as revolutions frequently include an unrestrained political component to gain organisational or human authority as well as funding from stakeholders in the innovation process (Özdemir & Hekim, 2018). According to Özdemir & Hekim (2018), the latter creates overpromising which may be harmful in the long run for strong and socially conscious impacts, credibility, and sustainability within an innovation ecosystem, despite potential momentary benefits.

To conclude, with the introduction of disruptive technologies and related concepts, it is expected that supply chains will have significant changes alongside organisations performing in them. The concept of Industry 4.0 represents these technologies and their impact while Industry 5.0 undertakes to ensure sustainability and compliance with social interests in the context of Industry 4.0. However, it is noted that changes brought by Industry 4.0 to supply chains are still scarce and far from the expected impact while Industry 5.0 is a fairly new concept, and it is still unclear how and to what extent it will render changes. Some researchers also note that there is a possibility that projected changes of Industry 4.0 and 5.0 might turn out overpromised. Nevertheless, the concepts of Industry 4.0 and 5.0 remain highly relevant.

1.3 The relevance of digital performance measurement in supply chains

Considering that Industry 4.0 and 5.0 are expected to bring significant changes to supply chains (Bienhaus & Haddud, 2018), the performance measurement and its methods will have to change and adapt to these changes accordingly, as it is argued that in order to undertake performance measurement successfully, it is essential for organisations participating in supply chains to modify performance measurement systems in accordance with the organisational context and the needs of stakeholders (Frederico et al., 2020; Klovienė & Uosytė, 2019). Researchers have noted that there is a significant lack of studies addressing performance measurement in the context of the supply chains affected by Industry 4.0 (Frederico et al., 2020; Tambare et al. 2021). Nevertheless, existing studies do provide useful insights. Klovienė & Uosytė (2019) have observed that solutions provided by Industry 4.0 enable new predictive analytics systems which are expected to be used in planning/ financial planning processes and address the companies' needs to have more accurate data in order to measure future performance. It is expected that predictive analytics, in the course of Industry 4.0, may become more complex, automated, a lot faster and will allow the use of larger amounts of data for measurement (Klovienė & Uosytė, 2019). Furthermore, Klovienė & Uosytė (2019) emphasise that the key difficulty for the present measurement function is to choose the appropriate techniques for measuring existing processes and to find new indicators that will aid in analysing the effects of technological breakthroughs on both the company's old and new processes. Tambare et al. (2021) propose that performance measurement in the context of Industry 4.0 is viable through standards of ISA-95 which defines entities where interaction between operation and information technologies occurs or ISO 22400 which it provides an overview of manufacturing key performance indicators and focuses on performance measures which emphasises the continuous of the operational performance in manufacturing. In the study provided by Tambare et al. (2021), ISA-95 is considered to focus on the Manufacturing Operation Center, which unifies and establishes a common ground between the periodic and Transactional Enterprise Resource planning worlds ideal for manufacturing facilities. The analysis of production loss based on Manufacturing Operation Center and Overall Equipment Efficiency is also covered in the research. The other standard addressed in this study is ISO 22400, which assists in the development of new key performance indicators for the manufacturing sector and the application of standards to define various key performance indicators for the measurement of other performance indicators in smart manufacturing. The research also included the most widely used key performance indicators in the sector (Tambare et al. 2021). Another study, conducted by Frederico et al. (2020), states that the majority of the existing studies are more specialised in manufacturing and technical areas rather than managerial ones, and are not directly related to the supply chains. Therefore, the study undertakes to address this area in a more holistic view and proposes Supply Chain 4.0 Scorecard which aligns the performance measurement method known as balanced scorecard to Industry 4.0 supply chain. This study has established five main dimensions of Industry 4.0 and has linked them with four perspectives of the balanced scorecard (Frederico et al., 2020). With the search on main scholar databases such as "Google Scholar", "Scopus" and "ScienceDirect" no studies which would directly address the supply chain performance measurement in the context of Industry 5.0 have been found. Nevertheless, researchers state that it is unclear how and to what extent Industry 5.0 will affect the environment of industries (European Commission et al., 2021) which makes it difficult to determine suitable supply chain performance measurement methods in the context of Industry 5.0. As it is anticipated that supply chains and business environment will undergo significant changes as a result of digitalisation, it is concluded that performance measurement in the context of digitalisation is a topic of high relevance. The expected changes will mandate the consequential adjustment of supply chains' performance measurement frameworks as the latter are highly dependent on the business environments. However, studies addressing the latter are still scarce. Moreover, the current changes are still far from expected and it is unknown how precisely they will alter business supply chains and organisational structures at this time. In order to achieve the proper alignment between performance measurement and the environmental changes brought on by digitalisation, it is crucial to conduct a deeper investigation of this subject.

2 Theoretical Aspects of Performance Measurement of Supply Chains in the Context of Digitalisation

In this chapter, the theoretical aspects of supply chain performance measurement and digitalisation shall be established by undertaking a scholarly literature analysis. Further, relying on the latter theoretical aspects, the conceptual model of the performance measurement of supply chains in the context of digitalisation will be established. In the sub-chapter of the theoretical aspects of supply chain performance measurement, the concept itself will be presented alongside its function, related frameworks (including balanced scorecard) and overview of performance measures and their categorisation. The sub-chapter addressing theoretical aspects of digitalisation will include a description of the concept, its function, types, benefits, opportunities and barriers. The last sub-chapter will include a conceptual model which will intend to align supply chains' performance measurement with further established dimensions of digitalisation.

2.1 Theoretical aspects of supply chain performance measurement

The concept of performance measurement. The foundation for performance measurement and management is considered to be based on theoretical frameworks in organisational and managerial control (Bititci et al., 2018). The concept of performance measurement itself tends to be defined differently. Bititci et al. (2018; p.3) define performance measurement as: "process measuring what matters, reporting these measures, reviewing performance and taking action, effectively describing a closed loop control system". Kamble & Gunasekaran (2019; p. 1) state that performance measurement is: "the process of quantifying the efficiency and effectiveness of action". Franceschini et al. (2019; p. 133-134) provide the following definition: "Performance measurement is the ongoing monitoring and reporting of program accomplishments, particularly progress towards pre-established goals. It is typically conducted by program or agency management. Performance indicators may address the type or level of program activities conducted (process), the direct products and services delivered by a program (outputs), and/or the results of those products and services (outcomes). A "program" may be any activity, project, function, or policy that has an identifiable purpose or set of objectives". In general performance measurement acts as a framework for evaluating a company's level of commitment and strategy (Rahim et al., 2018) and includes the four main components of any control system: measure, compare, analyse, and act (Bititci et al., 2018). Some of the desirable performance measurement features include alignment with organisational strategy (Kumar et al., 2022), approachability, comprehensiveness, balanced use of measures covering all of the organisation's aspects and a limited amount of measures collected and analysed (Fadel et al., 2021; Irawan & Zaki, 2022). The scope of performance measurement recently has not only expanded to include non-financial measures, but also expands further and now undertakes to measure performance not limiting itself to internal and external factors, but also considering supply chains as a whole (Shahbaz et al., 2018; Ka et al., 2019). Chalmeta & Santos-deLeón (2020; p. 3) define a supply chain as "a set of three or more entities (organisations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer.", and supports the expanded scope of performance measurement stating that the approach to performance measurement should address supply chain as a whole rather than its individual segments.

Function of performance measurement. It is stated that most business companies undertake performance measurement systems in one form or another (Gray et al., 2015) and the concept itself has become a common practice in all sectors (Bititci et al., 2018). Performance measurement provides information about the organisation's performance which consequently can be used to evaluate the latter, support forecasting and compare it with the organisation's strategic objectives thus tracking how well the organisation is performing in reference to its strategy (Asiaei & Bontis, 2019). Franceschini et al. (2019) consider that the outcome of performance measurement is performance measures, often depicted as numbers and units of measurement, which usually indicate such aspects as effectiveness, efficiency and degree of stakeholder satisfaction. As stated by Horngren et al. (2012), an organisation cannot simply decide on the set of performance measures it wants to employ. The specifics of how the measures are calculated must be decided upon by the organisation in several ways from determining the time over which the measurements are calculated to defining important concepts like "investment" and determining the specific components of each performance measure. By utilising an evidence-based approach, the concept of performance measurement is anticipated to increase the rationality of policy-making, enable successful multi-level governance, provide useful measures, strategic focus and incentives improving accountability (Giacomelli et al., 2019).

Performance measurement frameworks. Ka et al. (2019) state that performance measurement frameworks among the researchers tend to be referred to differently, usually as frameworks, systems, methods, models, approaches or techniques. Ka et al. (2019) assign performance measurement frameworks in the context of supply chains into the following three categories:

1. Process-based approaches;

   These performance measurement systems are developed considering the key operational processes in supply chains (Ka et al., 2019).

2. Perspective-based approaches;

   This kind of approach undertakes to assemble performance measures into perspectives which have their own view on supply chain problems, solutions and performance metrics (Ka et al., 2019). The following systems are best known to undertake this approach:

   2.1. Balanced scorecard;

   2.2. Supply Chain Operations Reference (SCOR). These systems will be overviewed further in the paper.

3. Hierarchical-based approaches;

   These approaches are undertaken by managers to make better decisions at each level of the supply chain including the strategic, tactical, and operational levels (Ka et al., 2019).

Additionally, Komatina et al. (2019) provide a list of notable performance measurement frameworks which include:

- Activity-based costing system (ABC) - this approach considers that there is a relationship between indirect costs and produced products and services. Thus, this system undertakes to allocate indirect and overhead costs to the related products and services. Therefore, the method intends to enhance the costing procedure expanding cost pools and rendering indirect costs traceable thus providing them with features of direct costs.

- Performance Measurement Matrix (PMM) - the basis of this model stands on a division of performance into four types: financial, non-financial, internal, and external. As it fits any performance measure, it is considered to provide comprehensiveness. However, it does not consider human resources or users and does not include any kind of performance measurement process.

- DOE/NV - established by the U.S. Department of Energy Nevada Operations Office, this model undertakes to measure the performance of an organisation at all levels by employing the following steps: process flow identification, identification of the critical activity being measured, determination of performance objectives, determining performance measures, identification of responsibilities, data collection, performance analysis, comparison of achieved performance with goals, defining corrective action, its realisation and re-evaluation of goals.

- Supply Chain Operations Reference (SCOR) - from a performance standpoint, the SCOR model divides supply chains into three levels and offers a general framework for supply chain systems that businesses may utilise in order to measure performance (Kottala & Herbert, 2019; Prasetyaningsih et al., 2020). There are thirteen metrics in SCOR that correspond to level 1, and they are divided into five categories where two of them- dependability and flexibility, are directly related to customers, and the rest- being responsiveness, cost and assets, are directly related to internal processes (Kottala & Herbert, 2019).

Additionally, Komatina et al. (2019) mention the balanced scorecard framework which is considered to be the most widely used for performance measurement of supply chains alongside the aforementioned SCOR model (Frederico et al., 2020; Ka et al., 2019). Furthermore, balanced scorecard is also considered to be the most suitable approach in measuring the performance of supply chains operating in the context of Industry 4.0 (Frederico et al., 2020), therefore it will be overviewed in greater detail compared to other frameworks.

Balanced Scorecard. The concept has been introduced by Robert S. Kaplan and David P. Norton in 1992 (Kumar et al., 2022). Organisations tend to apply this concept as a tool in performance measurement and strategy implementation processes (Aryani & Setiawan, 2020). The rationale for the development of this method was a consideration that organisations undertake their activities in highly complex environments where knowing their objectives and how to achieve them is essential to their survival (Frederico et al., 2020). It is stated that the basis of this framework is a consideration that the financial and non-financial measures used to measure performance have to be based on the organisational strategy (Kumar et al., 2022). Therefore, balanced scorecard undertakes to provide organisations with a set of performance measures which are derived from the organisation's goals and strategy. According to Frederico et al. (2020), balanced scorecard undertakes to measure performance through four main perspectives. Kaplan & Norton (1996) state that these perspectives undertake to provide a balance between: the organisation's short-term and long-term goals; subjective and objective measures; desired outcomes and their enablers. The following are four perspectives featured in balanced scorecard:

- Financial- considers all of the financial measures which show an organisation's financial performance (Kaplan & Norton, 1996) and evaluate its strategic profitability and shareholder value (Horngren et al., 2012). The measures provided by this perspective are considered to be the most substantial ones and tend to aid decision-makers in eliminating biased judgements related to an organisation's performance (Aryani & Setiawan, 2020). The measures undertake to establish financial performance targets in accordance with strategy and provide goals to non-financial perspectives (Fadel et al., 2021). According to Fadel et al. (2021), financial measures stand as a primary focus of techniques related to the balanced scorecard. The key areas this perspective undertakes to address are cost reduction, an increase of market growth, sales revenue and return on invested capital (Fadel et al., 2021);

- Customer- related to processes concerning the relationship with customers and their satisfaction, and establishes target customers, market segments and related measures (Horngren et al., 2012). From the point of view of a Porter's value chain, the Customer perspective include the following primary activities: outbound logistics, marketing & sales, and service. The key areas this perspective undertakes to address are customer cooperation, the performance of new products, and responsiveness of product or service delivery (Fadel et al., 2021);

- Business Processes- this perspective is concerned with the performance of internal processes which create value for customers and ultimately affect financial performance (Horngren et al., 2012). In Porter's value chain, the Business Processes perspective would consider the following primary activities: inbound logistics, operations and outbound logistics. Although inbound logistics and outbound logistics are considered to be both internal and external by nature, in this thesis they shall, nevertheless, be considered as internal processes. The key areas this perspective undertakes to address are efficiency, resilience and capabilities related to internal processes (Fadel et al., 2021). There are three main categories of internal processes: innovation processes- creation of products and services, operations processes- production and delivery of products and services, after sales-service processes- service and support after the products and services have been delivered (Horngren et al., 2012);

- Learning and Growth- directly related to the former perspective, Learning and Growth perspective undertakes to identify and improve internal capabilities in result increasing value created for various stakeholders (Horngren et al., 2012), and to measure how an organisation is capable to support improvements and changes with a focus on achieving the corporate goals (Kaplan & Norton, 1996). The key areas this perspective undertakes to address are the time taken to introduce new products to the market and the capability to develop new initiatives (Fadel et al., 2021).

Here the first one considers financial measures while the other three are non-financial (Fadel et al., 2021). The framework employs the aforementioned perspectives to compute a single score indicating the organisation's performance (Balaji et al., 2021) thus enabling organisations to identify the qualities of their strategies and accordingly improve their processes (Aryani & Setiawan, 2020). Horngren et al. (2012) provide an evident link between perspectives where the Financial Perspective is the core one depended on all the other perspectives out of which the Customer Perspective depends on the remaining two perspectives. Finally Business Processes Perspective directly depends on Learning and Growth Perspective. The balanced scorecard perspectives, alongside their dependency, are visually depicted in **Figure 1**.

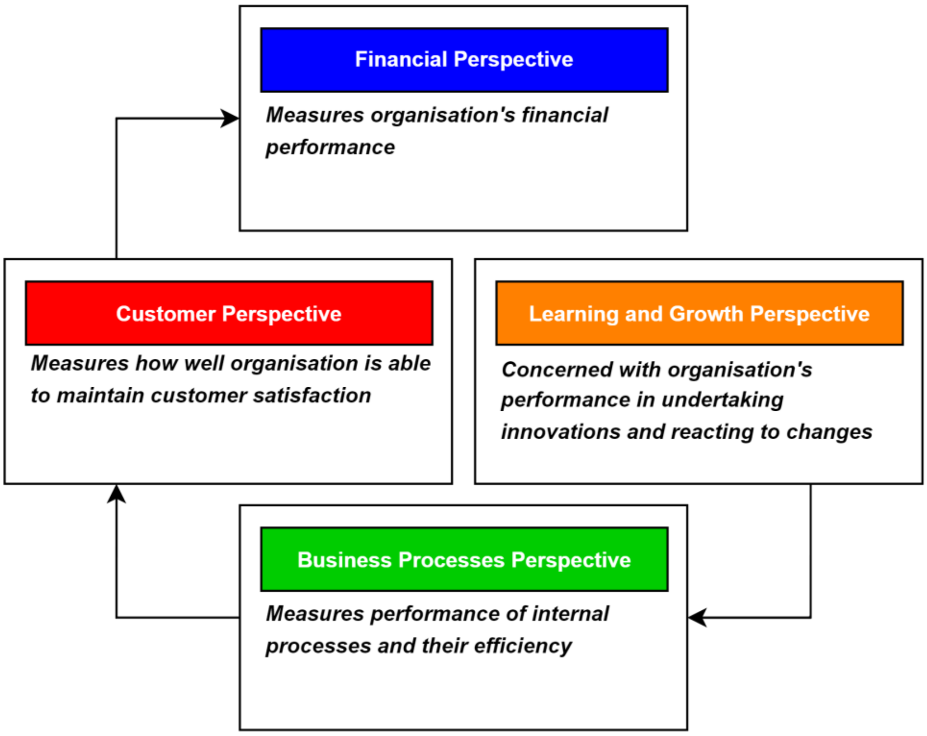

Fig. 1. Four balanced scorecard perspectives (Source: thesis author)

On the top of these perspectives, stands another very important concept related to balanced scorecard- a strategy map (Kumar et al., 2022). Horngren et al. (2012) define a strategy map as: "diagram that describes how an organisation creates value by connecting strategic objectives in explicit cause-and-effect relationships with each other in the financial, customer, internal business process, and learning and growth perspectives p. 471." and considers it to be the first step organisation has to undertake when designing balanced scorecard.

According to the study performed by Fadel et al. (2021), one of the important questions related to a balanced scorecard is whether its use and implementation render changes in the organisation's environment; and if so- whether the results are positive or negative. The results of the implementation of the balanced scorecard vary in practice from very positive, where balanced scorecard acts as a main enhancer of organisational performance, to no effect or small indirect effect (Fadel et al., 2021; Kumar et al., 2022). It is commonly considered that balanced scorecard provides numerous benefits, both direct and indirect, including provision of accurate and comprehensive information to managers, enhanced strategic planning and communication at all organisational levels, better understanding of the needs of stakeholders, increased focus on tasks undertaken to implement strategies, and enhancement of resource and time planning effectiveness (Fadel et al., 2021). On the other hand, balanced scorecard also attracts criticism and its successful implementation is deemed to be uncommon in practice (Kumar et al., 2022). It is stated that balanced scorecard tends to provide poor assumptions and lacks its intended features such as the ability to connect strategy with actual actions. Furthermore, it is claimed that the majority of the companies, which undertook to implement a balanced scorecard, have failed (Kumar et al., 2022). Fadel et al. (2021) also provide that it is difficult to assess whether or not balanced scorecard has rendered benefits. First of all, it is difficult to recognise the relationship between the balanced scorecard and organisational performance as there is an abundance of variables which affect the relationship. According to Fadel et al. (2021), the success of the implementation of the balanced scorecard depends on how the organisation itself approaches the framework and interprets it. The most significant mistakes affecting the results of balanced scorecard are considered to be a selection of irrelevant and excessive measures (Fadel et al., 2021). It is also suggested to rely on other performance measurement frameworks simultaneously while implementing balanced scorecard (Kumar et al., 2022).

Categorisation of performance measures. As mentioned before, performance measurement is usually divided into two categories: financial and non-financial (Rahim et al., 2018; Galankashi et al., 2021). These measures also tend to be referred to as quantitative and qualitative respectively (Rahim et al., 2018; Kumar et al., 2022), however, as non-financial measures tend to be both qualitative and quantitative in nature, for example the measure of a number of defects is both non-financial and quantitative, it is rather misleading to refer to financial and non-financial measures as quantitative and qualitative. Therefore, in this paper measures will be only categorised through financial and non-financial perspectives in order to avoid misinterpretation. The financial measures, also known as traditional, is a metric which considers quantitative financial values such as return on investment, residual income, revenues, net income, costs or profitability, and is termed to be objective, therefore can be undertaken autonomously and is related to the company’s account statements directly (Asiaei & Bontis, 2019; Rahim et al., 2018; Horngren et al., 2012). Non-financial measures, on the other hand, consider non-financial quantitative and qualitative values not directly related to company’s account statements and may include such measures as a number of defects or customer satisfaction, and tend to be subjective, therefore cannot be undertaken autonomously and are prone to subjective reasoning (Rahim et al., 2018; Horngren et al., 2012). Rahim et al. (2018) emphasise that financial measures are useful in evaluating present performance and communication of goals but lack the ability to forecast a company’s future performance while non-financial measures tend to be useful for both present and future evaluation of performance, but lack information power. Furthermore, in the context of the balanced scorecard, the financial measures are considered to define long-term objectives (Fadel et al., 2021). However, although non-financial measures tend to be more recent (Rahim et al., 2018), Kaplan & Norton (1996) argue that many non-financial measures, such as the level of customer satisfaction, share some of the same properties as financial measures including lack of strategic focus and a lagging factor which provides organisation’s past performance, but little guidance on future decisions. Nevertheless, it is also stated that financial and non-financial measures are not substitutes for each other and are encouraged to be used together as it is considered that they act in synergy (Rahim et al., 2018; Irawan & Zaki, 2022).

There is a wide variety of both financial and non-financial measures. As the balanced scorecard framework is considered to be the modern and best approach to measure performance in the context of Industry 4.0 supply chains (Frederico et al., 2020), the financial and non-financial measures shall be presented on the basis of this framework.

According to Horngren et al. (2012) companies most commonly use these four **financial measures** to evaluate economic performance: Return on investment, residual income, economic value added and return on sales. Return on investment answers the question of whether an organisation's investments into initiatives and processes will render additional economic value. It is used to either find out how efficient and profitable investments are or compare the investments to other ones (Phillips & Phillips, 2019). The formula is visually depicted in Appendix 1. Residual income is the normal earnings subtracted by accounting (Horngren et al., 2012; Thomas & Gup, 2010). In this case, normal earnings could be considered as income or profit (Horngren et al., 2012; Thomas & Gup, 2010), while the accounting earnings are considered to be equal to the required rate of return multiplied by the investment made (Horngren et al., 2012). According to Gray et al. (2015), by using the residual income model, analysts may concentrate on projecting future earnings patterns rather than trying to determine how the choice of accounting system impacts the elements of future profits and the present book value of equity. The formula is visually depicted in Appendix 2. Economic value added is considered to be one of the residual income measures and depicts the remaining residual income after the costs of capital are covered by the operating profits (Horngren et al., 2012; Gray et al., 2015). The measure consists of three elements: net operating profits after taxes, total capital and the cost of capital (Thomas & Gup, 2010). The formula is visually depicted in Appendix 3. Return on sales is a widely used financial performance measure, also sometimes referred to as income- to- revenues ratio and is considered to be one of the components of the return on investment measure (Horngren et al., 2012). Return on sales is equal to operating income divided by revenues (Horngren et al., 2012). The formula is visually depicted in Appendix 4. In general, return on sales depicts how well the costs are being managed (Horngren et al., 2012).

Although the aforementioned measures are considered to be the most widely used, there is an abundance of other financial measures which may include: cash flows, discounted cash flows, payback period, net present value, internal rate of return, profitability index, internal rate of return and accounting rate of return. Furthermore, the financial measures undertaken tend to vary depending on the case and environment of the analysed organisation (Horngren et al., 2012; Balaji et al., 2021). Cases analysed by Horngren et al. (2012) and Balaji et al. (2021) show a higher variety of financial measures used in practice. The former undertakes operating income from productivity gain, operating income from growth and revenue growth as financial measures, while the latter employs the following: profitability, sales growth by year, manufacturing cost, inventory cost and cash flow.

All the aforementioned measures are not alternatives to each other, therefore it is not possible, nor purposeful to distinguish the best measure out of them all, as these measures show different aspects of the performance and are intended to complement each other rather than show performance in general and substitute each other (Horngren et al., 2012). Also, all these financial measures in balanced scorecard can be assigned to the financial perspective of measurement.

Similarly, to financial measures, there is also a high abundance of **non-financial measures**. The measures are assigned to the following three balanced scorecard perspectives: customer; business processes (internal); learning and growth (Fadel et al., 2021). Just like financial measures, non-financial measures also tend to vary depending on the case and environment of the organisation (Horngren et al., 2012; Balaji et al., 2021). The cases analysed by Horngren et al. (2012) and Balaji et al. (2021) include the following non-financial measures assigned to each perspective:

1 Customer perspective measures: market share, number of new customers, customer satisfaction ratings, customer loyalty, product/ service quality, on-time delivery rate, timeliness.

2 Business Processes perspective measures: service response time, yield, order- delivery time, on-time delivery, number of major improvements, percentage of processes with advanced controls, quality, customer order cycle time, manufacturing cycle time, inventory replenishment cycle time, number of defects per order, waste reduction.

3 Learning and Growth perspective measures: human capital, employee satisfaction rating, percentage of low-level employees encouraged to take part in management processes, percentage of manufacturing processes which would provide real-time feedback, process innovation and information flow.

Furthermore, researchers also categorise measures into the impact and result measures. Impact measures are those whose addressed areas of performance directly influence the performance of other related areas. The latter areas are addressed by the result measures (Frederico et al., 2020). In the case of the balanced scorecard, the former measures may be applied for Learning and Growth and Business Processes perspectives while the latter can be used for Business Processes, Customer and Financial perspectives (Frederico et al., 2020). The measures assigned to each balanced scorecard perspective are visually depicted in Figure 2.

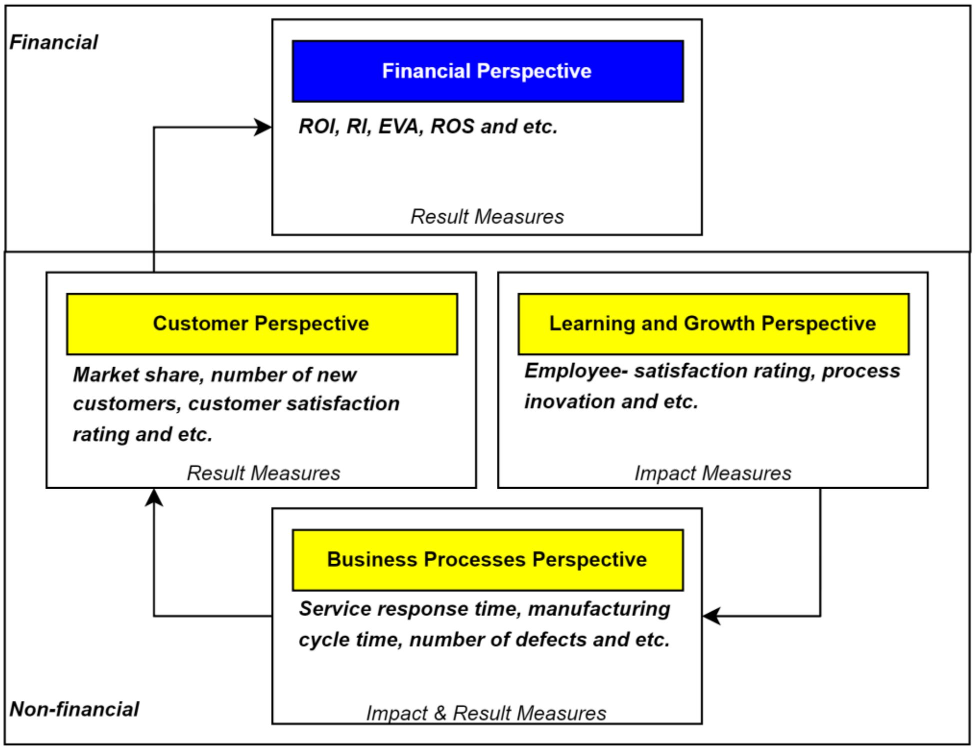

Fig. 2. Measures assigned to each balanced scorecard perspective (Source: thesis author)

To conclude the theoretical part of performance measurement of supply chains, it is evident that the frameworks related to performance measurement of organisations are becoming more extensive and complex. The frameworks of performance measurement now tend to measure performance not only on an individual, organisational, basis but also to the extent of the whole supply chain including various stakeholders from suppliers to customers. Furthermore, non-financial measures are becoming more used and tend to act in synergy with financial measures where measures belonging to each category complement each other. Currently, balanced scorecard is considered to be the most suitable framework to measure performance in the context of contemporary supply chains. However, although considered to be beneficial, it is also known to cause little or no benefit to organisations due to faulty implementation.

2.2 Theoretical aspects of digitalisation

Concept of digitalisation. Digitalisation tends to be defined differently. Fernández-Macías (2018; p. 18) defines digitalisation in his report as "use of sensors and rendering devices to translate parts of the physical production process into digital information (strings of bits), and vice versa". Szalavetz (2022; p. 333), on the other hand, provides that "digitalisation is defined as using digital technologies, such as artificial intelligence, big data technology, cloud technology, Internet of Things (IoT), and robotics to (i) execute, control, and/or improve every tangible and intangible activity that together comprise the value chain, (ii) create smart products and services, and (iii) transform the business model". Büchner et al. (2022; p. 11) states that digitalisation is: "a complex and heterogenous process leading to the increased relevance of digital technology and digital data in contemporary society". Zeranski & Sancak (2020; p. 5) define digitalisation as follows: "the use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business". Digitalisation is considered to be the main feature of Industry 4.0 (Liu et al., 2021; Frank et al., 2019) and Industry 5.0 (Carayannis & Morawska-Jancelewicz, 2022).

Industry 4.0 also tends to be approached and defined differently among researchers (Culot et al., 2020; Rupp et al., 2021). Rupp et al. (2021; p. 12) defines Industry 4.0 as follows: "Industry 4.0 is the implementation of Cyber Physical Systems for creating Smart Factories by using the Internet of Things, Big Data, Cloud Computing, Artificial Intelligence and Communication Technologies for Information and Communication in Real Time over the Value Chain". Ojra (2018; p. 2) provides such definition: "Industry 4.0 is an advanced digitalised manufacturing, where Internet of Things (IoT) is implemented within the manufacturing process". Zaidin et al. (2018; p. 2) defines Industry 4.0 as "a digital transformation of the industry by assimilating Internet of Things (IoT), information integration and other high-tech developments which begins with focusing on production/manufacturing sector and expands to many sectors beyond the industry". Mahmoodi et al. (2022; p. 2) considers Industry 4.0 to be "a technology-driven phenomenon, meaning the smart factories of Industry 4.0 rely on integrating disruptive technological innovations such as artificial intelligence within the existing production infrastructure, operations technologies, and processes".

Currently, Industry 5.0 tends to be defined in a similar manner as digitalisation and Industry 4.0. Saniuk et al. (2022; p. 3) define Industry 5.0 as "an industry that focuses on the return of humans to the production system. In this revolution, man and machine find ways to work together to improve the quality and efficiency of production. The interaction of human and artificial intelligence is paramount in Industry 5.0. The fifth industrial revolution is also more beneficial for the environment as companies develop systems that use renewable energy and eliminate waste". European Commission et al. (2021; p. 14) define Industry 5.0 as a concept recognising "the power of industry to achieve societal goals beyond jobs and growth to become a resilient provider of prosperity, by making production respect the boundaries of our planet and placing the wellbeing of the industry worker at the centre of the production process". Özdemir & Hekim (2018) consider Industry 5.0 to be an evolutionary and necessary addition to Industry 4.0 addressing the under considered asymmetries and limitations of the concept. Patil et al. (2022) also define Industry 5.0 as an addition to Industry 4.0.

It is evident that these three concepts, although defined differently, are very similar in essence. All of them share the same core basis which is considered to be significant changes to the businesses environment and supply chains rendered by the emerging disruptive technologies (Frederico et al., 2020; Zeranski & Sancak, 2020; Saniuk et al., 2022; Maddikunta et al., 2022; Alves et al., 2023). Furthermore, many researchers tend to consider these three concepts as one and the same concept (Queiroz et al., 2019; Haipeter, 2020; Meindl et al., 2021; Maddikunta et al., 2022). Therefore, in this paper, the theoretical aspects related to Industry 4.0 and 5.0 shall be assigned to the concept of digitalisation.

Functions of digitalisation. Functions of digitalisation are best described by the disruptive technologies related to the concept. The researchers tend to provide an abundance of technologies related to digitalisation, but only a few are considered to be fundamental ones. The technologies which stand as a basis for digitalisation are usually recognised differently. Frederico et al. (2020) and Pilloni (2018) consider Internet of Things and cyber-physical Systems as the main pillars of digitalisation while Queiroz et al. (2019) and Kunkel et al. (2022) emphasise that not only Internet of Things and cyber-physical systems are the basis of the concept, but also artificial intelligence and compose the important part of the fundamentals. On the other hand, Frank et al. (2019) consider Internet of Things, big data, analytics and cloud services as the base technologies in the context of digitalisation. Maddikunta et al. (2022) also give priority to these concepts when emphasising their impact in the context of digitalisation. Furthermore, Tay et al. (2018) distinguish even nine main elements of digitalisation. These include big data, simulation, Internet of Services, augmented reality, cyber-physical systems, additive manufacturing, Internet of Things, cloud computing and Autonomous Robots. Trentesaux & Caillaud (2020) also provides similar nine main elements of digitalisation. The mentioned Additive Manufacturing, by other researchers, is considered to be one of the digitalisation's dimensions rather than the basis (Frank et al., 2019). Although the views differ among the researchers, the following tend to be named the most as the basis of digitalisation: Internet of Things including the concept of cyber-physical systems, cloud computing, big data and its analytics and artificial intelligence.

These technologies include:

- Internet of Things and cyber-physical systems- according to Boyes et al. (2018), the concept of Internet of Things is defined as follows: "group of infrastructures, interconnecting connected objects and allowing their management, data mining and the access to data they generate" where connected objects are "sensor(s) and/or actuator(s) carrying out a specific function that is able to communicate with other equipment p. 3.". To put it another way, Internet of Things creates networks by connecting computing systems with physical entities such as assembly lines or with the help of the internet and sensors (Dai et al., 2019). According to Frank et al. (2019), recent advancements in internet technologies and reduced sensor costs have broadened the networking between physical and digital objects even more.

  The concept of cyber-physical systems tends to be defined similarly to Internet of Things. Akdogan & Vanli (2020; p. 2) define it as: "physical object or a process that is connected and interacting with a digital representation of that object or process". According to Tonelli et al

(2021), the concept is based on the management and collection of digital data which is employed in order to interact and manage physical objects interconnected into the system of networks. Τσαγδής (2022) states that cyber-physical systems are comprised of two components which are physical processes and cyber systems where the latter monitors and controls the former.

Although these two concepts are distinguished as separate, they do carry a lot of resemblance to each other and Greer et al. (2019) have recognised the theoretic overlap between the two. Greer et al. (2019) provide that currently there is no clear distinction between these concepts and that the views of researchers on this matter vary significantly: some state that Internet of Things and cyber-physical systems are two different concepts and only overlap partially, while others consider them as equivalent frameworks while several researchers state that Internet of Things is part of the cyber-physical systems' concept and vice versa. As a result, Greer et al. (2019) conclude that the convergence of these concepts may be beneficial, creating more opportunities for research in the field. Therefore, in this paper, Internet of Things and cyber-physical systems will be addressed jointly as CPS/IoT which is characterised as the concept of putting emphasis on the networks and interactions between physical and digital components (Greer et al., 2019; Sadeeq et al., 2021).

- Cloud Computing- the concept is characterised by the high capacity to store digital data and makes it possible for the objects and participants of the CPS/IoT networks to access the computing resources available in the shared pool in a convenient and on-demand way (Frank et al., 2019; Alam, 2020). According to Alam (2020), cloud computing aims to achieve economy of scale, optimisation of on-demand technology and information and hardware provisioning. The concept includes the following fundamental services: Software as a Service- considers software applications; Platform as a Service- considers tools intended to create and facilitate web applications; Infrastructure as a Service- concerned with the delivery of storage and computation; Expert as a Service- concerns with human resources (Alam, 2020). One of the significant features of Cloud Computing is considered to be pay-per-use nature where the organisations undertaking the concept of Cloud Computing are able to regulate the level of resource usage according to the need (Alam, 2020).

- Big data analytics- the latter concepts have conditioned the concurrent tendency of rapid increase of available digital data which has been recognised as an opportunity by many and thus there is a need to employ this kind of data (Iqbal et al., 2018). The attributes of contemporary digital data are considered to be very high volume, velocity, variety, veracity and variability (Chalmeta & Santos-deLeón, 2020; Gružauskas et al., 2023; Iqbal et al., 2018), all of which render difficulties to gather as much value as possible from digital data in the most efficient way (Chalmeta & Santos-deLeón, 2020). According to Chalmeta & Santos-deLeón (2020), although there is no universally accepted definition of the concept, the previously provided issue is the basis of big data Analytics which undertakes to provide solutions for it and is characterised by the ecosystem of complex and highly capable networks which undertake to collect, store, analyse and process various kinds of digital data from various sources.

- Artificial intelligence- according to Peres et al. (2020), the concept of artificial intelligence stands on the assumption that the process of learning and property of intelligence can be attributable to machines. The aforementioned is usually categorised into two categories: weak and strong artificial intelligence, where the former stands for machines which merely act as an investigative instrument while the latter considers machines which usually undertake automatic networking with other machines and are able to change their behaviour depending on their experience. The latter's properties of interconnectivity are also attributable to the concept of Internet of Things. Peres et al. (2020) also provide the following as economically significant disciplines related to artificial intelligence: robotisation, deep learning, the gig economy and dematerialisation. Considering the industrial applications of artificial intelligence, the concept of industrial artificial intelligence has been established. Peres et al. (2020) define industrial artificial intelligence as "a systematic discipline focusing on the development, validation, deployment and maintenance of AI solutions (in their varied forms) for industrial applications with sustainable performance p. 2.". According to Peres et al. (2020), industrial artificial intelligence consists of five dimensions: infrastructure- high emphasis on software and hardware capabilities, reliability and security; data- high attention to the digital data attributes and their sources; algorithms- physical and digital knowledge requirements due to the complexity of model management and governance; decision-making- strive to ensure efficiency and low-tolerance for errors; and objectives- major focus on value creation through such factors as quality improvement or scrap reduction.

Types of digitalisation. For the purpose of describing digitalisation and its use, several models have been put forth, many of which tend to undertake a maturity evolution point of view, thus describing how technologies should be implemented in the context of Industry 4.0 (Meindl et al., 2021). According to Meindl et al. (2021), the most commonly referenced model is the one proposed by Frank et al. (2019). The model has been established with the aim to understand what is necessary for organisations to utilise technologies related to Industry 4.0 efficiently. It focuses mainly on manufacturing companies and establishes layers of technology related to digitalisation, and displays adoption rates and their effects on organisations. It distinguishes two main layers of technologies related to digitalisation: front-end and base technologies. Here front-end technologies consider the changes in the way how raw materials are delivered, a transformation of manufacturing activities, the evolution of activities undertaken by employees and new ways of how the products are offered. In general, front-end technologies are concerned with the operational and market needs and are divided into four dimensions, also referred to as 4 Smarts (Meindl et al., 2021):

- Smart Manufacturing- also referred to as advanced manufacturing, considers the technologies addressing product processing and is characterised by adaptable, resilient, and flexible manufacturing systems which are capable of automatically change procedures in order to produce various kinds of products and services and adapt to varying environmental circumstances. It is considered to be the main dimension while the ones to be mentioned further act as interconnected ones. These technologies may address:
    - Factory's vertical integration- systems that integrate all levels of the organisation from the shop floor to the top management levels by undertaking sensors, actuators and Programmable Logic Controllers (PLC), Supervisory Control and Data Acquisition (SCADA), Manufacturing Execution System (MES), Enterprise Resource Planning (ERP)

and Machine-to-machine communication (M2M). As a result, factory’s vertical integration is intended to provide a higher level of control and transparency to the production process, also helping to improve decision-making at the shop floor level.

    - Automation- usage of artificial intelligence and robot in order to automate operational processes, data analysis, forecasting machinery failures, identification of product nonconformities and predicting production demands. These enable predictive maintenance, increased quality control, higher levels of productivity and reduced costs.
    - Internal traceability- undertakes to apply sensors in input and output materials in the organisation’s warehouses with an intention to increase flexibility to the manufacturing processes and support recall actions.
    - Flexibility- enable the production of different types of products in small quantities with the minimum loss of productivity and setup. This category also includes the concept of Additive Manufacturing.
    - Additive Manufacturing- addresses a higher level of product customisation enabled by 3D printing technology and applying the same raw materials to produce different products. However, this technology currently has some serious limitations: it requires additional post-processing processes, is possible only with a small amount of components, is not available for high-volume manufacturing and requires additional expertise (Agapovichev et al., 2018)
    - Energy management- comprises monitoring and improving the efficiency of the energy. The management is undertaken by monitoring the energy consumption data and scheduling the needed energy usage depending on electricity rates.

- Smart Products and Services- this dimension considers the technologies addressing product offering and emphasises that the products and services produced in the context of digitalisation are able to provide data feedback and new solutions to the customer. It is stated that this dimension establishes a connection between client-based information and data with the manufacturing system in order to increase external value-added. It is believed that technologies belonging to this dimension would enable new business models such as product-service systems and, therefore, create new opportunities for product manufacturers and service providers. These technologies may include the following:
    - Product connectivity enabling technologies- considers a network where related objects and systems are connected.
    - Product monitoring- considers technologies which would allow customers to gather information about the product condition and its parameters. Furthermore, this includes solutions for the provision of data related to product usage which can provide useful resources for a manufacturer in such processes as market segmentation and new product development.
    - Product control- considers the ability to control the product through remote digital interfaces.

    - Product optimisation- undertake to enhance products’ performance by using predictive algorithms which would provide the product with necessary corrections.
    - Product autonomy- emphasises the use of artificial intelligence with the intention to provide autonomy in relation to the final products.
- Smart Working- consider technologies which aim to enhance worker conditions in order to increase their productivity and flexibility with an intention to meet manufacturing requirements in a more proper manner. This is achieved by employing:
    - Remote monitoring and operation of production- considers the use of mobile devices which are intended to provide the ability to remotely control processes and enhance their visibility.
    - Virtual tools- intended to support the decision-making process by employing immersive simulation in order to accelerate workers’ training or using interactive real-time guidance to guide the workers for the steps needed to accomplish the tasks. The use of these technologies may also benefit the process of new product development by producing virtual product models which would substitute the physical prototypes, thus eliminating the need for the latter.
    - Collaborative robots- these robots are designed to support worker activities. The main purpose of this technology in Smart Working dimension would be to shift low-added value tasks from workers to collaborative robots and provide the former with more advanced tasks instead.
- Smart Supply Chains- undertakes to establish joint effort between a manufacturer and their supplier, or between a manufacturer and their client. This effort is expected to contain collaboration, shared capabilities, reduction of information distortion and synchronisation of resources and manufacturing processes. The aforementioned are expected to support the development of products and additional assets and services, thus creating more value. It is important to note, that this dimension only considers inbound and outbound logistics. Therefore, it does not address supply chain as a whole. Smart Supply Chain may include digital platforms which are intended to provide on-demand access to information shared between the organisation and its suppliers. These platforms may be used in order to remotely monitor traveling goods, maintaining optimal levels of warehoused raw materials, forecast and avoid possible delivery delays and in case of customer, these platforms may also help to attend to certain customer demands. The Smart Supply Chain, with a focus on external connectivity, undertaken through digital platforms, complements the Smart Manufacturing technologies which undertake to provide internal traceability.

Here Smart Manufacturing and Smart Working are considered to belong to internal dimensions while Smart Supply Chains and Smart Products and Services- to external dimensions.

Base technologies, on the other hand, provide intelligence and connectivity to front-end technologies, thus rendering them to be interconnected and enabling the concept of digitalisation. Frank et al. (2019) divide Base Technologies into four main elements: big data, analytics, Internet of Things and cloud services. As mentioned previously, the fundamental technologies in the context of digitalisation are recognised differently among researchers and in conclusion the four fundamental technologies which reflect the majority of views have been established. Therefore, in this case, the following disruptive technologies will be considered as Base Technologies: CPS/IoT, Cloud Computing, Big Data Analytics and Artificial Intelligence.

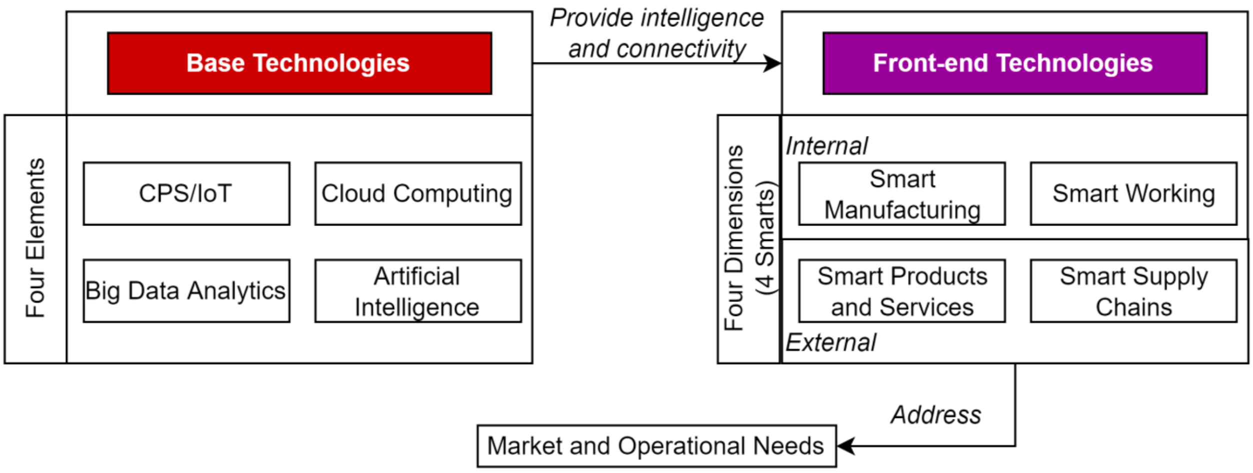

Fig. 3. The relationship between Base and Front-end technologies (Source: thesis author)

Frederico et al. (2020), on the other hand, provide a different set of dimensions directly attributable to digitalisation. These include:

- Capabilities- this dimension refers to the capabilities which are considered to be necessary for the concepts related to digitalisation to become fulfilled and fully adapted. These include such areas as human resources, organisational skills as well as regulatory compliance.

- Technologies- this dimension considers the aforementioned all of disruptive technologies attributable to digitalisation.

- Interoperability- considers the level of integration. The authors provide the following two types of integration:

  - Horizontal- considers interoperable products and services performing on the same level of the value chain (Bourreau & Krämer, 2022);

  - Vertical- considers interoperable products and services performing on the different levels of the value chain (Bourreau & Krämer, 2022).

  These two types of integration are considered to be a key factor in the implementation of digitalisation-related technologies and are expected to ensure the processes between technologies and information to be executed in proper manner thus enabling the expected level of automation and digitalisation in these processes.

- Supply Chain Processes- this dimension considers benefits related to digitalisation. These benefits may be related to efficiency, flexibility and transparency.

- Financial and Strategic results- consider profitability and cost reduction achieved as a result of digitalisation.

Benefits and opportunities of digitalisation. As mentioned before, researchers tend to state that digitalisation will create significant changes to the business environment and supply chains (Frederico et al., 2020; Queiroz et al. 2019; Kunkel et al., 2022; Sørensen, 2018; Xie et al., 2020; Mohamed, 2018). According to Mohamed (2018), there are numerous benefits which digitalisation is expected to render. Increased machine flexibility combined with dynamically programmable production technology is expected to benefit manufacturing processes by enabling higher quality and more options to make individualised products thus increasing diversity and value created, at the same time ensuring better resource allocation, flexibility including lower changeover times, and lower complexity (Mohamed, 2018; Frank et al., 2019). Additionally, digitalisation is also expected to synchronise manufacturing processes and provide a higher level of data feedback which would reduce delivery times and distortions of information thus lowering the possibility of bullwhip effects and provide more data useful for research and development processes (Frank et al., 2019). Further digitalisation is believed to bring a higher level of customisation for products and services, and higher resilience, flexibility and sustainability to the processes enabling and supporting the former (Maddikunta et al., 2022; Olsen & Tomlin, 2020; European Commission et al., 2021; Patil et al., 2022; Haleem & Javaid, 2019). In general, digitalisation is expected to increase productivity, felixibility and revenues (Mohamed, 2018) while maintaining or increasing levels of environmental sustainability (Maddikunta et al., 2022; European Commission et al., 2021; Patil et al., 2022) and customisation (Maddikunta et al., 2022; Haleem & Javaid, 2019). Overall digitalisation is expected to increase the value created (Frank et al., 2019).

Barriers of digitalisation. Although digitalisation is expected to render significant benefits, its drawbacks and limitations are also noticeable. Mohamed (2018) states that currently the majority of companies hesitate and are unwilling to embrace digitalisation as there are notable implementation barriers faced by the companies. Vaidya et al. (2018) provide the following as the main challenges and fundamental issues in the implementation of digitalisation in manufacturing companies: intelligent decision-making systems lack autonomy, absence of high-speed IWN protocols, inability to ensure high quality and integrity of the recorded data, scarcity of research related to self-organised manufacturing systems, higher level of connectivity rendering higher vulnerability of systems and high financial costs of implementation.

Additionally, cyber security is considered to be one of the major challenges related to digitalisation (Vaidya et al., 2018; Dai et al., 2019). Regarding CPS/IoT heterogeneity of data, diversity of devices and systems, and complexity of the network are all considered to be attributes of CPS/IoT as well as properties causing serious issues and vulnerabilities to cyber security (Dai et al., 2019). Augusto-Gonzalez et al. (2019) provide that the following tendencies related to CPS/IoT act as enablers to cyber security issues: internet exposition, interface/password breaches, lack of updates, low segregation, unencrypted passwords, leak of sensitisation, weak CPS/IoT protocols and applications. Furthermore, it is noted that the malicious attacks related to CPS/IoT have recently become more intense, severe and sophisticated with the tendency to advance more rapidly than security measures do (Augusto-Gonzalez et al., 2019). Cloud Computing is also challenged by the issues related to cyber security (Sadeeq et al., 2021; Basu et al., 2018; Alam, 2020). Alam (2020) considers that cyber security is the main challenge for the successful implementation of the concept and states that if this issue is to be ultimately solved, the use and popularity of cloud computing would grow significantly. Basu et al. (2018) provide the following cloud computing-related areas which are considered to be prone to security issues: data confidentiality and virtualisation, data and visualisation integrity, data availability, and virtual machine availability. Although there are numerous methods provided which deal with the security issues, Basu et al. (2018) emphasise that there are underexplored areas related to cloud security including cloud data location; mutual trust between CPS/IoT and the client; data or service compliance. According to Lee et al. (2021), industrial companies in Europe consider cyber security to be the main barrier to the successful implementation of the concepts related to digitalisation.

From a social point of view, recently ethics has been recognised as a serious barrier to digitalisation (Vallor & Rewak, 2018; Bartlett et al., 2019) and there is a tendency of digitalisation which challenges the ethics principles established by Global Business Standards Codex. One of the Global Business Standards Codex ethical principles currently contested is responsiveness. Vallor & Rewak (2018) provide that complexity of big data practices and the proprietary nature of technology and software are considered to be the main reasons for the aforementioned issue. The technologies related to big data practices, especially deep learning algorithms, tend to be complex and proprietary in nature, therefore creating both systematic and regulatory barriers for those trying to reconstruct how and why these algorithms have made certain decisions (Vallor & Rewak, 2018; Knight, 2020). The latter becomes a significant challenge for the companies to provide necessary information for stakeholders upon their request for information about the processes related to them thus rendering companies unable to comply with the ethical principle of responsiveness. Another Global Business Standards Codex ethical principle contested by digitalisation is the property principle. There is a tendency that politicians and regulators are failing to keep up with the current rapid technological advancements that are changing how companies operate while companies undertaking big data practices tend to collect high quantities of personal and confidential data about their stakeholders (Vallor & Rewak, 2018). There is currently a lack of an appropriate legal framework that would regulate this type of data collection, despite the fact that businesses can use such technology to gather, access, and even disclose various kinds of sensitive and private data that the client would never voluntarily disclose to the company in question (Mania, 2022). Therefore, if one considers such type of data as the intangible property of the client, it is safe to consider that in the context of digitalisation, companies risk violating the principle of property established by the Global Business Standards Codex. Furthermore, digitalisation-related practices tend to be prone to arbitrariness, errors, inaccuracies and hidden biases (Vallor & Rewak, 2018) all of which may negatively affect the principle of fairness. For example, it is evident that the judgements of artificial intelligence tend to be biased and depend on the racial or cultural background of the individual (Best et al., 2021). A study performed by researchers from UC Berkeley has provided that such algorithms used by mortgage lenders tend to treat African Americans and Latin Americans less favourably and charge them higher interest rates in comparison with people belonging to other social groups (Bartlett et al., 2019). Vallor & Rewak (2018) suggest that such bias is implicit as in the algorithms it is not intentionally created by the developers, but rather gained by the artificial intelligence in the process of learning from the datasets which may also have included biased data. The aforementioned example depicts the threat to the principle of fairness induced by digitalisation.

Organisation size also tends to be a barrier related to digitalisation. According to Masood & Sonntag (2020), there is a lack of frameworks which would focus on the adoption of digitalisation considering the environment and needs of small and medium-sized enterprises which tend to focus on the costs and short-time benefits while currently existing concepts related to digitalisation are more aligned to the nature of multinational companies focusing on long-term strategies and goals (Masood & Sonntag, 2020). Masood & Sonntag's (2020) findings suggest that financial boundaries stand as the greatest barrier for small and medium-sized enterprises wishing to embrace digitalisation. Considering that multinational companies are more likely to adopt digitalisation, there is a threat for small and medium-sized enterprises to lose their competitive advantage to the former. The relevance of the provided issue is based on a perception that small and medium-sized enterprises are the backbone of the economy creating more than half of the total added value and employing more than two-thirds of the total workforce in European Union member states (European Court of Auditors, 2020).

From the theoretical point of view, it is emphasised that there is a lack of agreed-upon definitions (Culot et al., 2020; Rupp et al., 2021). Furthermore, it is evident that currently there is no well-established theoretical framework in regard to digitalisation as researchers tend to establish theoretical aspects of digitalisation differently (Greer et al., 2019; Chalmeta & Santos-deLeón, 2020). These render serious limitations for research comparability and theory building (Culot et al., 2020; Greer et al., 2019).

To conclude the theoretical part of digitalisation, it is evident that the concept is highly relevant and expected to render both opportunities and benefits for organisations. These benefits include higher efficiency, resilience, environmental sustainability and customisation of the processes enabling products and services. However, although expectations are high, there is also an abundance of barriers preventing the successful implementation of digitalisation. The most notable barriers are related to ethics, cyber security, costs of implementation and theoretical inconsistencies. As mentioned before, it is still unclear how and to what extent digitalisation will change the business environment and supply chains.

2.3. The conceptual model of the performance measurement of supply chains in the context of digitalisation.

Due to the business environment's fast digitisation, conventional supply chain models are expected to be transformed into intelligent supply chains (Xie et al., 2020). Eliminating asymmetric information in the supply chain is the goal of an intelligent supply chain (Xie et al., 2020). In relation to digitalisation, expected considerable supply chain developments have created difficulties and concerns with regard to performance measurement (Frederico et al., 2020). The assumption that performance measurement will have to adjust to the changes brought by digitalisation to supply chains due to its dependency on the organisational environment (Frederico et al., 2020) is supported by Klovienė and Uosytė (2019) who state that digitalisation has indeed created the need for performance measurement systems to adjust.

As it has been established in the previous chapters, although many theoretical aspects of supply chain performance measurement are well established, currently there is a knowledge gap related to the performance measurement of supply chains in the context of digitalisation (Frederico et al., 2020; Xie et al., 2020).

Nevertheless, some researchers have established some basis for the former. Frederico et al. (2020) have stated that balanced scorecard is the contemporary approach which is best suited to undertake supply chain performance measurement in the context of digitalisation as strategic orientations and broader perspectives are both considered. Considering the latter, Frederico et al. (2020) have proposed the concept of Supply Chain 4.0 Scorecard. The concept undertakes to align established dimensions of Industry 4.0 supply chains operating and the perspectives provided by the concept of a balanced scorecard. The alignment is done by assigning the pre-established Supply Chain dimensions to the balanced scorecard perspectives:

- The dimension of Supply Chain Processes is assigned to the Business Processes perspective thus including such measures as responsivity, flexibility efficiency and measurement of waste reduction. Some of the proposed impact and result measures for this dimension include process efficiency, response time, level of flexibility, level and extension of transparency, level of collaboration, level of waste reduction, and level and extension of process integration.

- The dimensions of Technologies, Interoperability and Capabilities are assigned to the Learning and Growth perspective thus including such measures as focus company and customers and measurement of responsivity in product development involving suppliers. Some of the proposed impact measures for this dimension include adequacy and extension of technologies, level of infrastructure for new technologies, level of horizontal as well as vertical integration, human capital and level of compliance with regulatory requirements.

- The dimension of Financial and Strategic results is assigned to the Customer and Financial perspectives thus including such measures as revenue growth, return on assets and profit margin of supply chain partners. Some of the proposed result measures for this dimension include shareholder value; level of cost reduction; profitability; EVA; EBITDA; level of market share; value-added perception; level of customer interaction on processes; level of customer satisfaction.

The Supply Chain 4.0 Scorecard is a general framework, thus it is intended to serve as a basis and guidance rather than a straightforward framework for the development of specific performance indicators depending on the specific environment of the selected supply chain.

Xie et al. (2020) establish the framework of performance measurement indicators with a focus on digitalisation. The framework classifies the measures into the following seven first-layer indicators:

- Visibility- shows how effective the monitoring of supply chain operations is;

- Leagility- the indicator refers to the concepts of Lean and Agile. The indicator composes of the measures which undertake to evaluate the level of:

  - organisation’s ability of agile response to research and development, production and delivery;

  - organisation’s ability of achieving the overall cost optimisation;

  - organisation’s capabilities to be adaptable and flexible;

- Personalisation- the measures assigned to this indicator undertake to asses the level of the compliance with the customer needs;
- Information governance- includes the measures which evaluate the information's security, availability and sensitivity. The latter considers favourable time and level of convenience of information transfer during the supply chain management process.
- Supply chain warning- it refers to the early warnings which are situated in every link of the supply chain and are considered to be essential. Thus this indicator includes the measures which are related to the management decisions oriented into risk minimising, cost control in the each link of the supply chain with a predefined target, and the management activities addressing quality control.
- Green- quantification of environmental impact which is done with the purpose of measuring organisation's resource utilisation/ recyclability and environmental pollution. The former measures the extent to which a resource is being used to produce a product or service and the proportion of machines, raw materials, and tools being reused in the whole supply chain. The latter, on the other hand, undertake particulate measures such as CO_2 or SO_2 emissions.
- Innovation and learning- this category is considered to measure factors which drive the development of the concepts related to the aforementioned indicators. The measures in this category undertake to evaluate the organisation's ability to develop and explore new processes, products and services as well as adapting to the changes. Furthermore, the included measures consider adoption rate of the new technologies and development intensity of new services. The latter referring to the extent to which member enterprises in the supply chain effectively integrate information resources and customer participation to improve service quality for customer needs.

The aforementioned models, although bring some level of alignment for performance measurement in the context of digitalisation, nevertheless, these models have limitations. The framework provided by Frederico et al. (2020), according to the authors, lacks validation, is limited in terms of effectiveness and its focus on performance measurement systems is rather narrow. Xie et al. (2020) in their framework only focus on first-layer measures and do not include second-layer or third-layer measures. Furthermore, the aforementioned frameworks also focus on the previously established digitalisation barriers insufficiently. Only one of the selected frameworks undertakes to address cyber security and business ethics, the latter being addressed indirectly through compliance with customer needs and data security.

The further proposed framework is intended to measure organisation performance both within organisational boundaries and beyond them thus covering the supply chain as a whole. Considering the provided theoretical aspects of performance measurement of supply chains and digitalisation, and also taking in mind the previously provided frameworks intended for measurement of supply chains' performance, the proposal of the conceptual model is provided. The model is intended to provide further alignment for performance measurement of supply chains in the context of digitalisation. The model is based on balanced scorecard and the framework provided by Frank et al. (2019) which provides four digitalisation dimensions: Smart Manufacturing, Smart Products & Services, Smart Working and Smart Supply Chain. Front-end Technologies established by Frank et al. (2019) are categorised into Internal and External categories depending on their parameters, and further assigned to each balanced scorecard perspective:

- Smart Manufacturing is considered to be internal as it directly deals with manufacturing systems and provides them with advancement solutions. Also, it is considered to be a main pillar of internal processes. Therefore, further it is assigned to the Business Processes perspective of a balanced scorecard as the latter primarily deals with the internal processes.

- Smart Working is also considered to be internal as it deals with the support of the working activity. Therefore, further it is also assigned to the Business Processes perspective of balanced scorecard. Nevertheless, Smart Working also supports the process of employee training and new product development, thus it also shall be assigned to the Learning and Growth perspective.

- Smart Supply Chain is considered to be external as its area of focus expands beyond the frames of the organisation and focuses on the joint effort between the organisation and suppliers as well as the outbound logistics. Further the technology is assigned to Learning and Growth perspective as the former puts emphasise on the cooperation in development of products and services. As it addresses inbound and outbound logistics, it shall also be assigned to Business Processes and Customer perspectives.

- Smart Products and Services is also considered to be external as it focuses on external value-added of the products and services emphasising customer data integration within the production system. The dimension is assigned to the Customer perspective as it directly deals with customer-related information and data. Furthermore, it is also assigned to the Learning and Growth perspective as the customer-related data can be undertaken in the new product development or advancement processes.

Regarding the Financial perspective, all of the dimensions also include financial measures. The financial measures related to Smart Manufacturing, Smart Working and Smart Supply Chain tend to be derived from costs, while Smart Products and Services related financial measures consider income. The established alignment is provided in **Figure 4**.

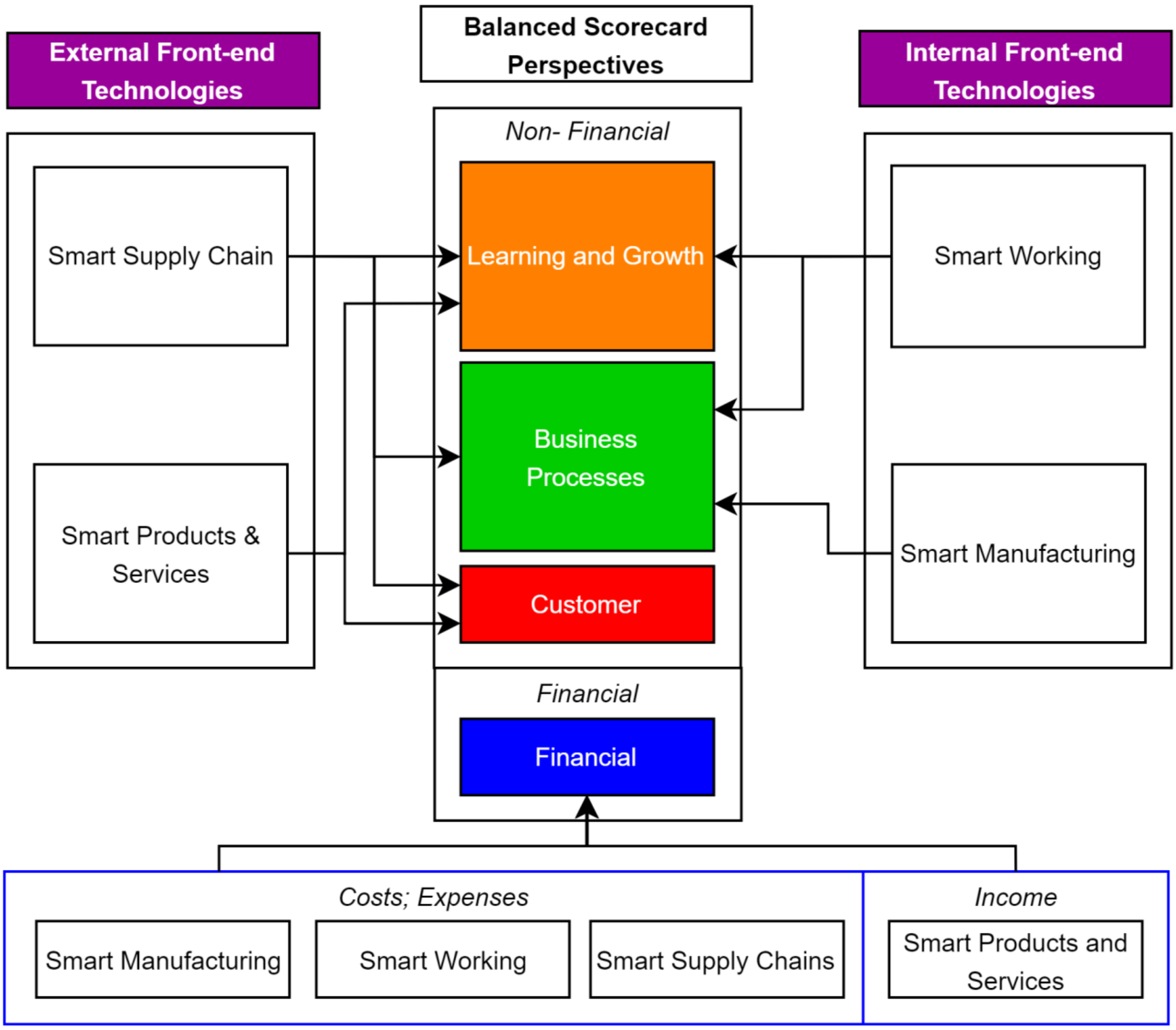

Fig. 4. Balance scorecard perspectives aligned with the dimensions of digitalisation (Source: thesis author)

Further, a more detailed categorisation is undertaken where each technology provided by Frank et al. (2019) inherent to the dimensions is individually assigned to the balanced scorecard perspectives. The "Product Connectivity" is excluded as it is already characterised by other selected technologies such as "Product Monitoring", "Product Control", "Product Optimisation" and "Product Autonomy".

- Smart Manufacturing technologies- **factory's vertical integration** category of technologies is assigned to Business Processes perspective. This perspective is considered as vertical integration supports manufacturing and outbound logistics processes. **Automation** category provides support for manufacturing, equipment maintenance and quality control processes, therefore it is assigned to Business Processes perspective. **Internal traceability** considers use of sensor for tracing raw materials and finished products internally, thus it is also assigned to Business Processes perspective. **Flexibility** addresses adjustments related to the manufacturing process. therefore it is assigned to Business Process. **Additive Manufacturing** directly address manufacturing process, thus is assigned to Business Processes perspective. **Energy management** also directly addresses the internal processes, therefore it also shall be assigned to Business Processes perspective.

- Smart Products and Services technologies- **product monitoring** provides customers with the capability to monitor their products' condition and parameters. Additionally, monitoring may provide manufacturers with the useful data which can be used for market segmentation or product development. Therefore, in case of customer undertaking the monitoring, the technology may be applied to Customer perspective while in case of manufacturer monitoring the product already owned by the customer- the technology may be assigned to Learning and Growth perspective. **Product control** element provides customer with direct value which is based on the ability to remotely control the product. Thus, it shall be assigned to Customer perspective. **Product optimisation** undertakes the usage of predictive diagnoses providing necessary enhancements may also be assigned to Customer perspective. **Product autonomy** also provides direct value to the customer; thus it shall also be assigned to the Customer perspective.

- Smart Working technologies- **remote monitoring and operation of production** intends to provide improvement to decision making process and enhance the information visibility. Such provision would address directly the productivity of the worker; thus, it shall be assigned to the Business Processes perspective. **Virtual tools**, as well as remote monitoring and operation of production, also help workers with tasks thus increasing their productivity. In this case, the technology shall be assigned to the Business Processes perspective. However, virtual tools also provide efficiency to workers training and support new product creation. Therefore, in the latter case, visual tools would be assigned to Learning and Growth perspective. **Collaborative robots** are considered to provide workers with direct help in working activities, therefore, the technology shall be assigned to Business Processes perspective.

- Smart Supply Chains technologies- **digital platforms for suppliers** provide databases mutually shared between the organisation and its suppliers. As a result, it enhances the processes related with inbound logistics and provide basis for the mutual efforts in product development. In the former case, the technology shall be assigned to Business Processes perspective, while in the latter case- to Learning and Growth perspective. **Digital platforms for customers** perform in the similar manner as the aforementioned ones. However, these technologies address outbound logistics and attention to specific customer demands instead. Here the former shall be assigned to Business Processes perspective, while the latter one- to Customer perspective.

The aforementioned alignment is depicted in **Table 1**.

Table 1. The digitalisation dimensions assigned to each balanced scorecard perspective (Source: thesis author)

Digitalisation dimensions \ Balanced scorecard perspectives		**Learning & Growth**	**Business Processes**	**Customer**	**Financial**
Smart Manufacturing	Factory's vertical integration		x		x
	Automation		x		x
	Internal traceability		x		x
	Flexibility		x		x
	Additive Manufacturing		x		x
	Energy management		x		x
Smart Products & Services	Product Monitoring	x		x	x
	Product Control			x	x
	Product Optimisation			x	x
	Product Autonomy			x	x
Smart Working	Remote monitoring and operation of production		x		x
	Virtual tools	x	x		x
	Collaborative robots		x		x
Smart Supply Chain	Digital platforms for suppliers	x	x		x
	Digital platforms for customers		x	x	x

So far, the conceptual model provides a deeper level of alignment between digitalisation and the performance measurement framework of the balanced scorecard. Further, it is possible to derive performance measures for each technology. These measures would show how well these technologies are implemented considering the expectations. The way measures are created depends on the organisational environment, how these technologies and to what extent are used in the organisation. When creating each measure, it is important to consider the barriers to digitalisation. Cybersecurity and Business Ethics are chosen to be considered when providing measures in this study. Cybersecurity is considered because it is recognised to be the major barrier to digitalisation (Vaidya et al., 2018; Dai et al., 2019). Business ethics also cannot be overlooked. First of all, because it deals with positive and negative moral and ethical consequences, and, furthermore, is considered to have a significant influence on the profitability and success of an organisation by affecting its competitivity, brand loyalty, trust, trustworthiness and dignity (Belas et al., 2020). Secondly, it is considered to be greatly affected by digitalisation (Vallor & Rewak, 2018; Bartlett et al., 2019).

3 Methodology of practical implementation of proposed model of performance measurement system in context of digitalisation

In this chapter, it is undertaken to establish a research methodology which will support the further parts of the thesis.

Research methods and measurements. In this thesis qualitative approach is preferred as the aim of the research undertakes to answer the question which mandates emphasis to be put on verbal (subjective) rather than numerical (objective) reasoning. Furthermore, a qualitative approach is also suitable, because in order to achieve the aim, it is important to approach the question in an exploratory manner which is inherent to the selected approach. Considering the established research objectives, a case study shall be undertaken as it seems to be the most suitable for this thesis due to the need of dealing with real-life events over which the author of the thesis has little control. The preferred method for the case study is a qualitative semi-structured interview.

Sampling procedure. As the case study approach is undertaken, the optimal sample size of 4-5 organisations is selected. The sample organisations shall be selected by undertaking the criteria that the organisation has to: comply with the category of small and medium-sized enterprises, perform in the manufacturing industry, undertake performance measurement practices and have to some level embraced digitalisation.

Procedure and ethics of empirical research. The data shall be collected by undertaking a qualitative approach. Qualitative semi-structured interviews are considered as they would provide more detailed and more relevant research information which may not be available to the general public. Furthermore, semi-structured interviews may also provide more focused, comprehensive and deeper information in relation to the research question. However, qualitative semi-structured interviews may provide biased information and are more expensive to conduct compared to qualitative document analysis. Nevertheless, qualitative document analysis and semi-structured interviews together would be expected to provide more valid and comprehensive information.

The gathered information shall be used with the intention to test the proposed conceptual model in the context of the selected sample organisations. The results should demonstrate how well and to what level the alignment between digitalisation and performance measurement is achieved through the conceptual model. The research shall be conducted considering the ethical principles. Respondents shall be informed about the interview and such related details as the aims of the research, objectives, methods, uses, who will be undertaking it, who is being asked to participate, what kind of information is being collected, how much of respondent's time is needed, that the participation in the research and responding to all questions is voluntary, who will have access to the respondent's provided data, how respondent's anonymity will be preserved and that respondent may withdraw from the interview at any time. Respondents shall be informed about the aforementioned in oral and written forms before the interview is conducted. This will contribute to avoiding deception and any harm to participants. Before the interview, the respondents have to provide their consent with the provided information otherwise interview shall not be conducted. This would fulfil the ethical principle of "Ensure informed consent of participants" and contribute towards respecting the privacy of respondents. The privacy of respondents shall be further ensured by undertaking that the information provided during the interview shall be considered as respondents' intellectual property and shall be used for this thesis only. Furthermore, it shall be ensured that respondents must be able to withdraw from the research at any time and that data gathered during the interviews must be held securely. The information gathered shall also be provided to each corresponding respondent after each interview. In order to produce positive benefits for respondents, if respondents do not object, it shall be undertaken to provide feedback to respondents about the research results.

Research instrument. The research instrument is established with the intention to gather data about how companies undertake the implementation of the concepts related to the proposed dimensions of digitalisation. Furthermore, it is also intended to find out how well these concepts have been implemented, how they perform compared to the expectation and how their performance is measured. All the gathered data is expected to provide support for the empirical test of the provided conceptual model. Both undertaken research methods are comprised of two topics: performance measurement which focuses on four balanced scorecard perspectives, and digitalisation including its dimensions. It is undertaken to find out which technologies related to each digitalisation dimension are implemented within the organisation, and how they perform compared to the company's expectations. It is also undertaken to gather information on how performance measurement of these technologies is approached by the company.

The research instrument for qualitative interview is provided in **Table 2**.

Table 2. Research instrument for qualitative interview (Source: thesis author)

Topic	Questions	References
Digitalisation	***Main question:*** What of the digitalisation-related technologies are being used in your company (for example, artificial intelligence, machine to machine communication, etc)? ***Additional question:*** What was the rationale for implementing these technologies?	Frank et al., 2019; Frederico et al., 2020; Meindl et al., 2021
Performance Measurement	***Main question:*** What performance measurement practices are undertaken (for example, balanced scorecard, activity-based costing system, etc)?	Kaplan & Norton, 1996; Horngren et al., 2012; Rahim et al., 2018; Komatina et al., 2019; Frederico et al., 2020; Fadel et al., 2021; Galankashi et al., 2021
Conceptual Model	***Main question:*** How do they perform compared to the expectations?	Kaplan & Norton, 1996; Horngren et al., 2012; Rahim et al., 2018; Frank et al., 2019; Komatina et al., 2019; Frederico et al., 2020; Fadel et al., 2021; Galankashi et al., 2021; Meindl et al., 2021
Responde nt related	***Main questions:*** What is your position in the company? What is your experience in the company?	

The research instrument provides a basis for the research and establishes an approach which shall be undertaken in order to collect relevant data during semi-structured interviews which may allow to reach the aim of this thesis. As the semi-structured interview approach is undertaken, additional questions may be provided to the respondents.

4 Results of research of the proposed model for the performance measurement of supply chains in the context of digitalisation

This chapter is intended to present the results of the empirical research of the proposed model for the performance measurement of supply chains in the context of digitalisation. The results were gathered from the selected sample companies by undertaking qualitative semi-structured interviews. Each sample company shall be presented as well as digitalisation-related technologies they employ alongside their performance. The latter shall be presented in accordance with the conceptual model. Further, the results of the research shall be discussed, and recommendations provided.

4.1 Description of the sample companies

Research participants, further referred to as sample companies, have been selected according to the criteria established in the research methodology. 4 sample companies have been selected for the research. In order to ensure anonymity, the names of companies and their respondents will not be mentioned as well as the exact values related to the companies. Each sample company is a manufacturer and undertakes digitalisation-related technologies to a certain extent. Furthermore, considering the companies' annual revenues, the number of employees and the total value of assets, it is clear that each sample company may be categorised as a small and medium-sized enterprise. The respondents who were questioned during semi-structured interviews have different experiences in the companies.

Sample company A. The sample company is a manufacturing company which undertakes the production of polyester straps intended for packaging the construction materials such as bricks, block interlocks, oil pipes, etc. It is a subsidiary of a public company. The company undertakes mass manufacturing and follows a differentiation strategy, thus seeking to provide high-quality products. Previously the company had produced steel straps, however, as they were both costly to produce and non-recyclable, the company had decided to purchase new manufacturing equipment and shift towards the production of polyester straps which are a substitute for steel straps. The newly installed equipment can be considered to be digitalisation related. The company employs over 30 employees, and its average annual revenue is approximately 6 000 000 euros. The sample company can be classified as a small and medium enterprise. A respondent representing this sample company is an accountant working there for 7 years.

Sample company B. The sample is a privately held manufacturing company which produces heat transfers, waterslide decals and stickers. The company undertakes a custom manufacturing and differentiation strategy, thus providing a high emphasis on quality control and customer relations. The company is more than 20 years old and employs about 50 employees and its annual revenue is approximately 2 000 000 euros. The sample company can be classified as a small and medium enterprise. A respondent representing this sample company is a head of administration with work experience in the company of 5 years.

Sample company C. The sample is a privately held chemical manufacturing company. The company is engaged in the research and development, as well as production of chemical products which are used in a high variety of fields and are intended for both professional users and the general public. The company undertakes mass manufacturing and follows the strategy of differentiation and puts high emphasis on the quality of raw materials, prompt delivery and customer support. Currently, the company employs 19 employees most of whom undertake administrative tasks and its annual revenue is approximately 2 500 000 euros. The sample company can be classified as a small and medium enterprise. The respondent representing the company is the CEO and a founder of the company working there for 30 years since the company's establishment.

Sample company D. The sample is a privately held Lithuanian company which undertakes custom manufacturing of wooden constructions which include houses, sheds, and various purpose cabins. The finished goods are usually exported to the United Kingdom and Ireland. The company undertakes a differentiation strategy as the company puts high emphasis on the quality of raw materials, human capital and quality control systems. The company employs 79 employees, and its annual revenue is approximately 7 500 000 euros. The respondent representing the company is the CEO and a founder of the company who has been working there for nearly 24 years.

The general information about the sample companies is provided in **Table 3**.

Table 3. General information about the sample companies (Source: thesis author)

	Sample A	**Sample B**	**Sample C**	**Sample D**
Approximate annual revenue (€000)	6 000	2 000	2 500	7 500
Number of employees	30	50	19	79
Strategy	Differentiation	Differentiation	Differentiation	Differentiation
Respondent's position	Accountant	Head of Administration	CEO	CEO
Respondent's experience in the company	7 years	5 years	30 years	24 years

Further, the research results of the aforementioned companies shall be presented.

4.2 Research of the sample companies according to the conceptual model

In this subchapter, the results of the research of the sample companies shall be presented. The research was undertaken by using the previously established conceptual model which aligns the balanced scorecard's performance measurement perspectives with dimensions of digitalisation.

4.2.1 Smart manufacturing

Factory's vertical integration. The concept aims to give the production processes a higher level of control and transparency by undertaking such technologies as sensors, actuators or machine-to-machine communication (Frank et al., 2019).

- Sample company B. This sample company is currently undergoing the implementation of factory's vertical integration technologies spanning from sales managers who communicate with the clients and process their orders to production workers who produce the final product. The sample company uses its currently used accounting system as a basis for the implementation of factory's vertical integration. Upon the accounting system, the company builds a customer relationship management system and digital technical sheets. These enable employees to access information about the product at any stage of its manufacturing process (see Appendix 6).

- *Internal Business perspective*- the newly implemented system has a high level of interoperability with other systems existing in the company. Most of the interoperability related barriers have been avoided as the new system operates within the existing accounting system. The system in general is considered to provide higher visibility and transparency to the operations activity and related information as it allows the employees performing on different levels of the company access the information of each order at each phase of the processes alongside the information about the client and their previous orders. The aforementioned mitigates the communication between employees working on the same cost object in the different phases of the production as well as provides the employees with useful information when it is needed. However, the system does not work as intended, thus rendering various performance-related issues. First of all, the system does not sufficiently substitute the communication and impairs it compared to the traditional communication methods undertaken in the company: "if a manager sends an email through the system, the client will receive it. However, if the client undertakes to reply to the message sent, the reply fails to reach the manager" (see Appendix 6). Furthermore, the system is complex and difficult to operate. In order to mitigate the latter, the company has assigned one of the employees to communicate with the system developers, analyse it and further provide training as well as assistance to the company employees who shall use the system: "as the system is newly developed and there are no demo versions or comprehensive manuals provided by the developer, the company undertook to assign one employee to test, describe the system and provide training for other employees" (see Appendix 6). Furthermore, such an approach is expected to help the company to utilise the system to its full potential: "although the system developer has provided the training, they were not enough to utilise the system to its full potential" (see Appendix 6).

- *Financial perspective*- although the system is still in the implementation phase, it has contributed to lower variable costs by mitigating the production processes. However, the system has also increased fixed costs as it comes with purchase cost and requires maintenance and employee training. Furthermore, it also creates depreciation expenses. As mentioned before, the company has assigned one employee to test, analyse, describe the system, and further provide training to other employees. It is mentioned that 30% of the employee's working time is assigned to this cause.

Automation. The concept is based on the use of robots, artificial intelligence or other means with the intention to automate operational procedures, data analysis, the prediction of machinery problems, the detection of product flaws, and the forecasting of production demands. The aforementioned are expected to enhance quality control, increase output productivity and lower costs (Frank et al., 2019).

Automation is undertaken more or less by all of the sample companies. The companies recognise automation-related technologies to be relevant and significantly contribute to quality control and reduction of costs. All of the sample companies have reduced the need for human resources. In most cases, the processes, where automation-related decisions were implemented, now require 4 to 5 times fewer employees than before. Furthermore, the latter also has significantly lowered the probability of human error, thus contributing to quality control.

- Sample company A. The company has automatised their main operation processes where raw materials are sorted and processed (see Appendix 5).
    - *Internal Business perspective*- automation has created a positive effect on quality control. It is noted that the technology has helped to reduce the defect rate of the final products almost to zero thus ensuring the quality. However, the effect on productivity is rather mixed. On the one hand, the daily production output has increased, but on the other hand machinery breakdowns are now more common which contributes to higher periods of idle time. Such idle times usually take about 4-5 hours per case. Furthermore, the technology is also complex, difficult to configure and maintain. As a result, specialists who are able to undertake the latter are scarce and not available in the company itself, nor in the region where the company operates. Therefore, in the cases of more serious equipment failures, the company is left with no other choice but to hire such specialists from abroad. This has a significant negative effect on efficiency increasing mean time to repair and idle times furthermore. The company's resilience is negatively affected as well because it is now more dependent on external factors. Nevertheless, technology has substituted a lot of human capital. Now the company in order to undertake all of the manufacturing processes requires 10 employees less than before. The aforementioned mitigates processes related to human resource management.
    - *Financial perspective*- regarding the costs, the automation has also rendered mixed results. The reduced number of employees has conditioned the lower fixed costs. However, the increase in total idle time, due to the more constant equipment failures and higher mean time to repair, has significantly contributed to the reduced output productivity, whereas the fixed costs remain unchanged and depreciation expenses are still present even though the machinery is at a halt. The company undertakes a straight-line method to record the depreciation of these technologies. In the cases of serious equipment failures, the absence of skilled specialists in the vicinity does increase costs. Furthermore, it is also noted that the quality control system tends to reject an abundance of good-to-use raw materials, thus increasing variable and fixed costs. Prior to implementing the technology, the company had determined the payback period which was acceptable. However, the calculations did not consider the aforementioned issues and, as a result, were not accurate.
- Sample company C. Most of the automation-related technologies are intended to enhance output productivity. Quality control is still left to be done manually (see Appendix 7).
    - *Internal Business perspective*- automation has helped significantly increase output productivity. The autonomous machines have increased the daily production output by up to 6 times. Some of the manufacturing processes now take 12 times less to produce the same output than before. Although none of the automation-related technologies in the

company addresses quality control, it is noted that these technologies execute the tasks with more accuracy and a higher level of diligence, thus conditioning the defect rate of final products to be minimal. However, the machinery is prone to failures which determines idle times from 30 minutes to 5 hours. Nevertheless, such cases are rare and have minimal influence on the general output productivity. Furthermore, the machinery is complex and requires respective human capital to configure and maintain it. The company in this manner undertakes the approach where the company's management conducts comprehensive research with the intention to learn all of the technologies' technical aspects. Although the research is demanding in the context of time and human resources, it provides management with valuable knowledge which gives the company the ability to undertake configuration, maintenance and repair tasks independently. The approach has also helped the company to substitute the resources necessary for equipment, but scarce in the market, with ordinary resources easily available. This results in lower mean time to repair, higher flexibility and resilience in the related activities.

  - *Financial perspective*- considering the greatly increased output productivity, the fixed costs allocated per cost object are also substantially lower than before. The company's approach to independent repair and maintenance tasks has proven to be cost-efficient. First of all, the machinery repair and maintenance services provided by machinery suppliers, or third parties tend to include very high markups. The latter being avoided lowers fixed costs per cost object. Furthermore, the autonomous repair and maintenance procedures determine the lower mean time to repair, thus also lowering fixed costs per cost object. The substitution of necessary resources required by the equipment has also proven to lower fixed costs as the substitutes tend to be cheaper. Moreover, it is also provided that payback period is very low considering purchase costs as well as human capital investments.

- Sample company D. The automation-related technology has been implemented in the company in order to increase output productivity. This technology automates processing procedures by autonomously undertaking raw material measuring, calculation and cutting procedures (see Appendix 8).

  - *Internal Business perspective*- the automation-related technologies implemented in the raw material processing tasks have proven to increase accuracy, lower defect rate and the quality of the final products. The procedures of measuring, calculating and cutting are prone to human errors which would cause the processed raw material to be unsuitable for further processing or negatively impact the quality of the final product. Therefore, the technology, by overtaking the aforementioned procedures, has mitigated the factor of human error, thus providing higher accuracy to the procedures and higher quality assurance for the finished goods. The technology substitutes up to 4 employees and provides additional assistance to those who take part in these procedures. The aforementioned mitigates the processes related to human resource management. However, there is resistance to change among the employees and they tend to avoid using the implemented technologies by undertaking the procedures the old way. This complicates human resource management and postpones the full embracement of digital technologies in the company. The company does not encounter issues related to the repair and maintenance procedures. According to the representative, the aforementioned procedures are undertaken by the equipment supplier. It is stated that the supplier reacts to any kind of equipment failures and resolves them in a prompt manner, thus conditioning the mean time to repair to be not material for the company's performance. The supplier maintains the equipment reliably as well. This indicates that the company is not resilient to supplier change as currently, the company does not have sufficient human capital to repair and maintain the equipment, nor there is a known alternative external entity which would undertake such procedures. The implementation of the technology recording the finished goods each time they are completed has also rendered positive results. It is stated that the system increases the level of automatisation and substitutes manual labour. It is also stated that it took a year for the company to implement this technology.

  - *Financial perspective*- after automation-related technologies have been implemented in the raw material processing procedures, the variable costs have dropped significantly. One of the reasons for the latter is that the new technology undertakes procedures with more accuracy and does not leave leftover raw materials which are not suitable for further manufacturing processes. Prior to the implementation, each processing procedure would generate small amounts of leftover raw materials. Although they are small in numbers, the total number of leftover raw materials would greatly contribute to the higher variable costs. The second reason is that the defect rate of processed raw materials has also significantly dropped. The substitution of employees has contributed to lower fixed costs.

Flexibility. The concept considers the technologies which are intended to enable mass customisation. The latter emphasises undertaking manufacturing which is characterised by mass manufacturing's relatively low variable costs, the adaptability and personalisation of custom-made items.

The sample companies A and C undertake mass manufacturing where the emphasis is put on large quantity production and efficiency rather than customisation and unique client preferences. Therefore, the flexibility in these companies tends to be limited. Nevertheless, both sample companies undertake digitalisation-related technologies in order to increase flexibility while maintaining the variable costs at the same or lower level, thus allowing mass customisation in the company.

The sample companies B and D, on the other hand, undertake custom manufacturing where the emphasis is put into the production of the products individually to each client according to their preferences. As a result, the level of customisation is high in these companies compared to the ones undertaking mass manufacturing. Nevertheless, flexibility-related technologies are relevant to these companies as they provide possibilities for them to lower variable costs by maintaining efficiency. However, in the cases of companies B and D there are no technologies observed during which could be assigned to this particular category.

- Sample company A. Sample company A undertakes the automated processing procedure. As the company's product, although standardised, comes in different parameters such as width or colour, the company is required to undertake a procedure where the parameters of the product are being changed (see Appendix 5).

  - *Internal Business perspective*- the silo control system provides additional flexibility as the company is now able to undertake mass manufacturing of their product with different parameters without losing efficiency. However, as mentioned before, the technology is prone to constant failures which conditions higher idle times. Furthermore, the system is complex which also contributes to increased idle time and mean time to repair.

  - *Financial perspective*- the financial performance is rather mixed. On the one hand, the technology allows the company to produce a higher variety of products while maintaining the costs at the efficient, mass production level, but on the other hand, the higher mean time to repair, longer idle times and more constant breakdowns significantly increases the fixed costs per one product.

- Sample company C. The sample company undertakes to enhance its flexibility by producing certain raw materials itself. At the moment, the company employs a thermal printer in order to produce labels which shall be put on the cost object. These labels are usually used for customised or less demanded products which do not conform to mass manufacturing and are produced in small quantities each. In other cases where products are created in large quantities, the company purchases the labels from the label suppliers (see Appendix 7).

  - *Internal Business perspective*- the technology provides the company with a higher level of flexibility and resilience. First of all, the company is able to prepare raw materials for less demanded products promptly. Furthermore, the company is less dependent on external factors such as supplier's schedule, their capabilities or delivery-related issues.

  - *Financial perspective*- the technology has proven to be cost-efficient. The production of the labels with the thermal printer for customised or less demanded products has proven to generate much less variable and fixed costs than their acquisition from the supplier as the quantity of these labels for each product type is lower than the supplier's set minimum order quantity. The cost advantages which could be received by undertaking economies of scale concepts and purchasing large amounts of labels from the suppliers in advance cannot be used by the company. First of all, the company is not able to forecast the demand for the custom and less demanded products. Secondly, the constantly changing regulations condition company to constantly change the information provided on the labels, thus there is a risk that the labels purchased in advance would become obsolete before they are used in manufacturing.

Additive Manufacturing. The concept is based on the 3D manufacturing of diverse goods with the same raw materials. It addresses a higher level of product customisation. Additive manufacturing is less undertaken among the sample companies, but, nevertheless, has proved to be beneficial.

- Sample company C. The company undertakes this front-end technology in the maintenance and repair processes. The company undertakes to produce certain spare parts for machinery by using additive manufacturing services provided by third parties (see Appendix 7).

  - *Internal Business perspective*- the use of additive manufacturing in the repair and maintenance processes has proved to increase the company's flexibility and resilience. First of all, the company is now able to acquire some spare parts in several days while otherwise, the period would span from several weeks to six or, in some cases, even twelve months. Secondly, the company is less dependent on external factors where spare parts become unavailable due to the supplier's decision not to produce them or logistical issues where the spare parts cannot be delivered.

    - *Financial perspective*- the additive manufacturing of spare parts has proven to be highly cost-efficient. First of all, the spare parts offered by machinery suppliers or third parties tend to be highly expensive in the market compared to the spare parts produced with additive manufacturing. Secondly, the costs related to logistics and delivery of the parts are also mitigated as the suppliers who produce the spare parts by undertaking additive manufacturing are located nearby to the sample company whereas the suppliers of the original parts tend to be abroad.

4.2.2 Smart Supply Chain

Digital platforms for customers. The goal of digital platforms for customers is to create a collaborative effort between a manufacturer and their client. Collaboration, shared skills, a decrease in information distortion, and synchronisation of resources and manufacturing processes are all expected to be part of this endeavour.

- Sample Company C. The mutually accessible automatic procurement system is employed in communication and collaboration between the sample company and its clients. The company has no control over these databases as they are implemented, administrated and fully controlled by the customer companies. Nevertheless, the system does affect the company's performance. The automatic procurement system monitors the current stock of goods in the client's warehouses and the volumes of sales of these goods for the selected period of time. According to the latter information, the system forecasts future sales and accordingly provides the sample company with the list and quantities of goods which shall be delivered to the client. Such systems are undertaken by several sample company clients which usually consist of larger retail companies (see Appendix 7).

    - *Internal Business perspective*- the system has proven to affect the sample company's performance both positively and negatively. First of all, the system provides both companies with a higher level of visibility. The latter significantly facilitates the communication between the companies, as the information from all of the client's departments is now automatically transferred into mutually accessible databases, thus eliminating the need for reaching out to each client company's departments for information. Secondly, the system performs procurement-related procedures automatically which further mitigates communication, and reduces the human element. Furthermore, the system undertakes procurement procedures in a consistent manner, as a result providing the sample company with convenience in outbound logistics and demand planning. The systems' sales forecasting feature also assists the sample company in its production planning. Nevertheless, the system has also proven to render the issues and negative effects on the sample company's performance. The main issue is discrepancies between actual facts and system-provided information. This information may include the product quantities in the client company's stock, sales volumes and forecasts. Such discrepancies appear as the system does not consider all of the factors which have an influence on the aforementioned. These factors may include human errors, faulty management or any other event which affects the actual quantities or forecasts, but are not provided to the system. For example, due to faulty management in the client company, the products may not be transferred from the department's warehouse to the shelves even though the system recognises these products as ready for sale (see Appendix 7). As a result, such department of the client company is not able to sell these products due to faulty management while the system recognises that the products are not sold due to the lower demand and further provides improper forecast which does not correspond with the reality. The aforementioned issue is a result of the system being considered to substitute communication to a higher level than it actually does.

- *Customer perspective*- regarding customer satisfaction and the relationship between them and the sample company, the digital platform has proven to be beneficial. The procurement processes, from the customer's point of view, are now mitigated by lowering or completely removing the human factor in these processes, thus lowering the need for human resources as well as their management. This has also proven to decrease the human error factor significantly. The aforementioned also tends to lower customer expenses, thus increasing satisfaction.
- *Financial perspective*- the system has mitigated the need for the company's sales managers to proactively manage sales with the clients, thus lowering manual communication and, therefore, reducing related fixed costs. Although the information discrepancies are evident, manual communication is still mitigated. In cases when the client's system works properly, manual communication tends to be almost fully substituted, thus lowering fixed costs even more.

The proposed conceptual model in the context of the selected sample companies has been tested and has provided relevant results. The results demonstrate balanced scorecard perspectives intended for performance measurement aligned with the organisational environment affected by digitalisation. The implemented conceptual model has shown benefits and issues, both financial and non-financial, as well as other factors related to digitalisation which influence the companies' and supply chains' performance. Further, the results shall be discussed in more detail, and, in accordance, the recommendations shall be provided.

4.3 Discussion and Recommendations

Discussion. The research has shown that dimensions of digitalisation established by Frank et al. (2019) are scarcely embraced by the sample companies. The smart manufacturing dimension is the only one applicable for all the sample companies while the smart supply chain dimension is applicable only for sample company C. Furthermore, these dimensions are not embraced by the sample companies to their full extent. The automation category of technologies tends to be the most widely embraced by the sample companies as well as flexibility. Factory's vertical integration, additive manufacturing and digital platforms for customers are also embraced by the sample companies. These are the only digitalisation-related categories of technologies implemented by the sample companies. The dimensions of smart working, as well as smart products and services, are not embraced by the sample companies at all. Therefore, it is evident that digitalisation is still scarce in the supply chain among small and medium-sized enterprises, thus confirming the statement provided by Frederico et al. (2020). The categories of digitalisation-related technologies alongside their status of implementation in the sample companies are shown in **Table 4**.

Table 4. Categories of digitalisation-related technologies alongside their status of implementation in the sample companies (Source: thesis author)

	Sample A	Sample B	Sample C	Sample D
Automation	x		x	x
Flexibility	x		x	
Factory's vertical integration		x		
Additive manufacturing			x	
Digital platforms for customers			x	

Nevertheless, digitalisation has, to some extent, changed the way organisations perform. These changes tend to be positive and negative in both financial and non-financial perspectives. The most of non-financial benefits the sample companies encounter are increased output productivity, mitigated processes related to human resource management, substituted human capital, higher visibility, information accessibility and accuracy. The most common of the benefits is a lower defect rate. Higher transparency, quality control and elimination of information inconsistencies are the benefits which are also encountered in the sample companies. These defects do correspond with the ones established in the literature analysis.

However, the non-financial digitalisation related issues are also evident. Among the sample companies, the most common issue is related to the complexity of the digitalisation-related technologies. The latter creates such issues as:

- Higher need for human capital- the complexity of these technologies mandates specialised skills intended to operate them as well as undertake the tasks related to the maintenance and repair of these technologies. However, these skills tend to be absent in the companies. As a result, companies are required to either search for human capital capable of doing such tasks or invest in employee training and development. The cases of the sample companies show that the companies tend to undertake different approaches in this matter. Some companies undertake to invest in human capital and train their own employees to be able to manage these technologies (see Appendices 6 & 7) while others tend to rely on external human capital (see Appendices 5 & 8). Nevertheless, the issue is still present and the lack of skilled human capital aggravates the human resource management and conditions longer mean time to repair. Furthermore, the continuous and rapid advancement of technologies creates the need for employees to constantly update their skills and knowledge in order to keep up with the changes.

- Higher mean time to repair- the complexity of digitalisation-related technologies tend to increase the mean time to repair. The aforementioned lack of adequate human capital is one of the reasons for the latter. The digitalisation-related technologies undertaken in the companies require specialised skills to be maintained. The absence of a skilled workforce creates difficulties in repair and maintenance processes, thus increasing the mean time to repair. Furthermore, these technologies involve interdependent, multi-layered software and hardware components which create difficulties to identify the root cause of the problem if one occurs.

- Lower resilience- the high complexity of digitalisation-related technologies tends to also have a negative effect on the resilience of the companies. It is evident that the complexity of these technologies mandates higher human capital (see Appendices 5; 6; 7 & 8). The companies which undertake to invest in human capital (see Appendix 8) are capable of relatively independently repairing and maintaining the technologies, thus preserving their resilience. In other cases, the companies tend to be more reliable on the external factors which may be favourable and provide companies with sufficient support in repair and maintenance procedures (see Appendix 9) or unfavourable where external support for companies is insufficient, thus limiting their resilience (see Appendix 6). It is also evident that in some cases these technologies require unique resources in order to repair and maintain them (see Appendices 5 & 7). Being exceptional and unstandardised, solely intended specifically for one or a small group of technologies, these resources tend to be scarce in the market and usually provided by a limited number of suppliers. As a result, the companies become less resilient to supply chain disruptions and more dependent on their suppliers and other external factors.

The representatives of the sample companies B, C and D have also mentioned the issues related to interoperability. The representative of sample company B mentioned that the company is unsure whether to invest in technology that meets its current needs but will need to be changed in the future, resulting in additional implementation costs, or to acquire more capable and expensive technology which would enable the company to avoid additional technology implementation costs in the future, but also would not be used to its full potential initially. The aforementioned shows that the current technologies are unable to evolve according to the company's needs. Furthermore, the representative agrees that the lack of interoperability in the digitalisation-related technologies aggravates their implementation process and increases its costs. The company has been able to mitigate the latter as the digitalisation-related technologies are being implemented on the basis of the system already used in the company. As a result, however, the issue of interoperability has limited the company's choice of digitalisation technologies, thus lowering the company's resilience and increasing its dependency on the technology supplier. The aforementioned factors have become a reason for hesitation for sample company C. The company hesitates to implement some of the digitalisation-related technologies even though they would provide long-time benefits for the company. Instead, the company uses outdated technologies in order to avoid short-time high implementation costs. The sample company D has been able to implement the digitalisation-related technologies even though a lack of interoperability was evident. According to the company's representative, the process was long and exhausting requiring the assistance of the third parties which helped to transfer all the data from the old system to the new one without losing its integrity. In general, the research has shown that lack of interoperability in digitalisation-related technologies aggravates their implementation, thus increasing short-term costs, limiting the organisation's resilience, or even discouraging the implementation. In general, the research has shown that the most digitalisation related issues arise from the complexity of the technologies. The latter lowers the resilience and is even more aggravated by insufficient human capital.

It is evident that the most common issues observed and analysed during the research do differ from the main digitalisation related barriers established during the literature analysis. The latter would include the following: cyber security (Vaidya et al., 2018; Dai et al., 2019), ethics (Vallor & Rewak, 2018; Bartlett et al., 2019), lack of frameworks intended for small and medium-sized enterprises (Masood & Sonntag, 2020) as well as agreed upon definitions (Culot et al., 2020; Rupp et al., 2021). The main issue of digitalisation-related technologies' complexity has been indirectly mentioned in the literature analysis. Vallor & Rewak (2018) state that the complexity of digitalisation-related technologies acts as one of the major factors alongside the proprietary nature of technology aggravating ethics.

The financial effect of digitalisation on the sample companies has also been both positive and negative. Although in most cases the sample companies have been able to significantly lower fixed and variable costs, the non-financial issues tend to also induce high costs. Almost in all cases companies are effected by purchase costs as well as depreciation expenses which increase fixed costs, only with exception when the technology belongs to other entities (see Appendix 7). In cases when the issues are not managed sufficiently, the costs may even outweigh the positive financial effect (see Appendix 5). According to the conducted research, the most costs are rendered by the lack of human capital, higher mean time to repair, more frequent equipment failures and lower resilience. All the aforementioned are the result of the complex nature of digitalisation-related technologies. The lack of human capital has demanded additional costs either in the form of investments towards existing human capital or reliance on external human capital. The higher mean time to repair as well as more frequent equipment failures condition higher fixed costs. The lower resilience conditions significantly higher costs in cases of equipment failures or other situations and interruptions.

It is clear that the companies which manage to mitigate at least some of these issues are able to gain the benefits of the technologies without the additional costs:

- Sample company B is trying to mitigate the need for human capital by proactively communicating with technology suppliers during the implementation phase as well as additionally investing in human capital. The aforementioned is attempted with the intention and expectation to gain enough knowledge and skills needed in order to fully utilise the technology.

- Sample company C, by investing in human capital, was able to avoid prolonged idle times and maintain resilience. The latter was also reinforced by additive manufacturing and flexibility-oriented technologies.

- Sample company D has managed to mitigate the idle times by choosing a reliable technology supplier which is able to provide the needed support and assistance in a prompt manner whenever it is needed.

The financial and non-financial benefits and issues are visually depicted in **Figure 5**.

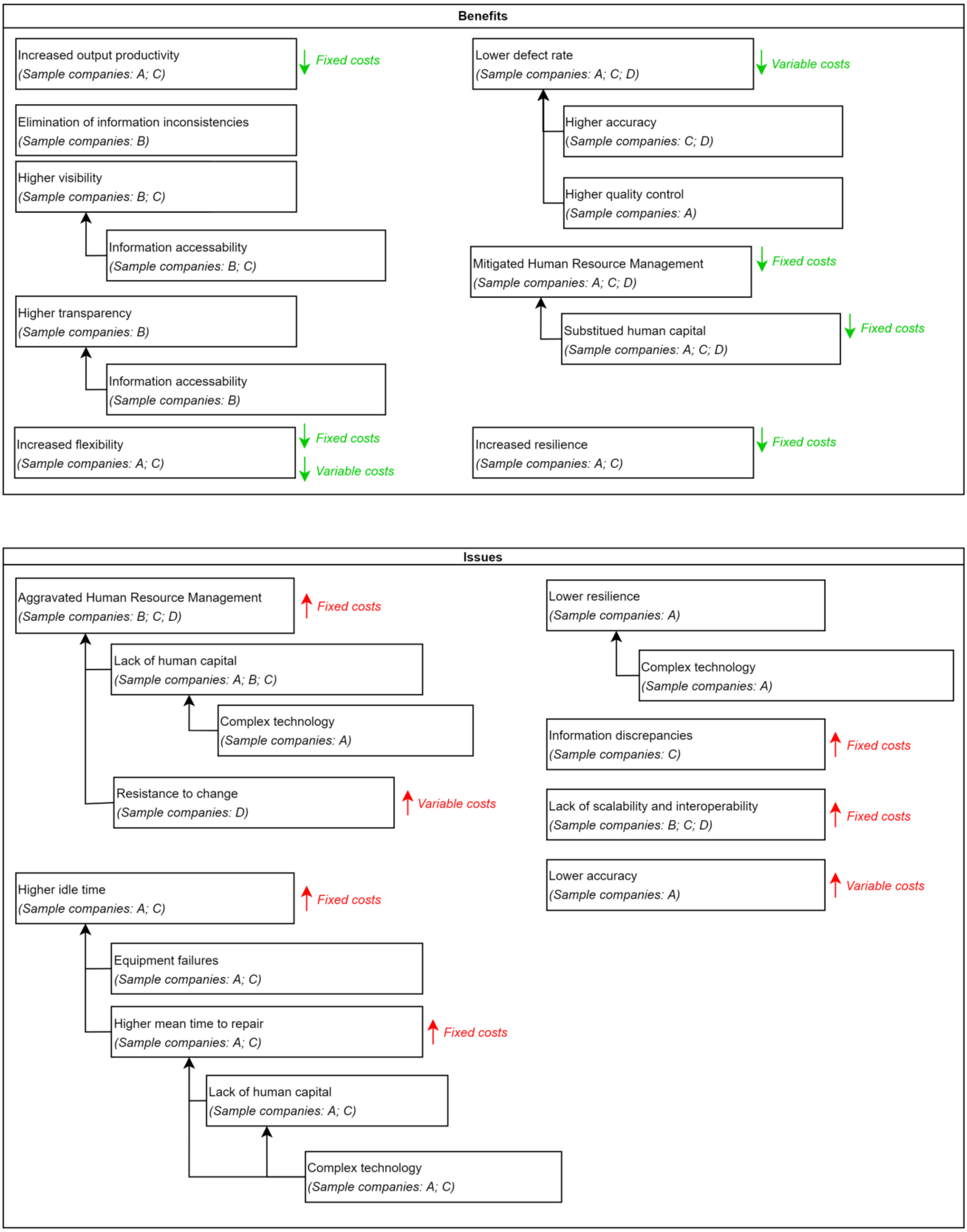

Fig. 5. Financial and non-financial benefits and issues the sample companies encounter in the context of digitalisation (Source: thesis author)

Recommendations. Considering both financial and non-financial benefits and issues, alongside their causes, it is possible to establish several non-financial measures which may aid the organisation when implementing digitalisation-related technologies. Proactive in nature, these measures shall be intended for use before implementation of the digitalisation-related technologies. The establishment shall consider the following: digitalisation-related technology suppliers, the organisation's human capital and resilience.

In the case of the digitalisation-related technology supplier, research has shown that reputable supplier is an important factor determining the success of the technology implementation. The emphasis shall be put on the supplier's ability not only to provide the technology for the organisation but also to provide adequate training and further support. This element is very important as the lack of the supplier's engagement in the implementation and operation processes does render risks of insufficient human capital, increased idle time and lack of resilience. Therefore, the supplier's responsibilities and engagement during and after the technology procurement process shall be considered.

In the case of human capital, prior to purchasing the technology, it is important to evaluate the available human capital within the organisation and the market. As previously mentioned, human capital is a critical factor in the implementation of digital technologies. Inadequate human capital can limit or even hinder the technology's operation, repair and maintenance procedures. Therefore, the established measure shall consider the following: availability of human capital, including its ability to operate and maintain the technology, and availability of resources providing necessary skills for the human capital.

With regard to resilience, it is important to evaluate the organisation's prospects to operate, repair and maintain the technology independently after its implementation. The research has shown that sufficient human capital and the availability of resources necessary for the aforementioned processes have a significant influence on the organisation's resilience. Therefore, the following factors shall be considered when establishing the measure: the number of suppliers capable to provide the aforementioned resources in the market, and the availability of human capital to gain the required skills.

Considering the aforementioned, the following factors may be established:

1. The level of training the supplier commits to provide the organisation. The training shall be divided into two areas: operating the equipment and undertaking repair and maintenance procedures.

2. Human capital's capability to operate the technology. The capability shows to what extent the organisation's employees are able to utilise the technology. The higher capability is, the more benefits the organisation may receive from the use of the technology. As provided by sample company B, it is an important factor as there is a tendency that organisations to invest in technologies, but are unable to fully utilise them, thus missing benefits while incurring the costs (see Appendix 7).

3. Human capital's capability to repair and maintain the technology. The capability depicts the level to which the employees are able to repair and maintain the technology. The higher the

factor is, the more required repair and maintenance procedures can be undertaken by the employees independently, thus conditioning a high level of resilience, lower costs and mean time to repair. The factor is highly important and the negligence of it may cause serious issues in the organisation (see Appendix 5).

4. Availability of sources and their comprehensiveness describing how to operate, repair and maintain the technology. This factor would show to what extent the available information covers the aforementioned procedures. These sources may include manuals, instructional videos and any other material which may provide the employees with instructions on how to operate, repair and maintain the technology. The availability may also consider the comprehensiveness of the aforementioned sources as well as consideration to what level the suppliers recognise the technical data of their provided digital technology to be proprietary, as the latter tends to be an issue (Vallor & Rewak, 2018).

5. The supplier's commitment to providing the aforementioned sources.

6. Resilience- resilience may be defined by a number of suppliers capable to provide the resources required for operating, repairing and maintaining the technology. The more of there are suppliers in the market, the more resilient the organisation is with regard to the implemented technology.

As these factors are dependent on each other, it is important to determine how much they affect each other. In this case, the creation of correlations among the factors may help to determine the quantitative value defining their relationship. The correlations may be created by undertaking assumptions. The following are provided relations between the factors as well as possible assumptions helping to determine their correlation:

1. The more supplier commits to providing training to the organisation's employees, the more likely the company's employees will be able to operate, repair and maintain the technology independently. Therefore, the correlation between the factors is positive and is characterised as follows $0 < \rho \leq 1$.

2. The more supplier commits to providing sources about the operation, repair and maintenance of the equipment, the more of it will be available. This relation between the factors also influences the following relation. Therefore, the correlation between the factors is positive $0 < \rho \leq 1$.

3. The more sources describing the operation, repair and maintenance of the technology are available, the more organisation will be able to enhance human capital's capabilities. Therefore, the correlation between the factors is positive $0 < \rho \leq 1$.

4. The more there are suppliers in the market providing necessary resources for operating, repairing, and maintaining the equipment, the higher organisation's resilience will be. The relation between the supplier's number in the market and the organisation's resilience is defined by Spearman's correlation when the more suppliers there are in the market, the lower correlation is between the variables. The assumption is made by considering that there is a very high impact on the organisation's resilience if the quantity of the suppliers increases, for example, from, 1 to 2, but is very low if such an increase occurs when there is a higher number

of suppliers. The relation may also be defined by market structure, whether there is a monopoly, oligopoly, monopolistic competition or perfect competition. The market structure depends on the supplier quantity thus substituting the aforementioned method of correlation. Therefore, the correlation between the factor shall be high if the market is monopolistic and low if there is perfect competition. Furthermore, as mentioned before human capital and the availability of sources also have a positive correlation with resilience.

The correlations between the factors are depicted in **Figure 6**.

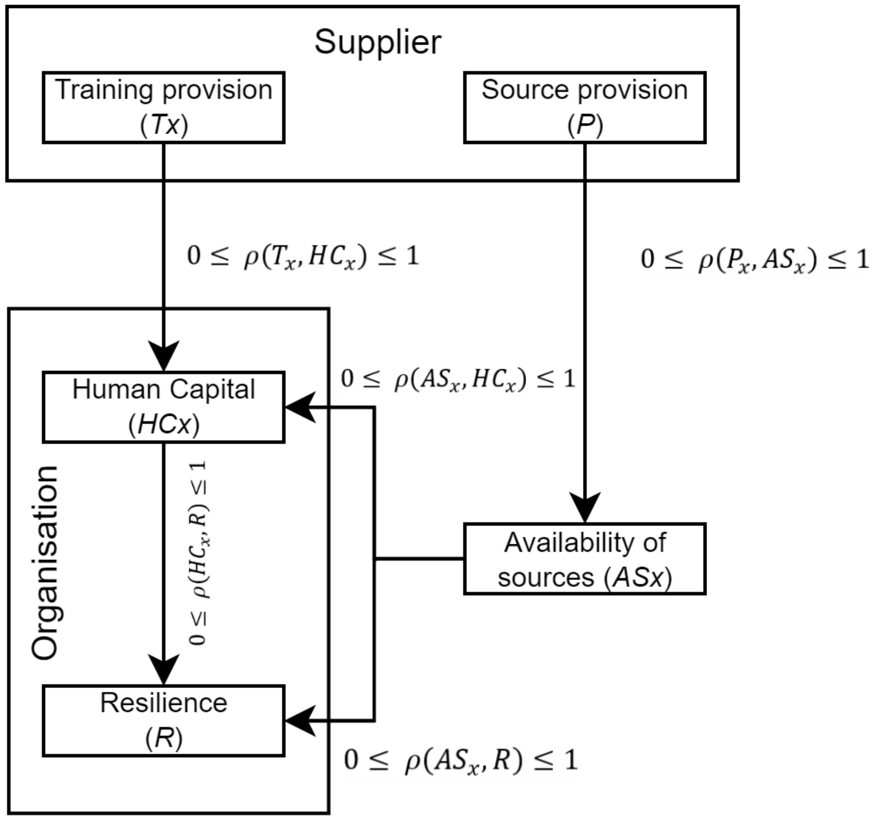

Fig. 6. Correlation between the factors influencing an organisation's ability to operate, repair and maintain the technology (Source: thesis author)

Having established the correlations between the factors, it is possible to determine an organisation's ability to operate, repair and maintain the technology. The factors related to the supplier's involvement and the organisation's human capital may be determined:

1. Extent to which the supplier commits to provide training to the organisation's employees may be determined by analysing, for example, whether the supplier undertakes to provide one-time training for the organisation's employees or is obliged to provide continuous training and consultations throughout the technology's use.

2. Extent to which the supplier commits to provide instructional material on how the technology is operated, repaired and maintained may be determined by evaluating how much information

about the technology the supplier is willing to provide. For example, whether the supplier provides manuals or instructional videos and to what extent they are comprehensive.

3. Human capital's capability to operate the technology may be determined by analysing to what extent the employees are able to utilise the technology. The level of this factor could be affected by the supplier's involvement, which includes offering training resources and educational materials. The latter's availability in general may also influence the factor.

4. Human capital's capability to repair and maintain the technology may be determined in a similar manner as the factor before. However, this factor puts emphasis on the organisation's resilience rather than the receival of benefits. The factor shows how well the organisation understands the technology, can react to equipment failures and to what level it is dependent on the supplier. The high value of this factor exhibits relatively low idle time, mean time to repair, increased resilience and, in general, mitigated complexity of the technology. This factor may be influenced by the supplier's engagement such as the provision of training and learning material as well as the latter's availability.

5. Resilience- may be determined by evaluating the organisation's dependency on external factors which influence the use of digitalisation-related technologies.

The factors used in the measurement shall be weighted by the respective correlations. The correlations may be established by the assumption of how much training and availability of sources influence human capital's capabilities to operate, repair and maintain equipment. The measurement shall consist of the normalised sum of all weighted factors expressed in percentage. Each variable is received by undertaking several formulas.

The first formula defines human capital's ability to operate digital technology. It consists of the training level on operating the technology provided to the company's employees by the supplier weighted by the weight determined by the correlation between the training and human capital's capability to operate the equipment. The level is expressed in percentage from 0-100 while correlation shall be $0 < \rho(T_O, HC_O) \leq 1$. The other part of the formula consists of available sources describing on how to operate the technology weighted by the correlation between the available sources and human capital's capability to operate the equipment. The available sources shall be expressed in percentage from 0-100 as well when a correlation is $0 < \rho(AS_O, HC_O) \leq 1$. These two parts are summed and normalised, thus defining human capability to operate the technology (see formula 1).

$$HC_O = \frac{T_O \times \rho(T_O, HC_O) + AS_O \times \rho(AS_O, HC_O)}{2} \tag{1}$$

HC_O- human capital capability to operate the technology;

T_O- the extent to which supplier commits to provide training on how to operate the equipment for the organisation's employees;

AS_O- the percentage of operations described in the available sources;

In a similar manner, the second formula may be established and would define human capital's capability to repair and maintain the technology. The latter also considers resilience which is defined by the number of suppliers in the market capable of supplying the organisation with resources necessary for repairing and maintaining the technology. As mentioned before, the resilience may be either defined by Spearman's correlation coefficient between quantity of supplier's and organisation's independency as well as a score determined by the market structure. As well as in the previous formulas, here the variables are also expressed in percentage 0-100% while the correlations are $0 < \rho \leq 1$ (see formula 2).

$$HC_{RM} = \frac{T_{RM} \times \rho(T_{RM}, HC_{RM}) + AS_{RM} \times \rho(AS_{RM}, HC_{RM}) + R}{3} \quad (2)$$

HC_{RM}- human capital capability to undertake repair and maintenance procedures of the technology;

T_{RM}- the extent to which supplier commits to provide repair and maintenance related training to the organisation's employees;

AS_{RM}- the amount of repair and maintenance procedures described in the available sources;

R- resilience score.

The human capital capability to operate the technology and human capital capability to repair and maintain it both define the overall organisation's ability to employ the technology. Therefore, the latter is the normalised average of the former values (see formula 3).

$$OC = \frac{HC_O + HC_{RM}}{2} \quad (3)$$

OC- overall organisation's ability to employ the technology.

HC_O- human capital capability to operate the technology;

HC_{RM}- human capital capability to undertake repair and maintenance procedures of the technology.

The final measure depicts how well the organisation will be capable of resiliently operating, repairing and maintaining the newly implemented technology. Such variables as extent of training or provision of learning material may guide the organisation whether to negotiate the higher supplier's engagement in the process of technology implementation while the variable of resilience may indicate future costs and dependency on the supplier.

The measure considers both human capital's capability to operate and maintain the technology, and availability of resources providing necessary skills for the human capital. The resilience is also considered regarding the implementation of digitalisation-related technology. It is important to note that the provided measurement has an abundance of limitations. First of all, the human capital's experience, expertise, and problem-solving skills are not considered by the measure even though these can be equally important in implementing and maintaining digitalisation-related technologies. The current human capital capabilities are also not considered by the measurement. Another limitation of the measure would be that it undertakes solely quantitative approach and may not consider certain qualitative factors which may influence the processes related to equipment’s use, repair and maintenance. Furthermore, the correlation currently is being determined by subjective considerations such as the assumptions. As a result, this approach may generate inaccurate results. Lastly, the measurement has not been tested in practice. Nevertheless, the formula considers issues related to the implementation of digitalisation-related technologies and provides guidance on the areas which are required to be addressed in order to successfully implement digitalisation-related technologies.

To conclude, the research has shown an environment of small and medium-sized enterprises in the context of digitalisation. Although the digitalisation is still scarce in those companies, the effect on their and supply chains’ performance is evident. Digitalisation has caused both positive and negative influence on the companies and stakeholders in the supply chains. The positive effects do correspond with the expectations of the companies and scholars. However, the negative effects tend to be unexpected. Most of these negative results are usually caused by the complexity of digitalisation-related technologies. Nevertheless, the research has also shown that some of the companies are able to mitigate these issues by taking appropriate actions with regard to repair and maintenance procedures. As a result, the recommendations have been provided which may help the companies to measure their future performance considering the aforementioned issue.

Limitations and further directions. The current study is limited in terms of the variety of case studies and the depth of their analysis. Therefore, future studies may consider the implementation of the conceptual model with the cases of different-sized companies performing in other sectors. Future studies may as well undertake a more comprehensive analysis of the case studies by employing wider research methodologies. The recommendations proposed in this thesis may also be tested in practice to determine their eligibility.

Conclusions

1. The undertaken problem analysis of supply chain's performance measurement in the context of digitalisation has led to the conclusion that this topic is relevant due to the expectations that digitalisation will bring significant changes to supply chains thus changing the organisational environment of the companies. The latter will require performance measurement change accordingly due to its high dependency on the companies' environment. However, there is a lack of studies addressing the alignment of the supply chain's performance measurement with the expected digitalisation changes. Furthermore, the changes related to digitalisation are still scarce and currently it is unclear how exactly they will change the supply chains and organisational environment of the companies. Therefore, it is important to undertake a deeper analysis of this topic in order to establish the appropriate alignment between performance measurement and the environmental changes rendered by digitalisation.

2. The main theoretical aspects of performance measurement and digitalisation demonstrate their main concept and function alongside categories, types, benefits and barriers. With regard to performance measurement, it is determined that its frameworks have become more complex and tend to extend beyond the organisational boundaries encompassing the supply chain as a whole. The measures tend to be categorised into financial and non-financial where the latter are being increasingly used in conjunction with financial measures to complement each other. The balanced scorecard as a performance measurement framework is currently considered to be the most suitable for measuring the performance of contemporary supply chains. Contemporary supply chains are characterised by the spread of digitalisation. The latter is currently highly relevant and expected to provide significant benefits to organisations. However, it is evident that there are numerous barriers to successful implementation. Although the potential impact of digitalisation on business environments and supply chains remains uncertain, it is clear that it represents both opportunities and challenges for organisations. Based on the established theoretical aspects, the conceptual model is created and considers the measurement framework intended to measure the performance of the organisation performing in the context of digitalisation. The model aligns a balanced scorecard with dimensions of digitalisation.

3. The established methodological approach considers qualitative semi-structured interviews of small and medium-sized enterprises performing in the environment where digitalisation-related technologies have been employed. The semi-structured interviews would provide insight on how organisation perform in context of digitalisation. The collected information shall be analysed according to the conceptual model emphasising the main areas of importance. According to the latter, the measure shall be created and intended to measure performance in the context of digitalisation.

4. The results of research of the proposed model for the performance measurement of supply chains in the context of digitalisation have showed that the employment of digitalisation-related technologies in the companies is rather scarce, but nevertheless does provide significant influence on their performance. It was determined that the digitalisation's effect on the companies' performance is mixed and includes both financial and non-financial benefits and issues. The main and most common issues among the researched companies have

been determined to be higher idle time, lack of human capital, longer main time to repair and lower resilience, all of which are conditioned by a complex nature of digitalisation-related technologies. In accordance with these results, a measurement has been established which defines overall organisation’s ability to employ the digitalisation-related technology considering the identified main issues.

List of references

1 Abou-Foul, M., Ruiz-Alba, J. L., & Soares, A. (2021). The impact of digitalization and servitization on the financial performance of a firm: an empirical analysis. *Production Planning & Control*, *32*(12), 975-989.

2 Agapovichev, A., Sotov, A., Kokareva, V., & Smelov, V. (2018). Possibilities and limitations of titanium alloy additive manufacturing. *MATEC Web of Conferences* (Vol. 224, p. 01064). EDP Sciences.

3 Akdogan, A., & Vanli, A. S. (2020). Introductory chapter: mass production and industry 4.0. *Mass Production Processes*. IntechOpen.

4 Alam, T. (2020). Cloud Computing and its role in the Information Technology. *IAIC Transactions on Sustainable Digital Innovation (ITSDI)*, *1*(2), 108-115.

5 Alves, J., Lima, T. M., & Gaspar, P. D. (2023). Is Industry 5.0 a Human-Centred Approach A Systematic Review. Processes, 11(1), 193.

6 Aryani, Y. A., & Setiawan, D. (2020). Balanced Scorecard: Is it beneficial enough? A literature review. *Asian Journal of Accounting Perspectives*, *13*(1), 65-84.

7 Asiaei, K., & Bontis, N. (2019). Translating knowledge management into performance: the role of performance measurement systems. *Management Research Review*.

8 Aslam, F., Aimin, W., Li, M., & Ur Rehman, K. (2020). Innovation in the era of IoT and industry 5.0: Absolute innovation management (AIM) framework. *Information*, *11*(2), 124.

9 Augusto-Gonzalez, J., Collen, A., Evangelatos, S., Anagnostopoulos, M., Spathoulas, G., Giannoutakis, K. M., Nijdam, N. A. (2019, September). From internet of threats to IoT: A cyber security architecture for smart homes. In *2019 IEEE 24th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD)* (pp. 1-6). IEEE.

10 Balaji, M., Dinesh, S. N., Kumar, P. M., & Ram, K. H. (2021). Balanced Scorecard approach in deducing supply chain performance. *Materials Today: Proceedings, 47,* 5217-5222.

11 Bartik, A. W., Bertrand, M., Cullen, Z., Glaeser, E. L., Luca, M., & Stanton, C. (2020). The impact of COVID-19 on small business outcomes and expectations. *Proceedings of the national academy of sciences*, *117*(30), 17656-17666.

12 Bartlett, R., Morse, A., Stanton, R., & Wallace, N. (2019). *Consumer-Lending Discrimination in the FinTech Era*. Berkeley UC. Retrieved November 26, 2021, from http://faculty.haas.berkeley.edu/morse/research/papers/discrim.pdf.

13 Basu, S., Bardhan, A., Gupta, K., Saha, P., Pal, M., Bose, M., Basu, K., Chaudhury, S., & Sarkar, P. (2018, January). Cloud computing security challenges & solutions-A survey. In *2018 IEEE 8th Annual Computing and Communication Workshop and Conference (CCWC)* (pp. 347-356). IEEE.

14 Belas, J., Khan, K. A., Maroušek, J., & Rozsa, Z. (2020). Perceptions of the importance of business ethics in SMEs: A comparative study of Czech and Slovak entrepreneurs. *Ethics & Bioethics*, *10*(1-2), 96-106.

15 Best, M., Rao, A., & Lendler, J. (2021). *Understanding algorithmic bias and how to build trust in ai*. PwC. Retrieved November 26, 2021, from https://www.pwc.com/us/en/tech-effect/ai-analytics/algorithmic-bias-and-trust-in-ai.html.

16 Bienhaus, F., & Haddud, A. (2018). Procurement 4.0: factors influencing the digitisation of procurement and supply chains. *Business Process Management Journal*.

17 Bititci, U. S., Bourne, M., Cross, J. A. F., Nudurupati, S. S., & Sang, K. (2018). Towards a theoretical foundation for performance measurement and management.

18 Bourreau, M., & Krämer, J. (2022). Interoperability in digital markets. *Available at SSRN 4181838*.

19 Boyes, H., Hallaq, B., Cunningham, J., & Watson, T. (2018). The industrial IoT (IIoT): An analysis framework. Computers in industry, 101, 1-12.

20 Büchner, S., Hergesell, J., & Kallinikos, J. (2022). Digital Transformation (s): On the Entanglement of Long-Term Processes and Digital Social Change; An Introduction. Historical Social Research, 47(3), 7-39.

21 Carayannis, E. G., & Morawska-Jancelewicz, J. (2022). The futures of Europe: Society 5.0 and Industry 5.0 as driving forces of future universities. *Journal of the Knowledge Economy*, 1-27.

22 Chalmeta, R., & Santos-deLeón, N. J. (2020). Sustainable supply chain in the era of industry 4.0 and big data: A systematic analysis of literature and research. *Sustainability*, *12*(10), 4108.

23 Culot, G., Nassimbeni, G., Orzes, G., & Sartor, M. (2020). Behind the definition of Industry 4.0: Analysis and open questions. *International Journal of Production Economics*, *226*, 107617.

24 Dai, H. N., Zheng, Z., & Zhang, Y. (2019). Blockchain for IoT: A survey. *IEEE IoT*

25 European Commission, Directorate-General for Research and Innovation, Breque, M., De Nul, L., Petridis, A. (2021). Industry 5.0 towards a sustainable, human-centric and resilient European industry, Publications Office. httpsdata.europa.eudoi10.2777308407

26 European Court of Auditors (2020); Special Report The SME Instrument in action: an effective and innovative Programme facing challenges, p. 17.

27 Fadel, S., Necib, H., Rouaski, K., Challal, M., & Bouaicha, H. (2021). The Balanced Scorecard (BSC) as a Multidimensional Performance Measurement System Tool: Case the Company of Algeria Post.

28 Fernández-Macías, E. (2018). *Automation, digitalisation and platforms: Implications for work and employment*.

29 Fisher, N. I. (2021). *Performance measurement: Issues, approaches, and opportunities*.

30 Fleming, S. (2021, March 15). *What is digital sovereignty and why is Europe so interested in it?* World Economic Forum. Retrieved April 20, 2022, from https://www.weforum.org/agenda/2021/03/europe-digital-sovereignty/

31 Franceschini, F., Galetto, M., & Maisano, D. (2019). *Designing performance measurement systems theory and practice of key performance indicators*. Springer International Publishing.

32 Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics*, *210*, 15-26.

33 Frederico, G. F., Garza-Reyes, J. A., Kumar, A., & Kumar, V. (2020). Performance measurement for supply chains in the Industry 4.0 era: a Balanced Scorecard approach. *International Journal of Productivity and Performance Management*, *70*(4), 789-807.

34 Galankashi, M. R., & Rafiei, F. M. (2021). Financial performance measurement of supply chains: a review. *International Journal of Productivity and Performance Management*.

35 Ghobakhloo, M. (2020). Industry 4.0, digitization, and opportunities for sustainability. *Journal of cleaner production*, *252*, 119869.

36 Giacomelli, G., Annesi, N., Barsanti, S., & Battaglia, M. (2019). Combining ideal types of performance and performance regimes: An integrated framework of analysis of performance management systems for public organizations. *International Journal of Public Sector Management*.

37 Gray, D., Micheli, P., & Pavlov, A. (2015). *Measurement madness: Recognizing and avoiding the pitfalls of Performance Measurement*. Wiley.

38 Greer, C., Burns, M., Wollman, D., & Griffor, E. (2019). *Cyber-physical systems and internet of things*.

39 Gurjanov, A. V., Zakoldaev, D. A., Shukalov, A. V., & Zharinov, I. O. (2018, November). The integration of automatized systems and cyber and physical equipment of the Industry 4.0 item designing company. In *IOP Conference Series: Materials Science and Engineering* (Vol. 450, No. 3, p. 032046). IOP Publishing.

40 Haipeter, T. (2020). Digitalisation, unions and participation: The German case of 'industry 4.0'. *Industrial Relations Journal*, *51*(3), 242-260.

41 Haleem, A., & Javaid, M. (2019). Industry 5.0 and its applications in orthopaedics. *Journal of Clinical Orthopaedics & Trauma*, *10*(4), 807-808.

42 Hariri, R. H., Fredericks, E. M., & Bowers, K. M. (2019). *Uncertainty in big data analytics: survey, opportunities, and challenges*. Journal of Big Data, 6(1), 1-16.

43 Horngren, C. T., Datar, S. M., & Rajan, M. (2012). Preface. In *Cost Accounting: A Managerial Emphasis* (14th ed., p. XV). preface, Pearson Prentice Hall.

44 Iqbal, M., Kazmi, S. H. A., Manzoor, A., Soomrani, A. R., Butt, S. H., & Shaikh, K. A. (2018, March). A study of big data for business growth in SMEs: Opportunities & challenges. In *2018 International Conference on Computing, Mathematics and Engineering Technologies (iCoMET)* (pp. 1-7). IEEE.

45 Irawan, A. W., & Zaki, N. A. M. (2022). Preparation of Balanced Scorecard as Performance Measurement Instrument in PP. Kecap Maja Menjangan. *Journal of Social Transformation and Regional Development*, *4*(1), 73-83. *Journal*, *6*(5), 8076-8094.

46 Ka, J. M. R., Ab, N. R., & Lb, K. (2019). A review on supply chain performance measurement systems. *Procedia Manuf*, *30*, 40-47.

47 Kamble, S. S., & Gunasekaran, A. (2020). Big data-driven supply chain performance measurement system: a review and framework for implementation. *International Journal of Production Research*, *58*(1), 65-86.

48 Kaplan, R. S., & Norton, D. P. (1996). Linking the Balanced Scorecard to strategy. *California management review*, *39*(1), 53-79.

49 Klovienė, L., & Uosytė, I. (2019). Development of performance measurement system in the context of industry 4.0: a case study. *Inžinerinė ekonomika*, *30*(4), 472-482.

50 Knight, W. (2020, April 2). *The dark secret at the heart of ai*. MIT Technology Review. Retrieved November 24, 2021, from https://www.technologyreview.com/2017/04/11/5113/the-dark-secret-at-the-heart-of-ai/.

51 Komatina, N., Nestic, S., & Aleksic, A. (2019). Analysis of the performance measurement models according to the requirements of the procurement business process. *International Journal of Industrial Engineering and Management*.

52 Kottala, S. Y., & Herbert, K. (2019). An empirical investigation of supply chain operations reference model practices and supply chain performance: Evidence from manufacturing sector. *International Journal of Productivity and Performance Management*, *69*(9), 1925-1954.

53 Kumar, J., Prince, N., & Baker, H. K. (2022). Balanced Scorecard: A systematic literature review and future research issues. *FIIB Business Review*, *11*(2), 147-161.

54 Kunkel, S., Matthess, M., Xue, B., & Beier, G. (2022). Industry 4.0 in sustainable supply chain collaboration: Insights from an interview study with international buying firms and Chinese suppliers in the electronics industry. *Resources, conservation and recycling*, *182*, 106274.

55 Lee, E., Seo, Y. D., Oh, S. R., & Kim, Y. G. (2021). A Survey on Standards for Interoperability and Security in the IoT. *IEEE Communications Surveys & Tutorials*, *23*(2), 1020-1047.

56 Liu, C., Zheng, P., & Xu, X. (2021). Digitalisation and servitisation of machine tools in the era of Industry 4.0: a review. *International Journal of Production Research*, 1-33.

57 Longo, F., Padovano, A., & Umbrello, S. (2020). Value-oriented and ethical technology engineering in industry 5.0: A human-centric perspective for the design of the factory of the future. *Applied Sciences*, *10*(12), 4182.

58 Maddikunta, P. K. R., Pham, Q. V., Prabadevi, B., Deepa, N., Dev, K., Gadekallu, T. R., ... & Liyanage, M. (2022). Industry 5.0: A survey on enabling technologies and potential applications. *Journal of Industrial Information Integration*, *26*, 100257.

59 Maddikunta, P. K. R., Pham, Q. V., Prabadevi, B., Deepa, N., Dev, K., Gadekallu, T. R., ... & Liyanage, M. (2022). Industry 5.0: A survey on enabling technologies and potential applications. *Journal of Industrial Information Integration*, *26*, 100257.

60 Maestrini, V., Luzzini, D., Maccarrone, P., & Caniato, F. (2017). Supply chain performance measurement systems: A systematic review and research agenda. *International Journal of Production Economics*, *183*, 299-315.

61 Mahmoodi, E., Fathi, M., & Ghobakhloo, M. (2022). The impact of Industry 4.0 on bottleneck analysis in production and manufacturing: Current trends and future perspectives. *Computers & industrial engineering*, *174*, 108801.

62 Mania, B. (2022). Big Data and Artificial Intelligence: An examination of the existing legal framework from a privacy perspective.

63 Martini, L. K. B., & Suardana, I. B. R. (2019). Company performance measurement applying Balanced Scorecard approach. *International Journal of Social Sciences and Humanities*, 3(1).

64 Masood, T., & Sonntag, P. (2020). Industry 4.0: Adoption challenges and benefits for SMEs. *Computers in Industry*, *121*, 103261.

65 Meindl, B., Ayala, N. F., Mendonça, J., & Frank, A. G. (2021). The four smarts of Industry 4.0: Evolution of ten years of research and future perspectives. *Technological Forecasting and Social Change*, *168*, 120784.

66 Mohamed, M. (2018). Challenges and benefits of industry 4.0: An overview. *International Journal of Supply and Operations Management*, *5*(3), 256-265.

67 Ojra, A. (2018, July). Revisiting Industry 4.0: A new definition. In *Science and Information Conference* (pp. 1156-1162). Springer, Cham.

68 Olsen, T. L., & Tomlin, B. (2020). Industry 4.0: Opportunities and challenges for operations management. *Manufacturing & Service Operations Management*, *22*(1), 113-122.

69 Ozdemir, Y. S. (2022). A Spherical Fuzzy Multi-Criteria Decision-Making Model for Industry 4.0 Performance Measurement. *Axioms*, *11*(7), 325.

70 Özdemir, V., & Hekim, N. (2018). Birth of industry 5.0: Making sense of big data with artificial intelligence,"the internet of things" and next-generation technology policy. *Omics: a journal of integrative biology*, *22*(1), 65-76.

71 Patil, A. R., Thakur, K., Gandhi, K., Savale, V., & Sayyed, N. (2022). A Review on Industry 5.0: The Techno-Social Revolution.

72 Pereira, A. G., Lima, T. M., & Santos, F. C. (2020). Industry 4.0 and Society 5.0: opportunities and threats. *International Journal of Recent Technology and Engineering*, *8*(5), 3305-3308.

73 Peres, R. S., Jia, X., Lee, J., Sun, K., Colombo, A. W., & Barata, J. (2020). Industrial artificial intelligence in industry 4.0-systematic review, challenges and outlook. *IEEE Access*, *8*, 220121-220139.

74 Philbeck, T., Davis, N., & Larsen, A. M. E. (2018, August). Values, ethics and innovation: Rethinking technological development in the fourth industrial revolution. World Economic Forum.

75 Phillips, P. P., & Phillips, J. J. (2019). *ROI basics*. American Society for Training and Development.

76 Pilloni, V. (2018). How data will transform industrial processes: Crowdsensing, crowdsourcing and big data as pillars of industry 4.0. *Future Internet*, *10*(3), 24.

77 Prasetyaningsih, E., Muhamad, C. R., & Amolina, S. (2020, April). Assessing of supply chain performance by adopting Supply Chain Operation Reference (SCOR) model. In *IOP Conference Series: Materials Science and Engineering* (Vol. 830, No. 3, p. 032083). IOP Publishing.

78 Protega, I. (2021). The Role of Project Management for Digitalisation in Retail Industry in the Countries of the Western Balkans. *ZA ČLOVEKA GRE: DIGITALNA TRANSFORMACIJA.*

79 Queiroz, M. M., Pereira, S. C. F., Telles, R., & Machado, M. C. (2019). Industry 4.0 and digital supply chain capabilities: A framework for understanding digitalisation challenges and opportunities. *Benchmarking: an international journal*.

80 Rahim, A. G., Ofuani, A. B., & Olonode, O. P. (2018). Trends in business performance measurement: A literature analysis.

81 Rupp, M., Schneckenburger, M., Merkel, M., Börret, R., & Harrison, D. K. (2021). Industry 4.0: A technological-oriented definition based on bibliometric analysis and literature review. *Journal of Open Innovation: Technology, Market, and Complexity*, *7*(1), 68.

82 Sadeeq, M. M., Abdulkareem, N. M., Zeebaree, S. R., Ahmed, D. M., Sami, A. S., & Zebari, R. R. (2021). IoT and Cloud computing issues, challenges and opportunities: A review. *Qubahan Academic Journal*, *1*(2), 1-7.

83 Saniuk, S., Grabowska, S., & Straka, M. (2022). Identification of Social and Economic Expectations: Contextual Reasons for the Transformation Process of Industry 4.0 into the Industry 5.0 Concept. Sustainability, 14(3), 1391.

84 Shahbaz, M. S., Rasi, R. Z. R. M., Zulfakar, M. H., Ahmad, M. B., Abbas, Z., & Mubarak, M. F. (2018). A novel metric of measuring performance for supply chain risk management: drawbacks and qualities of good performance. *Journal of Fundamental and Applied Sciences*, *10*(3S), 967-988.

85 Simniškytė, B. (2020). *Model of the application of digitalisation in the performance measurement in public healthcare organizations* (Doctoral dissertation, Kauno technologijos universitetas).

86 Szalavetz, A. (2022). The digitalisation of manufacturing and blurring industry boundaries. *CIRP Journal of Manufacturing Science and Technology*, *37*, 332-343.

87 Sørensen, B. T. (2018). Digitalisation: an Opportunity or a Risk?. *Journal of European Competition Law & Practice*, *9*(6), 349-350.

88 Tambare, P., Meshram, C., Lee, C. C., Ramteke, R. J., & Imoize, A. L. (2021). Performance measurement system and quality management in data-driven Industry 4.0: A review. *Sensors*, *22*(1), 224.

89 Tawse, A., & Tabesh, P. (2022). Thirty years with the Balanced Scorecard: What we have learned. *Business Horizons*.

90 Tay, S. I., Lee, T. C., Hamid, N. Z. A., & Ahmad, A. N. A. (2018). An overview of industry 4.0: Definition, components, and government initiatives. *Journal of Advanced Research in Dynamical and Control Systems*, *10*(14), 1379-1387.

91 Thomas, R., & Gup, B. E. (2010). *The valuation handbook: Valuation techniques from today's top practitioners*. John Wiley.

92 Tonelli, F., Demartini, M., Pacella, M., & Lala, R. (2021). Cyber-physical systems (CPS) in supply chain management: from foundations to practical implementation. *Procedia CIRP*, *99*, 598-603.
93 Trentesaux, D., & Caillaud, E. (2020). Ethical stakes of Industry 4.0. *IFAC-PapersOnLine*, *53*(2), 17002-17007.
94 Vaidya, S., Ambad, P., & Bhosle, S. (2018). Industry 4.0–a glimpse. *Procedia manufacturing*, *20*, 233-238.

95 Gružauskas, V., Štimac, H., & Vašek, J. (2023). *International Logistics*. University of Chemistry and Technology Prague. Retrieved January 12, 2023, from https://vscht.future-books.cz/book/international-logistic/?/title-page/.
96 Vallor, S., & Rewak, W. J. (2018). *An Introduction to Data Ethics*. Santa Clara University. Retrieved November 22, 2021, from https://www.scu.edu/media/ethics-center/technology-ethics/IntroToDataEthics.pdf.

97 Wang, Y., & Sarkis, J. (2021). Emerging digitalisation technologies in freight transport and logistics: current trends and future directions. *Transportation Research Part E: Logistics and Transportation Review*, *148*, 102291.

98 Xie, Y., Yin, Y., Xue, W., Shi, H., & Chong, D. (2020). Intelligent supply chain performance measurement in Industry 4.0. *Systems Research and Behavioral Science*, *37*(4), 711-718.

99 Zaidin, N. H. M., Diah, M. N. M., Yee, P. H., & Sorooshian, S. (2018). Quality management in industry 4.0 era. *Journal of Management and Science*, *8*(2), 82-91.

100 Zeranski, S., & Sancak, I. E. (2020). Digitalisation of Financial Supervision with Supervisory Technology (SupTech). *Journal of International Banking Law & Regulation*.
101 Τσαγδής, A. (2022). Hardware-based Security Methods for Internet of Things (IoT), Internet of Everything (IoE) & Cyber-Physical Systems (CPS).

Appendices

Appendix 1. ROI calculation formula

$$ROI = I/C$$

ROI- Return on Interest;

I- income (could be operating or net income);

C- costs (could be total assets or total assets minus current liabilities).

Appendix 2. RI calculation formula

$$RI = NE - (ROR_r \times Inv)$$

RI- Residual Income;

NE- normal earnings (income or profit);

Inv- investments made.

Appendix 3. EVA calculation formula

$$EVA = NOPAT - (C \times WACC)$$

EVA- Economic Value Added;

NOPAT- net operating profit after tax;

WACC- weighted average capital costs;

C- the company's capital.

Appendix 4. ROS calculation formula

$$ROS = OI/Rev$$

ROS- Return on Sales;

OI- operating income;

Rev- revenues.

Appendix 5. Notes on the interview of company A

Sample company A	What of the digitalisation-related technologies are being used in your company (for example, artificial intelligence, machine to machine communication, etc)?	*Automatic Sorting Machine* - the company's main raw material is polyester scrap which includes various used bottles and packages. The scrap is purchased from municipally, however, it often includes not only polyester but also HDPE or PPE plastic scrap. The latter is not suitable for the manufacturing process, therefore the company needs to undertake a sorting procedure before transferring the raw materials to further processes. At first, the company was using manual labour where 4-5 employees were manning the conveyor and sorting the raw materials. However, this method was prone to human error, thus many non-polyester plastics used to be transferred to the further manufacturing processes. This has led to a faulty manufacturing process where a mixture of plastic is used instead of pure polyester, in result producing an abundance of low-quality plastic straps which lack durability. Therefore, in order to mitigate this issue, the company has installed new automated sorting machinery which would sort the raw materials with the help of the laser, thus eliminating the human error factor in the process. The company admits that this technology has significantly contributed to the performance almost completely eliminating the probability of non- polyester plastic reaching the manufacturing process. As a result, most of the final products are now high quality and suitable for sale. *Silo Control System* - After the sorting procedure, the company undertakes to process the raw materials in crusher and heating silos. In the past, the company used to fill the silo manually- employees would collect the raw materials into bags and carry them to the silo on foot. One needed to monitor the silo's capacity and constantly fill it. In case the quantity of the processed raw material would fall down, the processing machinery would automatically stop causing losses. Furthermore, as the plastic straps were produced in different thicknesses and colours, each time the straps needed to be produced with different parameters, one would have needed to stop the silo, clean it and reload with raw materials. The latter used to be time-consuming and would interrupt the manufacturing process. Therefore, the company decided to install the silo control system. Now the raw materials are transferred to the silo automatically through the pipe and the system automatically controls the quantities. Furthermore, it allows mass customisation without additional unit costs. The system provides a possibility to produce polyester straps with different parameters without cleaning and reloading the silo.
	How do they perform compared to the expectations?	According to the company's representative, before purchasing the aforementioned digitalisation-related technology, the main performance-related expectations were: increased output productivity, lower level of manual labour alongside reduced need for human resources, lower variable and fixed costs and lowered total idle time. The technology's payback period has been also determined to be low. After the implementation of the technology, the expectations were partly met. The representative admits that the new technology has significantly increased the output productivity and helped to automatise the processes and now instead of 40 employees, only 30 are needed to undertake the processes. Furthermore, the customisation has increased without additional unit costs, and the

		cases of faulty final products have reduced almost to zero. However, the new technology has also put a severe burden on maintenance and repair processes which were unforeseen when purchasing the technology. First of all, spare parts are non- existent in the local market and scarce generally, thus making them expensive. Secondly, the equipment is prone to constant failures due to errors in the system. The equipment failures tend to cause idle times for 4-5 hours. The aforementioned would usually be caused by several reasons. The first reason would be faulty configuration. Due to the desert environment which is present where the company is located, most of the raw materials are contaminated with sand and it is very difficult to fully clean it from the raw materials. As a result, the control system of the silo, once filled, recognises that a certain amount of the silo is filled with unsuitable raw materials and undertakes a forced stop. This stops the processing procedure until the silo is cleaned from the unwanted materials, refilled and restarted. According to the representative, the rejected raw materials would then be discarded and often sold to competitors who produce the same product, but with different, less sophisticated equipment. It was mentioned that the discarded raw materials are accepted by their machinery and are successfully processed. The representative also added that there is an absence of companies using similar equipment in the market. As a result, there is a lack of skilled specialists who are able to configure, repair and maintain such equipment. Therefore, in cases of more serious equipment failures, the company is required to hire a specialist from abroad. This tends to be very costly and time-consuming. It was also mentioned that the straight line depreciation is applied for the equipment
	What performance measurement practices are undertaken (for example, balanced scorecard, activity-based costing system, etc)?	The company undertakes mostly financial (traditional) measures derived from such company's financial statements as income statement and balance sheet.
	What is your position in the company? What is your experience in the company?	The company's representative has worked in the company as an accountant for five years.

Appendix 6. Notes on the interview of company B

Sample company B	What of the digitalisation-related technologies are being used in your company (for example, artificial intelligence, machine to machine communication, etc)?	*Customer Relationship Management* – the company is currently implementing the customer relationship management system. The system has been installed with the intention to digitise, sort and merge customer-related data in order to enhance its accessibility and availability throughout the company. According to the company's representative, the implementation of this technology is expected to tackle the issue where the customer-related data is being recorded by the managers on paper or non-interconnected digital documents and tends to be lost, not available when it is needed or, in such cases as not transferred to the other employees properly. Furthermore, the system is expected to automatise such processes as follow-ups and various reminders which would previously be scheduled and

		executed by sales managers themselves. *Digital Technical Sheet* – currently the company undertakes to digitise the technical sheets used before and during the manufacturing procedure. The technical sheets are necessary as the company undertakes custom production and each customer's order is unique. Therefore, the technical sheets are needed as they include all of the technical data about the customer's required product. The first version of the technical sheet is developed by the sales manager according to the customer's needs. Later on, the technical sheet is transferred through various technicians who analyse it and edit it in order for it to be compatible with the production process. Once edits are done, the sheet is transferred to the production team leader who, according to the sheet, assigns the tasks to production workers. The digitised technical sheets are expected to, first of all, facilitate the customisation process as it would allow the sales managers easily look up previously created technical sheets and use them, thus eliminating the need to develop them repeatedly in case the clients provide the same or similar orders. This would also mitigate the need to edit these technical sheets as they would contain the data already made compatible for production.
	How do they perform compared to the expectations?	*Customer Relationship Management* – the technology at the moment does not perform as the company had expected. At the moment, the system is not fully operational and is still undergoing the installation phase. The system is interoperable with the accounting software currently used in the sample company as both are created by a single supplier. The aforementioned ensures a lot of customer-related data is easily interchanged between both systems in a consistent manner, thus also mitigating the installation process. Nevertheless, the company is currently experiencing difficulties while implementing the system. First of all, the system has technical flaws such as if a manager sends an email through the system, the client will receive it. However, if the client undertakes to reply to the message sent, the reply fails to reach the manager. Furthermore, the system is difficult to operate. According to the representative, as the system is newly developed and there are no demo versions or comprehensive manuals provided by the developer, the company undertook to assign one employee to test, describe the system and provide training for other employees. This activity takes 30% of employees' work time. He communicates with the system developer and tries to utilise all of the possible functions of the system, further providing guidelines and consultations for other employees on the usage of the system. The representative of the company admits that although the system developer has provided the training, they were not enough to utilise the system to its full potential. The representative also adds that companies, when implementing such technologies, tend to utilise such systems not fully and only use the primary basic functions, therefore, the sample company expects that assigning one person to fully analyse the system will in the future help the company to utilise all of the functions provided by the system. Digital technical sheets- this technology allows the company to manage technical sheets more efficiently. The technical sheets contain all the required data about the client's order. The main issue

		with the technical sheets is that it is moderated by six employees with different responsibilities and skills. At first, the technical sheet is created by the sales manager who takes the order from the client and further provides the client's needs on the technical sheet. Then technical sheet is transferred to designer, chemist, paint specialist, production manager and team leader subsequently. Each specialist provides their own adjustments to the technical sheet in order for it to be suitable for production. At the end of the chain, the technical sheet is provided to the employees who undertake to produce the product. In case the technical sheet turns out to have a mistake at some point in the chain, it is brought back to the specialist before for adjustments. Furthermore, the technical sheets tend to pile up, thus making it difficult to find specific sheets in the archive if necessary. As a result, if the same client makes an identical order after some time, the new technical sheet is created from scratch. All of this creates difficulties and aggravates the process of preparation for production. Currently undertaken digitalisation of technical sheets seeks to mitigate the aforementioned process by increasing visibility and transparency. The technology provides the ability for employees to see the status and data of each technical sheet and allows easier adjustments of data. Furthermore, it allows one to look up the order history of each client and if there are the same or similar orders, easily use the already created technical sheets. It is stated that both technologies are compatible with each other as they are established on the same basis and provided by the same supplier. According to the representative, one of the challenges when implementing digitalisation-related technologies is the dilemma of how to approach the implementation of these technologies. As the company is constantly developing and advancing, there is a question of whether to attempt implementation of the technologies which would suit the company's current needs or to undertake higher investments and implement the technology whose capabilities would not be fully utilised at the moment, but rather in future. By undertaking the first alternative, the company would have technologies which could be fully utilised from the beginning and have a lower payback period but would bring boundaries in the context of the company's expansion and development as the company's needs would change. These boundaries would mostly be conditioned by the noninteroperable nature of different digitalisation-related technologies. On the other hand, the second alternative would provide the company with a more expansive and complex system and mitigate the aforementioned boundaries. However, it would also condition a higher payback period and provide a risk that the system in the future may not be aligned with the company's environment as expected, thus making its full utilisation improbable. With such consideration, the company has chosen to undertake the first alternative, but also considering that the newly implemented technologies would be as much interoperable as possible so that in the future the process of shifting from one system to another would be as easy as possible.

	What performance measurement practices are undertaken (for example, balanced scorecard, activity-based costing system, etc)?	Regarding digitalisation-related technologies, before each purchase and implementation process, the company undertakes a financial analysis on how the technology will financially affect the company. The very first measurement is a payback period taking into consideration not only the price of the technology but also such aspects as the possible maintenance-related costs, change of production time of one product and level of automatisation. Furthermore, the company undertakes to determine which processes the technology would undertake in the company and ensure that there is a need for such technology in the first place. Such a point of view ensures that the newly implemented technology's capabilities would be utilised as much and as soon as possible. Otherwise, the investment would prolong the payback period and increase capital costs.
	What is your position in the company? What is your experience in the company?	The respondent has worked in the company for five years and is a head of the administration

Appendix 7. Notes on the interview of company C

Sample company C	What of the digitalisation-related technologies are being used in your company (for example, artificial intelligence, machine to machine communication, etc)?	The company undertakes several digitalisation-related technologies which are used in the manufacturing processes. These technologies include the control systems controlling initiation and termination of the processes, detecting equipment failures, controlling the processing environment and autonomously undertaking production processes such as mixing and packaging. The company employs thermal printer in order to produce labels which are intermediate goods and are later used for the production of the final product. Furthermore, the company undertakes digitalisation-related technologies based in other entities which, nevertheless, does affect the company‘s performance significantly. One of such technology is a 3D printer used to produce custom spare parts for the company. Although the company does not own this technology itself, it undertakes to employ it by renting. The company prepares a technical drawing of the required part and provides it to the owner of the printer who then proceeds to produce the spare part. The other technology-based outside the sample company is a mutual procurement system between the sample company and its clients. At the moment about 12 of the company‘s clients undertakes such procurement system to a certain level. The system, on the client‘s side, undertakes monitoring of the sales and current stock of goods, forecasts future sales, and in accordance with the aforementioned data, provides the sample company with an order.
	How do they perform compared to the expectations?	Most of this equipment performs in the whole automated production line. First of all, the equipment has proven to increase output productivity as it autonomously performs production tasks much more efficiently than manual labour does. In general, the company is able to produce 6 times more production and some processes are 12 times faster. The tasks are also performed in a consistent and thrifty manner, thus using as many resources as necessary and as

		little as possible. The company’s representative admits that automation has helped to save a lot of raw materials. Furthermore, the higher accuracy has also contributed to the higher product quality. Alongside benefits, it is also stated that repair and maintenance of the equipment have become aggravated as it is complex and requires special skills to be undertaken. As a result, equipment failures are more common and their troubleshooting takes a much longer time. Nevertheless, the idle times tend to be short and do not inflict high costs or productivity losses. The latter is enabled by the company’s constant investment towards its human capital and aims to undertake as much as possible of repair and maintenance procedures independently. The representative admits that it is a demanding approach, but also necessary to save costs and ensure consistency of production. It is stated that if the company would rely on third parties or equipment suppliers, the repair and maintenance procedures would be much more expensive due to high markups in the market. It is also stated that in cases of equipment failure, the mean time to repair would increase due to external factors such as the supplier’s schedule. Some of the company’s equipment is also considered to enhance the company’s flexibility. The company's use of thermal printers has led to an increased level of flexibility and resilience. In particular, the company can now swiftly prepare raw materials for less demanded products and is less reliant on external factors such as supplier schedules, capabilities, and delivery issues. The implementation of this technology has also proven to be cost-effective, as producing customised or less popular product labels with a thermal printer incurs fewer costs than purchasing them from suppliers, whose minimum order quantities are typically higher than the quantities of the custom products needed to be labelled. Despite the potential cost advantages of economies of scale through purchasing large quantities of labels in advance, this strategy is not viable for the company due to its inability to predict demand for custom and less popular products, as well as the need to frequently update the information provided on the labels in response to changing regulations. The company also undertakes additive manufacturing where it produces spare parts for its equipment with the help of 3D printing technology in case it is possible. The utilisation of additive manufacturing has enabled the company to obtain spare parts in a matter of days, compared to the previous timeframe which could stretch to several weeks or even months. The company is also less reliant on external factors such as the unavailability of spare parts due to the supplier's decision not to produce them or logistical issues which might prevent the delivery of the required parts. The production of spare parts using additive manufacturing has also proven to be a cost-effective solution. The spare parts available through machinery suppliers or third parties are often expensive in the market. Additionally, a lot of costs related to the delivery of the spare parts are also avoided. However, the approach requires sufficient human capital as the sample company itself has to prepare accurate technical drawings of the required spare parts. The procurement technologies employed by the clients provide a mixed influence on the sample company’s performance. It is stated that the technology significantly lowers the human factor, thus mitigating the communication between the companies. This lowers the need for managers to communicate with the clients, constantly visit them and check whether they need something to order. Other human-related factors are also eliminated such as manipulations from the client’s employees and human errors. Furthermore, the

		orders are now made in a consistent manner and the sample company is provided with relevant data such as current stock or sales forecasts from the client's side, thus allowing the sample company to more easily plan its processes. However, not all of these systems perform as intended, thus creating inconsistencies between the data provided by the system and the actual quantities of stock and future sales. These inconsistencies tend to be conditioned by faulty management, human errors, lack of configuration and the system's inability to consider necessary factors which may effect the results of the forecasts. Faulty management and human errors tend to create inconsistencies in such cases: when the employee inputs wrong information about the arrived or sold goods, when there is an unnoticed theft, when the goods are not put on the shelves or in any other cases where goods are not suitable for sale even though the system recognises the contrary, thus providing faulty forecasts. These inconsistencies require the sample company to undertake communication with the clients more actively in order to avoid these inconsistencies.
	What performance measurement practices are undertaken (for example, balanced scorecard, activity-based costing system, etc)?	The company mostly undertakes financial measures in order to measure its performance. The most common measures is profitability.
	What is your position in the company? What is your experience in the company?	The respondent has worked in the company for 30 years and is its CEO as well as a founder

Appendix 8. Notes on the interview of company D

Sample company D	What of the digitalisation-related technologies are being used in your company (for example, artificial intelligence, machine to machine communication, etc)?	The company undertakes automation in raw material processing procedures. It uses automated equipment which calculates and cuts the raw materials (wooden planks) according to the set parameters. The wooden planks are put into equipment manually and with the help of laser sensors are measured and cut according to the set parameters in the software. The cut planks are intermediary goods and are later used for the construction of wooden houses and cabins. The company has also implemented technology to merge accounting with manufacturing processes. The technology allows the company to record production-related data such as the quantities of produced finally.
	How do they perform compared to the expectations?	The automation in the processing tasks resulted in higher accuracy, lower quantities of faulty products and higher quality, as the human error factor has been mitigated. Before the implementation, the procedures of measuring, calculating and cutting would be prone to human error where an employee would often perform these processes inaccurately leaving a lot of leftover raw materials. The company has installed 3 pieces of such automated equipment each of them substituting up to 5 employees. However, there is resistance to change among the employees. Those who are left to work with equipment are not keen to learn how to use the new technologies. According to the representative, the employees are afraid of using digital technologies as they fear breaking or in other ways spoiling

		them. As a result, employees tend to undertake certain procedures manually instead of using the new equipment. This has had a negative impact on the accuracy and aggravated human resource management. Nevertheless, the representative admits that the employees, although slowly, are getting used to the new equipment and it is expected that the resistance to the change worns out eventually. It is also stated that the employees who were able to learn how to use the equipment, no longer have fears of using it. According to the representative equipment works fine and the company haven‘t experienced any kind of equipment failures which would cause a material idle time. However, the technology is repaired and maintained not by the company itself, but by its supplier who tends to react to any kind of equipment failure promptly. With regard to the merger of accounting systems and production, it has helped to avoid manual labour and has enhanced the level of automation. It took a year for the company to implement the technology
	What performance measurement practices are undertaken (for example, balanced scorecard, activity-based costing system, etc)?	The company mostly undertakes financial measures in order to measure its performance. Such non-financial measures as notability and employee turnover rate.
	What is your position in the company? What is your experience in the company?	The respondent has worked in the company for 24 years and is its CEO as well as one of the founders