Kaunas University of Technology
School of Economics and Business

Matching Lean and Digital Manufacturing for Business Performance

Master's Final Degree Project

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Summary

Relevance of the theme. With the constant changes in modern industry, companies in the manufacturing field must always keep close attention to their performance. There is an increasing emphasis on the benefits of monitoring business performance for the goal of increasing company success. In this competitive environment for manufacturing companies, it is important to keep business running as smoothly as possible. Lean production and digital manufacturing in the wave of the fourth industrial revolution allow manufacturing companies to improve their processes and work methods.

The object of this paper is to match lean production and digital manufacturing for the improvement of business performance indicators. The aim of the paper is to determine the effects of lean and digital manufacturing and their matching on the business performance of manufacturing companies. To achieve this goal, the following tasks have been set: review the effects of lean and digital manufacturing on business performance; ground the effects of lean production, digital manufacturing and their matching on business performance; ground methodology in order to evaluate the effects of lean production, digital manufacturing and their matching on business performance; reveal the results of the evaluation of the effects of lean production, digital manufacturing and their matching on business performance. Research methods used: scientific literature review, quantitative research, and statistical data analysis.

In this paper the current situation of lean production and digital manufacturing effect on business performance is evaluated as well as their matching effect on business performance, highlighting the problems – currently, there are few pieces of research regarding lean production or digital manufacturing effect on business performance and the field is not fully analyzed, as well as the effect of matching both lean production and digital manufacturing for business performance is unclear if it has a positive impact.

An analysis of the scientific literature has revealed that both lean production and digital manufacturing are affecting business performance measurements. It highlights the importance for manufacturing companies to keep an overview of chosen specific performance indicators, such as sales growth, quality, and market share. Literature analysis confirmed the possibility of matching lean production and digital manufacturing for better business performance results. Manufacturing companies use both lean production and digital manufacturing technologies to avoid waste, evaluate their performances and introduce improved work methods. Reviewing the scientific analysis, a framework has been created that illustrates the hypothesis of lean production effect on business performance, digital manufacturing effect on business performance and their interrelation as well as matching of two methodologies to affect business performance.

After review of current findings regarding digital manufacturing and lean production's effect on business performance and analyzing the scientific literature, the survey data from the European Union’s Horizon 2020 research and innovation programme, project title “Industry 4.0 impact on management practices and economics (IN4ACT)” has been analyzed. The aim of the survey was to overview the current situation overview in Lithuanian manufacturing companies, their characteristics, currently implemented practices of lean production and digital manufacturing as well as business performance changes. The results of the research revealed that business performance is both affected positively by digital manufacturing and lean production and there is a positive relation between them. However, it was concluded that matching lean production and digital technologies does not have an effect on the business performance of the company.

Based on the analysis of the company's situation, scientific literature, and research results, reccomendations were made: to evaluate the possibility of implementing lean production or digital technology tools as they have a significant and positive effect on business performance and there is no need to implement both lean production and digital manufacturing practices on the same level as it does not have a significant effect on business performance.

Marcinkevičiūtė, Neringa. „Lean“ ir skaitmeninės gamybos derinimo poveikis verslo pasiekimams. Magistro baigiamasis projektas / vadovas Prof. dr. Mantas Vilkas; Kauno technologijos universitetas, Ekonomikos ir verslo fakultetas.

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Reikšminiai žodžiai: Lean, skaitmeninė gamyba, verslo našumas, derinimas.

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Santrauka

Temos aktualumas. Vykstant nuolatiniams pokyčiams šiuolaikinėje pramonėje, gamybos srityje veikiančios įmonės visada turi atidžiai stebėti savo rezultatus. Vis dažniau pabrėžiama verslo veiklos našumo stebėsenos nauda siekiant didinti įmonės sėkmę. Šioje konkurencinėje aplinkoje gamybos įmonėms svarbu, kad verslas vystytųsi kuo sklandžiau. “Lean” ir skaitmeninė gamyba ketvirtosios pramonės revoliucijos bangoje sudaro sąlygas gamybos įmonėms tobulinti procesus ir darbo metodus.

Šio darbo objekto tikslas yra suderinti “Lean” ir skaimeninę gamybą siekiant pagerinti verslo našumą. Šiam tikslui pasiekti iškelti uždaviniai: apžvelgti “Lean” ir skaitmeninės gamybos poveikį verslo našumui; pagrįsti “Lean”, skaitmeninės gamybos ir jų suderinamumo poveikį verslo našumui; pagrįsti metodiką, siekiant įvertinti “Lean”, skaitmeninės gamybos ir jų derinimo poveikį verslo našumui; atskleisti poveikio vertinimo rezultatus “Lean”, skaitmeninėje gamyboje ir jų atitikimą verslo našumui. Taikyti tyrimo metodai: mokslinės literatūros apžvalga, kiekybinis tyrimas, statistinė duomenų analizė.

Šiame darbe vertinama dabartinė padėtis, susijusi su “Lean” ir skaitmeninės gamybos poveikiu verslo našumui, taip pat jų suderinimo poveikis verslo našumo rezultatams, išryškinant šias problemas – šiuo metu yra atlikta nedidelis kiekis tyrimų, susijusių su “Lean” gamybos ar skaitmeninės gamybos poveikiu verslo našumu, ši sritis nėra išsamiai išanalizuota, taip pat neaišku, ar “Lean” gamybos ir skaitmeninės gamybos suderinimas turi teigiamą poveikį verslo našumo rezultatams.

Mokslinės literatūros analizė atskleidė, kad tiek “Lean”, tiek skaitmeninė gamyba daro įtaka verslo veiklos rezultatų matavimams. Atskleidžiama, kad gamybos įmonėms svarbu stebėti pasirinktus konkrečius veiklos rodiklius, pavyzdžiui, pardavimų augimą, kokybę ir užimamą rinkos dalį. Literatūros analizė patvirtino galimybę suderinti “Lean” ir skaitmeninę gamybą siekiant geresnių verslo veiklos rezultatų. Gamybos įmonės naudoja ir “Lean” įrankius ir skaitmeninės gamybos technologijas. Pasitelkdamos šias priemones siekia, kad išvengtų išteklių švaistymo, įvertintų savo rezultatus ir įdiegtų patobulintus darbo metodus. Atlikus mokslinę analizę, sukurtas modelis, kuris iliustruoja hipotezes teigiančias apie “Lean” poveikį verslo našumo rezultatams, skaitmeninės gamybos poveikį verslo našumui ir jų tarpusavio ryšį, taip pat dviejų metodikų suderinimą siekiant paveikti verslo rezultatus.

Apžvelgus dabartinę situaciją apie skaitmeninės gamybos ir “Lean” poveikį verslo rezultatams ir išanalizavus susijusią mokslinės literatūrą, remiantis European Union’s Horizon 2020 inovacijų projekto pavadinimu “Industry 4.0 impact on management practices and economics (IN4ACT)” buvo analizuojami tyrimo duomenys. Apklausos tikslas – dabartinės situacijos Lietuvos gamybos įmonėse apžvalga, įmonių charakteristikų atskleidimas bei surinkti duomenis apie šiuo metu diegiamų “Lean” ir skaitmeninės gamybos praktikų bei verslo našumo pokyčius. Tyrimo rezultatai atskleidė, kad tiek

skaitmeninė gamyba, tiek “Lean” daro teigiamą įtaką verslo našumui ir tarp jų egzistuoja teigiamas reikšmingas ryšys. Tačiau taip pat padaryta išvada, kad “Lean” ir skaitmeninių technologijų suderinimas neturi įtakos verslo našumui.

Remiantis įmonės situacijos analize, moksline literatūra ir tyrimų rezultatais, buvo pateikti pasiūlymai: įvertinti galimybę diegti “Lean” ar skaitmeninės gamybos įrankius, kadangi jie turi reikšmingą ir teigiamą poveikį verslo našumui. Taip pat, nėra poreikio tame pačiame lygmenyje diegti tiek “Lean” tiek skaitmeninės gamybos metodus, kadangi tai neturės reikšmingos įtakos verslo našumui.

Table of contents

List of figures

List of tables

Introduction

Relevance of the topic. Digital manufacturing and Lean production can be seen as two separate topics which are rarely considered together. Although lean was introduced decades ago it is still very important for companies to this day. Lean main principles are focusing on eliminating waste in business processes, value definition and creation for the customer, improvement of processes and resources. Lean methodology has many different tools which can be used in companies and are especially popular in manufacturing companies. They are such tools as: 5S, Kaizen, Kanban and many more developed tools. It helps companies to become more efficient and productive while focusing on the areas where there is demand, improving their use of resources. Similar benefits can come from digital technologies as well. Companies are installing different systems such as: ERP, warehouse control systems, automation solutions and similar digital technology solutions. Digitalization increases efficiency of company systems, helps to track their processes, resources and manage data easily. Companies are seeking to strengthen their position and manage the risks they are facing. Method transformations from both of these methodologies increase their chances to success. However, there are discussions whether could lean methods and digital technologies help one another or do they replace each other. The first statement if proved, can help companies grow even more quickly. It could reduce their costs, improve their productivity. The second statement if proved would be helpful too. This would show that instead of trying to combine two methods and areas it is more valuable to focus on one of them. This would help companies to indicate if they should focus of implementation for both of the methodologies or one of them and this way impacting their business performance as both of them can be seen as having an impact on it. The secondary publicly unavailable empirical data was used for this master thesis.

Problem question – how lean and digital manufacturing contribute to business performance? Whether the matching of lean and digital manufacturing innovations contribute to increased business performance?

Aim – to determine the effects of lean, digital manufacturing and their matching on the business performance of manufacturing companies**.**

Tasks:

1. Review the effects of lean and digital manufacturing on business performance.

2. Ground the effects of lean production, digital manufacturing and their matching on business performance.

3. Ground methodology in order to evaluate the effects of lean production, digital manufacturing and their matching on business performance.

4. Reveal the results of evaluation of the effects of lean production, digital manufacturing and their matching on business performance.

Research methods: scientific literature review, secondary quantitative data analysis, statistical data analysis.

Scientific literature analysis method has been used in order to ground the effects of lean production, digital manufacturing and their matching on business performance. By using this method it was also aimed at analyzing the used tools and technologies, what affects both lean production and digital manufacturing as well as how business performance can be divided. Based on scientific literature the performance indicators have been described, which can be affected by lean production or digital manufacturing and the possible impact of lean production and digital manufacturing matching for business performance.

The empirical part is based on the quantitative secondary data analysis. The secondary publicly unavailable empirical data was used for this master thesis. The empirical data was collected as part of the European Union's Horizon 2020 research and innovation programme, project title "Industry 4.0 impact on management practices and economics (IN4ACT)", (No 810318). The sample (N=250) contains data collected in Lithuania (Vilkas et al., 2023) as part of European manufacturing survey in 2023. Using this empirical data the relationship between lean production and digital technologies has been analyzed, the effect of both practices on business performance as well as the effect of matching lean production and digital manufacturing on business performance.

The theoretical relevance of this paper:

- Systematized lean production effect on business performance, which of the performance indicators are affected mostly.
- Systematized digital manufacturing tools and their effect on business performance, which of the performance indicators are mainly associated with implementation of it.
- Lean production and digital manufacturing matching framework creation. Description of how lean production and digital manufacturing can affect separate performance indicators as well as possible environment and practice choice influence on the effect.
- Identified the relationships between lean production and digital technologies as well as their separate relationships related to business performance.

The practical relevance of this paper:

- Identified most commonly used lean production practices in Lithuanian manufacturing companies and overall lean production effect on business performance. Implementation of lean production tools is popular among Lithuanian manufacturing companies and they have a significant and positive relationship regarding business performance (sales growth, market share and quality.
- Identified most commonly used digital manufacturing technologies in Lithuanian manufacturing companies and overall digital manufacturing effect on business performance. Implementation of digital manufacturing technologies is less popular among Lithuanian manufacturing companies. Nevertheless, it has been found that there is a significant and positive relationship regarding business performance indicators (sales growth, market share and quality.

This paper structure has been decided according to the raised task sequence in order to reach set goal. Paper contains four main parts:

- First part of the paper has answered the first task. In this part the scientific literature has been analyzed and it was found that both lean production and digital manufacturing can be seen as positive effect for business performance, however the research is very limited and due to business performance being a very broad topic it can differ.
- Second part has been done based on the second task of the paper. Lean production and digital manufacturing tools, origin and their determinants have been thoroughly analyzed. Next, the effect on performance of both methodologies has been analyzed and business performance has been defined.
- Third part answered the third task of the paper. The empirical data has been chosen as well as the questions. The reliability of the selected questions has been reviewed.
- Fourth part responds to the last task of the paper. In this part the characteristics have been described of Lithuanian manufacturing companies as well most and least used tools of lean production and digital manufacturing. Last of all, the hypothesis have been tested in order to find if lean production and digital manufacturing matching has effect on business performance and if they have that effect separately.

1. Lean production and digital manufacturing matching for business performance problem analysis

1.1. Effects of lean production on business performance

In current years there is pressure for manufacturing companies to constantly improve and change due to increasing competitive nature, globalization and evolving digital technologies. (Lai, Wong, Halim, & Lu, 2019). According to Cianoa, Dallasega, Orzes, & Rossia (2020) the topic that has attracted a lot of attention in recent decades is lean methodology and lean production. Buer, Strandhagen, & Chan (2018) have concluded that lean methodology in its purest form is independent and does not involve any kind of informational technology. Lean methodology is improving mainly manufacturing company results while minimizing their waste. According to Čiarnienė & Vienažindienė (2012) Lean is manufacturing philosophy that merges different principles, techniques or tools into business, management processes which help with time optimization, resources, costs and their organizations productivity, as well improving quality of production and services provided to customers. Over the years this methodology helped many organizations to reduce waste, improve their performance, optimize production time and lower their costs. It has become well know and used in companies due to its simplicity and high effectiveness.

Further, if talking about the disadvantages of lean one of them is that many companies have a problem to correctly implement lean methodology. In lean it is important to apply it the way that would suit the company best. They are struggling to successfully transform into lean organizations (Jadhav Rane, 2014). One of the statements raised by Kolberg & Zühlke (2015) is that it looks as if lean production has reached limitations: big shifts in market demands are not meeting with logic of levelled capacity utilization. The authors also notice the creation of methodology has been invented in 1950s and there are no modern informational technology possibilities taken into account.

Lean production effect on business performance has been researched empirically and some positive results have been found. However, the results also are questioned for their applicability (Abreu-Ledón, Luján-García, Garrido-Vega, & Escobar-Pérez, 2018). The research has been mainly theoretical and the results can be viewed in many different ways. There is no clear conclusions as there are many different combinations of lean production tools and methods used in the companies. Abreu-Ledón, Luján-García, Garrido-Vega, & Escobar-Pérez (2018) have conducted a meta-analytic study in which the research on lean production and business performance relation has been used from year 2000 to 2016. There were main seven hypothesis which overviewed lean producion effect on business performance as well as six most commonly used lean production practices:

- Process Control & Improvement;
- Just in Time;
- Workforce development;
- Maintenance management;
- Customer focus;
- Supplier relationship.

The hypothesis stated that there would be positive impact of lean production and six main principles with business performance. Overall results can be seen in Table 1.

Table 1. Lean production impact on business performance

Hypothesis	**Main hypothesis results**
H1. Lean Production → Business performance	Yes
H2. Process Control & Improvement → Business performance	Yes
H3. Just in Time - Flow → Business performance	No
H4. Workforce Development → Business performance	Yes
H5. Maintenance Management → Business performance	No
H6. Customer Focus → Business performance	Yes
H7. Supplier Relationship → Business performance	No

From the results it can be seen that overall, from the findings lean production has an effect on business performance. However, regarding different practices implemented not all of them have a positive relation to business performance. Just in time, maintenance management and supplier relationship can be seen as not having an effect. Due to big variability in lean practices and performance metrics the research result can vary as well. Main focus of the study was on financial and market performance and other metrics have not been analyzed. This leaves a gap in business performance which yet can be analyzed.

Overall, due to different factors of business performance being reviewed and many combinations of the lean production practices being used in companies further research would be beneficial to conduct. As there are many different factors in place as well, such as company size, the region of the company.

1.2. Effects of digital manufacturing on business performance

One of the drivers for change can be established as fourth industry revolution or shortly - 'Industry 4.0'. According to Cifone, Hoberg, Holweg, & Staudacher (2021) most recently developed digital technologies are usually referred to as 'Industry 4.0' and this is a term created in German manufacturing industry and is used since 2011. Industry 4.0 is very popular topic at the moment in professional and also the academic field according to Liao et al. (2017). Schroeder, Bigdeli, Zarcos, & Baines (2019) claim that Industry 4.0 is digital transformation of all manufacturing and customer markets and it includes from inclusion of digital technologies in production to digitization of whole value delivery channels. Industry 4.0 has created a revolution in manufacturing field as well as others fields. It provides organizations more possibilities to improve their timing and effectiveness, to analyze their data and make insights, make quicker decisions if they know what to pay attention to.

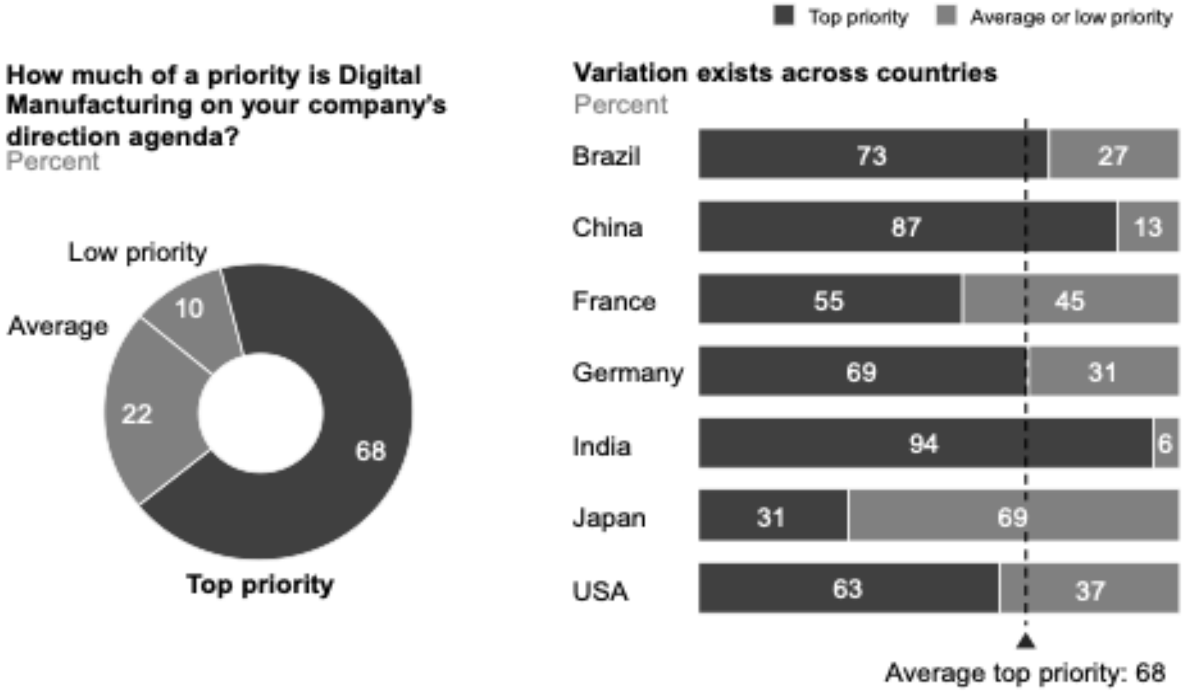

Figure 1 Digital manufacturing prioritization (Company, 2018)

In figure 1 research done by McKinsey & Company in 2018 can be seen. This shows that currently for manufacturing companies digital manufacturing is one of the top priority topics with 68% of companies choosing this answer. Only 10% of the companies have answered that it is a low priority for them and the rest 20% look at digital manufacturing implementation as an average priority. The keenest on implementation countries are: India (94%), China (87%) and Brazil (63%). This shows that companies in different parts of the world see digital manufacturing as an opportunity to improve their company performance or gain competitive advantage.

Digital manufacturing can enhance productivity and efficiency by automating and improving manufacturing processes. This enables businesses to save costs and have less waste. As well as improve quality of the products as digital technologies can provide data and analytics in real time. This way any issues can be solved as quickly as possible. This also can result in better customer satisfaction for the company. As the quality is improved the customer needs are better met as well. Implementation of technologies also shorten the time of production. By applying manufacturing technologies in company competitive advantage can be gained.

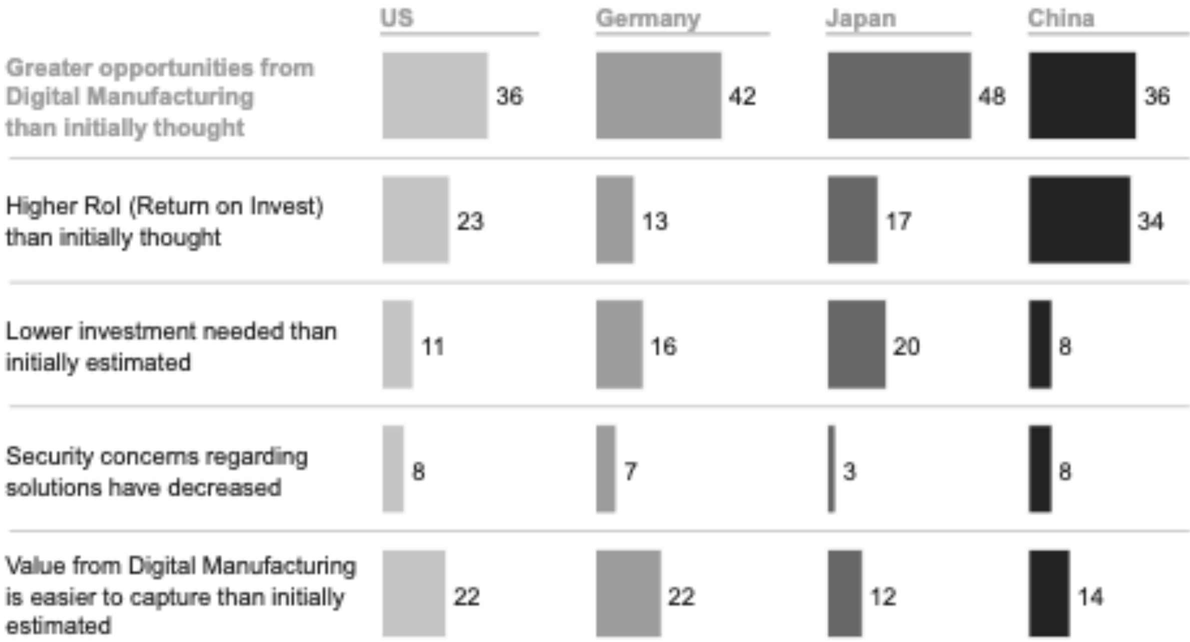

Figure 2 Digital manufacturing implementation opportunities (Company, Digital Manufacturing. Capturing sustainable impact at scale, 2017)

According to research done by McKinsey & Company (2017) companies implementing digital manufacturing practices have few main areas related to performance which can benefit the company. The research was conducted in four different country companies with over 400 of responses collected. The main benefit by companies from US, China is seen as higher return of investments. Germany sees the greatest opportunities for digital manufacturing regarding value evaluation of improvements in the company. While Japan sees the opportunity to lower the investments to gain wanted results.

According to Khanchanapong, et al. (2014) few studies have been conducted prior to review the impact of manufacturing technologies on firm performance. This shows, that the topic is quite new and the conclusions regarding digital manufacturing and impact on business performance cannot be confidently made.

1.3. Lean production and digital manufacturing matching

Comparing lean production and digital manufacturing which enables digital technology implementation in manufacturing companies it can be viewed as having the same core goal even if their strategies are different. Frank (2014) agrees that lean production and digital manufacturing have very different approaches but that their objectives are the same – increasing company productivity and flexibility.

Though the main idea is the same its affect and relationship with one another have been under-researched. According to Buer, Strandhagen, & Chan (2018) it has not been widely studied Industry 4.0 can influence management practices which are already established such as lean manufacturing and practices can influence the implementation of digital technologies.

Looking more thoroughly in the current research of the interrelations of mentioned two different strategies there are different visions seen by researchers. First one is that lean is a necessary foundation for a companies implementation of digital technologies (Rosin, Forget, Lamouri, &

Pellerin, 2019). This idea has been supported by Mayr et al. (2018). Lean has been seen as an enabler for digital manufacturing tools implementation. It is viewed that successful lean principles implementation is necessary for successful Industry 4.0 solution implementation. It is also supported by Bill Gates hypothesis that automation of unsuccessful processes will only grow their inefficient processes (Mayr, et al., 2018).

Three key parts are seen as important from lean production by the authors for introduction of digital manufacturing:

- Processes – easily duplicatable, standardized and transparent;
- Lean management competencies – to make decisions and avoid waste while considering the value which it would bring to the customer;
- Complexity reduction – easier process or product complexity can impact implementation of more efficient and better economic use of digital technologies.

These ideas have also been endorsed by Prinz, Kreggenfeld, & Kuhlenkötter (2018) who stated that digitization can be successful in a company only if the processes have been adjusted following lean methods and their aspects.

Another view for the impact between lean and digital technologies is that it is a necessary complement to 'traditional' lean. Cifone, Hoberg, Holweg, & Staudacher (2021) argue that in today's market requirements to be successful are very demanding and customers the require for personalized products. This makes traditional lean practices to be not as effective as before. This supports the idea of digital technology implementation viewed as a necessity. It is especially important in areas where money saving and basic methods of lean are not completely satisfying conditions. According to Sanders, Elangeswaran, & Wulfsberg (2016) all problems from the integration perspective for implementation of lean production have solutions in Industry 4.0 digital technologies. This shows that companies with implemented lean principles can adapt lean to the new trends with the help of digital technologies enabled by Industry 4.0 and preserve the processes already implemented in manufacturing.

According to literature review conducted by Hurta & Noskievičová (2021) qualitative analysis has shown the biggest part of authors view Industry 4.0 as a supporting role for Lean Manufacturing rather and a smaller part sees it the other way around. The research of the relation of both practices is not extensive and main focus is on them separately or in support of one another. If it focuses on the relation of lean and digital technologies it is mainly regarding the potential of positive interrelation or the possible benefits that can come from it.

In conclusion, lean production and digital manufacturing can be seen as complimentary strategies that are essential to raising the effectiveness, productivity, and competitiveness of manufacturing firms. In contrast to lean manufacturing, which emphasizes waste reduction, quality improvement, and employee engagement, digital manufacturing makes use of innovative technologies to improve such areas as supply chain, provide data-driven insights, and enhance operational efficiency. A manufacturing organization can become more efficient, effective and productive by putting both strategies in use.

It can be stated that the interrelation of digital technologies and Lean is not clear and lacks in depth analysis. One of the main problems is lack of empirical research. Cifone, Hoberg, Holweg, & Staudacher (2021) argue that even if a clear view is beginning to emerge, much of it still is conceptual and lack empirical research which could further confirm a unified understanding.

2. Lean production and digital manufacturing matching for business performance theoretical aspects

2.1. Lean production concept definition

For companies to make effective implementations of new solutions and new technologies the research needs to be done of how they interact and relate to the existing practices. For manufacturing companies this dilemma is particularly important regarding lean philosophy as it is popularly used by them. The philosophy for Lean has evolved from innovations in Toyota Motors Company. Many tools that are well known now were first created and used in the company due to intense competition between automotive companies in Japan. The main focus of it was on eliminating the waste. Wastes are the ones that do not add value to the company. They are described as several different types of waste (Junior, Inácio, Silva, Hassui, & Barbosa, 2022):

1. Transportation – any extra movement of parts or information that does not benefit or support immediate production;
2. Motion – any additional movement which does not contribute to adding value to the production, it can be for example, due to ineffective layouts of the plant;
3. Inventory - storage of high-cost and any supply which can be seen as excess due to not being necessary in production;
4. Over-processing – any use of inappropriate procedures, work in production or communication which does not enhance value of products or services;
5. Waiting – due to lack of synchronization and waste of time due to lack of equipment, inconsistent work methods;
6. Defects – due to the low quality of the produced product. It is loss of products due to scrap, repair or rework;
7. Overproduction – manufacturing more than what is needed or doing it faster or before the need is expressed.

One of the authors that have described lean management methodology were Womack, Jones, & Roos (1990). It was seen that the problems faced by Japanese manufacturing company were universal and not only specific to the automotive sector. This increased drastically the popularity of lean in European companies. In later work of Womack and Jones in 1996 the authors have identified that there are five main lean principles (figure 3).

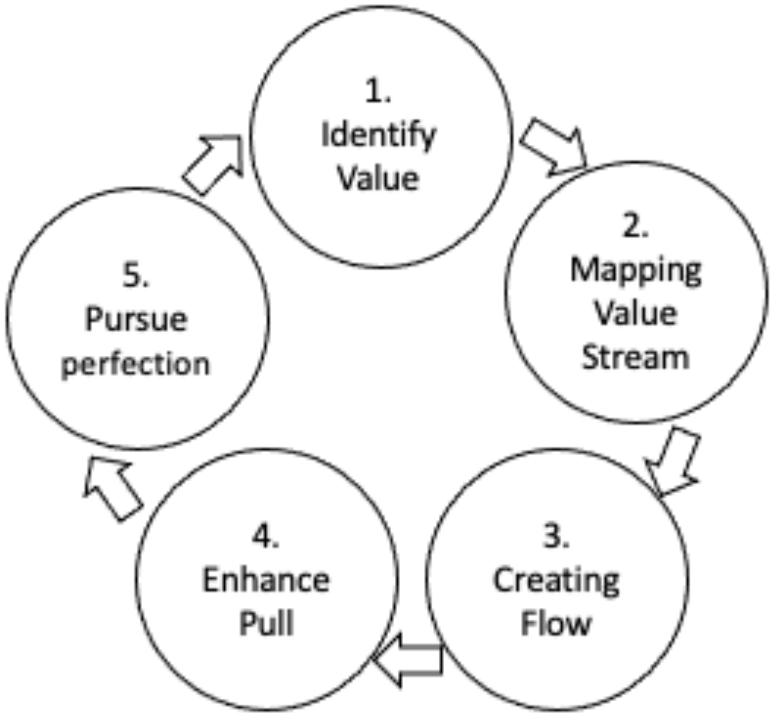

Figure 3 Lean principles (created by author based on Womack and Jones (1996))

First one is **specifying the value**. To know what the actual value is for a company the attention has to be brought mainly to the customer. According to Thangarajoo and Smith (2015) in lean thinking the real value cannot be decided by the departments such as research and development or finance, it has to come from what value does the customer see in the product. Womack and Jones stated the need for business to define their value accurately for specified products with particular capabilities provided at set prices in negotiations with specific customers.

The second principle is **identifying the value stream**. The Value Stream is defined as all actions which are required so the product would be brought to the customer. However, it has its differences from the traditional supply chain management as it only focuses on the parts that only bring value to the organization. It pushes the organization to review the activities in product creation, determine which add value and eliminate the one identified as waste (Smith & Thangarajoo, 2015).

The third principle is **creating the flow**. According to Lian & Landeghem (2002) flow principle main purpose is to make parts in one piece from raw materials to the final product and that there would not be any waiting time when moving them one at a time from one workstation to the next one. This principle is based on the main goal – to move the material through the process without any disturbances and as quickly as possible. These are the reasons why manufacturing companies implement the principle as they are highly focused on efficiency.

The fourth principle is **pull**. As Lean thinking is highly based on minimizing and extracting waste and this principle also responds to this idea. The materials are sent to manufacturing or to the next production station only when there is demand for it. This way the waste of time, costs and materials is minimized. However, this requires deep knowledge of customer demands as it highly correlates with customer needs anticipation.

Fifth principle is **pursuing perfection**. This principle stands by the idea that there is always an opportunity to reduce the costs more, improve the timing or the quality of the production. It means that even if the four mentioned principles are implemented there is always place for improvement. This indicates the constant need of evolving the processes and reviewing through the four principles to remove all nonvalue activities that might not been eliminated before.

As mentioned before lean originated from Toyota and have a widely accepted system called Toyota production system (TPS). Which is a base for a lot of lean manufacturing tools. The main two pillars for it are just-in-time and autonomation (jidoka). They are described by (Ohno, 1988).

- The main meaning behind **just-in-time** is that the materials or parts needed in production need to reach it at the right time and in correct amount. It is difficult to fully establish this process if the product has a lot of materials or parts as it has many different stages and processes. This way the made calculations can be disregarded even if planned carefully. However, if this method is mastered it can bring a lot of benefits to the company even going as far as ideally reaching zero inventory, so no materials would be stored in storage.
- The other pillar of Toyota production system is **autonomation**. It involves adding the human touch to automation. If the machines is working even when there is damage and scrapped details are being made the company quickly can lose huge amounts of material and have very high scrap costs. This can be avoided. Adding an automated stopping device which could recognize when the products are not made in the right way and stop the whole production line of it. This also shows that the employee is not needed when everything is right. It is only needed when there are problems and the attention of one employee can be divided between several lines of production.

Every principle can have the tools that are used to implement it in companies. There are many different tools which can be used in Lean methodology. Over the years many tools have been developed and it is become a system of highly inter-related components and array of management practices (Bhamu & Sangwan, 2013). Some of the most of the popular tools have been identified by Sanders, Subramanian, Redlich & Wulfsberg (2017). Through literature research the most significant tools have been selected.

Kaizen – it is a Japanese term which was first introduced by Imai in 1986. It is defined as continuous improvement and the word means "change for the good". It is consisting of incremental, small, independent innovations of the processes which are generated by employees and are repeating (Iwao, 2017). According to Brunet and New (2003) the activities can be divided in three different levels in company - individual, management and group and it can be adjusted depending on the organization.

Total Productive Maintenance – this tool is used to eliminate waste in the equipment and machines used in manufacturing. It is aimed to increase productivity and efficiency of the machines.

Standardization – main idea of this tool is use of common processes, tools or components. It drastically reduces complexity in manufacturing systems, improves productivity and can reduce number of managing reference points (Jasti, Kota, & Kale, 2020).

5S – stands for five phrases: sort, set-in-order, shine, standardize, self-discipline. It is important to keep the environment safe, clean and organized. These are the main ideas behind the concept.

Value Stream Mapping – the aim is to visualize and build maps which can represent the flow of information and flow of materials.

Kanban – another visualization tool. It is for the work flow of organization. The main purpose of it to visually quickly notice and correctly asses the problems of the work flow.

Andon – created to alert the employees if there is a defect or an issue in the production line. It is made so the line could be stopped in time. As well as the decisions could be made on the spot so the work could resume as quickly as possible.

Poka Yoke – error prevention method. It is focused on making processes as easy as possible and without any mistakes. "With Poka-Yoke is also possible to obtain reduced time required for training employees, eliminating many quality control operations, reducing the amount of defects and a 100% control of the process." (Rewers, Trojanowska, & Chabowski, 2016).

Single minute Exchange of Die (SMED) – There are four stages of SMED which are described by Shingeo Singo. First of all, it is inspection of the current state of workstation. Second is separation of internal and external operations. Third, transformation of internal operations to external operations. Fourth, is improvement of all features of the changeover. The main task is minimizing changeover time by transforming the operations of internal to external.

Shah and Ward (2007) have proposed a conceptual definition of lean which can be divided in to internal and external practices. External practises are separated into two parts – suppliers and customers. This way the different tools that are used in a company can be separated by looking if they will have an impact on company performances internally or if they will affect the suppliers and customers. The suggested model by Shash and Ward can be seen in figure 4.

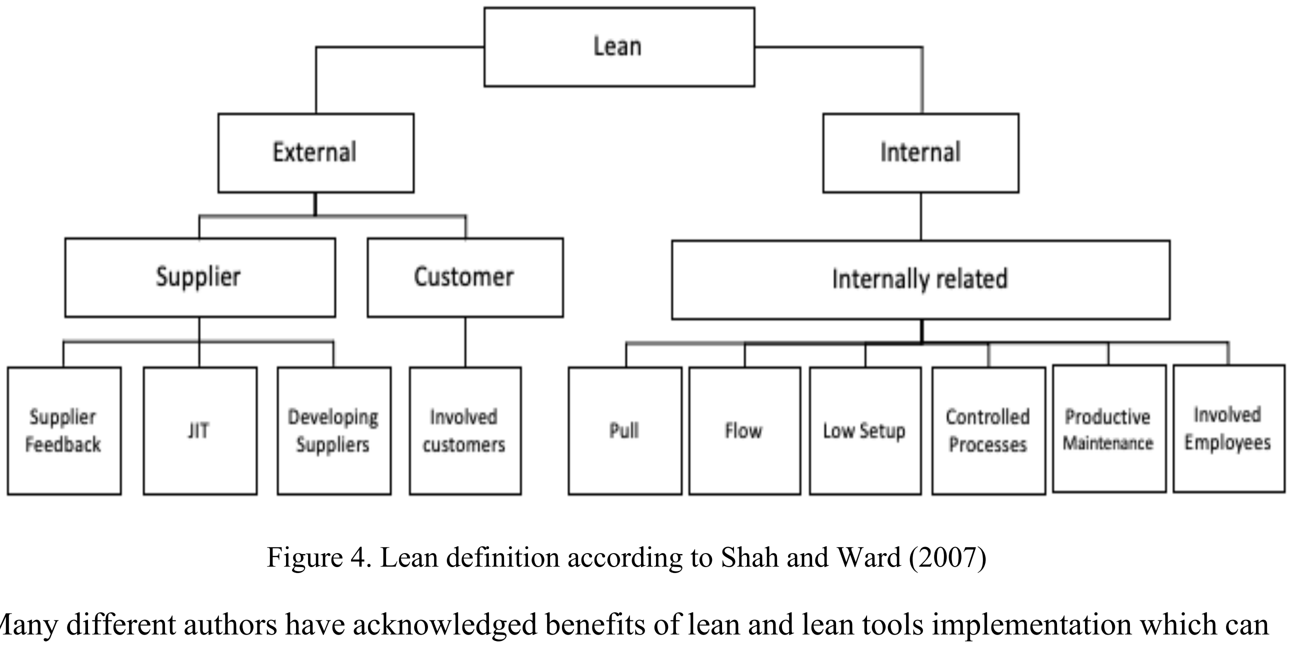

Figure 4. Lean definition according to Shah and Ward (2007)

Many different authors have acknowledged benefits of lean and lean tools implementation which can result in production, processing or cycle and set up time improvement (Bhamu & Sangwan, 2013). It can improve the efficiency of machines with helping to identify defects, scrap. There are also benefits of qualitative type: improved communication and employee morale, standardized processes which improves job satisfaction and team decision making improvement.

2.2. Digital manufacturing concept definition

Industry 4.0 is seen as a new industrial stage which integrates manufacturing operations with informational or communication technologies. It changes the rules for business in competition as adopting informational technologies and digitization of factories reframes their business models (Dalenogare, Benitez, Ayala, & Frank, 2018). Andreas Schumacher (2016) said that expressions such as “automation”, “digitization” and “digitalization” are widespread and can be seen as the motive for scientific, social or business developments. The changes in technological sector which create advanced solutions open new opportunities for businesses to implement them and shift the old ones. It has an effect on every sector and provides them with new possibilities. According to Bley et al. (2016) for a long time topics such as Industry 4.0 was seen as mainly affecting the large companies as it was seen as too complicated and expensive for medium and small companies. It is no longer viewed as only beneficial for large companies. However, the term „digitalization“ according to Reis, Amorim, Melão, Cohen & Rodrigues (2020) there are only few articles that separate terms digitalization, digitization and digitation or sometimes according to the authors there might be confusion regarding the correct use of these terms. This is also reinforced by J. Scott Brennen and Daniel Reis who declared that ‘Digitization’ and ‘digitalization’ are two terms that are closely connected and are used in place of one another in a big range of theoretical literature.

There are few models which propose how to define and apply Industry 4.0 and most of them describe how and what technologies should be implemented. From the standpoint of the market, digital manufacturing technologies allow firms to offer fresh digital solutions to customers, like web-based services built into products. Models on the industry side are Acatech Industrie 4.0 Maturity Index and Reference Architecture Model Industrie 4.0. On the academic side models are for small and medium-sized enterprises, assessing Industry 4.0 readiness, digital technology roadmap (Meindl, Ayala, Mendonça, & Frank, 2021). The most often referenced model has been created by Frank, Dalenogare & Ayala (2019). It describes different technology application dimensions that are connected to manufacturing activity. In this model it is described that Smart Supply Chains and Smart Products and Services are part of digital technology implementation in industry 4.0. Most models are focusing on when and which levels of Industry 4.0 should be implemented. Frank, Dalenogare & Ayala (2019) focus more on what technologies and practices should be implemented of digital manufacturing. The conceptual model can be divided into two main parts. They are “base technologies” and “front-end technologies”. The framework can be seen in figure 5.

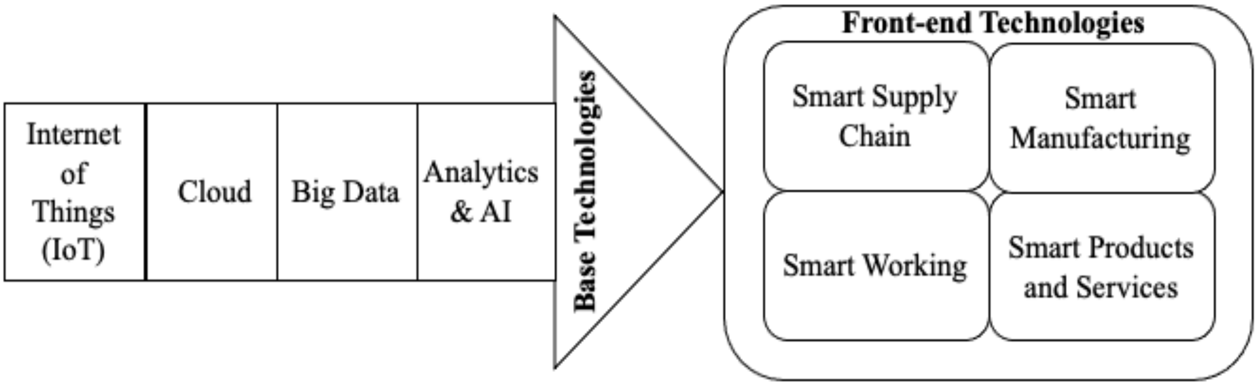

Figure 5. Framework of digital manufacturing technologies (created by author adapted from Frank, Dalenogare & Ayala (2019))

As mentioned before the framework is separated into "base technologies" and "front-end technologies". "Base technologies" are the support and basis for the "front-end technologies" because they are present in different dimensions of technologies. "They leverage the Industry 4.0 dimensions and make the interconnectivity possible as well as they provide the intelligence of the new manufacturing systems" (Frank, Dalenogare, & Ayala, 2019). These technologies include:

1. Internet of Things (IoT) – it represents the integrations of sensors, computing in internet through wireless communication (Tao, Qi, Liu, & Kusiak, 2018).
2. Cloud services - they permit network access to a shared pool of computing resources on demand. With the use of remote access, this technology has the ability to save data on an internet server provider.
3. Big data – it is huge amount of data gathering from systems or objects.
4. Analytics – allows advanced predictive capabilities that can help identifying problems that affect production before they happen.

All four technologies have different capabilities however big data and analytics are most related to one another. Big data and analytics can be seen as most important drivers of digital manufacturing and a main source of competitive advantage for companies in the future.

"Front-end technologies" are divided into four layers: "smart supply chain", "smart manufacturing", "smart working" and "smart products and services". "Smart working" and "smart services and manufacturing" are adding value to the product and manufacturing of it, while "smart supply chain" and "smart working" are providing efficiency to the operational activities.

"Smart manufacturing" technologies work as a main part of internal functions. It is assumed as a beginning of Industry 4.0. It uses base technologies – internet of things (IoT), big data, cloud and artificial intelligence on the shop floor. The technologies of this layer are divided into six sub-categories (Frank, Dalenogare, & Ayala, 2019):

1. Vertical integration – it provides control and clarity of processes in production and also aids in enhancing the decision-making process on the shop floor. The technologies in this

category include: sensors, actuators and Programmable Logic Controllers (PLC), Supervisory Control and Data Acquisition (SCADA), Manufacturing Execution System (MES), Enterprise Resource Planning (ERP).

2. Virtualization – simulates operations of processes, virtually sets up and validates procedures. The technologies in this category include: virtual commissioning, simulation of processes, artificial intelligence for predictive maintenance and planning of production.

3. Automation – automatization of internal operations in manufacturing. The technologies in this category include: machine-to-machine communication (M2M), industrial robots.

4. Traceability – technologies for identification and traceability of raw materials or final products.

5. Flexibility – for adaptation of machines to the requirements needed regarding to the product and materials. In this layer technologies are for additive manufacturing, flexible and autonomous lines.

6. Energy management – enhancement of factory efficiency by using energy efficiency monitoring and improving system.

Literature findings have recently revealed that the organizations vary in benefits expected from implemented technologies and should systemically implement them (Dalenogare, Benitez, Ayala, & Frank, 2018). Overall, these technologies makes it possible to improve quality, productivity, and flexibility while also enabling the production of customized goods on a large scale, sustainably, and with less resource consumption.

"Smart products and services" are consisting of two parts: services and products. Products are supported by Industry 4.0 base technologies to collect, monitor, control and optimize user data while services employ digital technologies in order to offer services to their users, for example cloud or monitoring services (Meindl, Ayala, Mendonça, & Frank, 2021). The main category is only one – capabilities of smart, connected products. The technologies in this category are connected to product's connectivity, monitoring, control, optimization and autonomy.

The third group is "smart supply chain". This groups is consisting of technologies which are in support of horizontal integrations in the organization. It is integration technologies with external suppliers for improvement of materials and products delivery, which impact on operational costs and delivery time, which can affect operating expenses and delivery time. It is also including integrations with customers. To sum up the technologies in this group are digital platforms with suppliers, customers and other company units.

Fourth group is "smart working". The aim of this group of technologies is to support employee tasks which can improve their productivity and flexibility while attending to manufacturing system requirements. Also, virtual tools can be regarded as a component of "smart working" because they support decision-making process which is compatible with improvement of productivity.

Implementation in all four groups of "front-end technologies" should be planned with a focus on integrating the different dimensions which leads to bigger benefits from the model (Meindl, Ayala, Mendonça, & Frank, 2021). According to literature, the industry can benefit from the integration of digital technologies in a number of ways. The benefits regarding business operations are that the manufacturing lines can become flexible and reconfigurable which makes it easier to produce customized or small quantity products. Mentioned technologies can increase productivity, better resource use and save energy. Industry 4.0 solution implementations can help organizations to manage risks, adapt to changes and seize new opportunities through the horizontal integration concept. This opens new opportunities for business growth.

2.3. Lean and digital manufacturing matching

Further the possible matching of digital manufacturing and lean are explored. While it is important to find out what kind of effect each of them have on one another it is also crucial to review what can influence or affect this relation as well as what positive outcomes come from the possible relation. First step is to analyze what affects digital technologies and lean.

Environmental factors are seen as influential to the implementation approaches for improvement programs and their applicability (Buer, Strandhagen, & Chan, 2018). Different types of environments are likely to need different approaches. There are four main contingencies which have been identified by Netland when implementing systems (2016).

First of all, the ownership of manufacturing by different corporations can affect the implementation of improvement programs. This is because corporations compete with different strategies, different markets and products. This makes it difficult to implement the same methods and systems to separate factories.

Second, the size of manufacturing company affects the chosen methods. Different sized companies face different challenges. As smaller organizations can lack company resources and financial resources. But for large corporations can take long time implementing different approaches.

Third factor is the knowledge of the companies or their maturity. Experience of the company can affect implementation of different approaches. This means that past experiences of the organization can play a key role in implementing new improvements programs.

Fourth is national culture and view on implementation of such improvement approaches as lean. As culture is very hard to change and is part of specific society. There are agreements in the literature that implementation of lean is easier in collectivistic cultures rather than in cultures that are characterized by individualism (Netland, 2016).

Overall, lean manufacturing has emerged in automotive organizations and it has been easily adopted by other repetitive production companies as it was developed for mass production. For non-repetitive production environments lean principles are seen as harder to implement and according to Buer, Strandhagen, & Chan (2018) benefits of it are more questionable. Similar tendencies are seen for Industry 4.0 digital technologies implementation. It was found through multiple case studies that organizations with repetitive production systems are more likely to have easier transition to these improvement system implementations than non-repetitive production companies.

Next the impact of lean production and digital manufacturing on performance is analyzed. According to Buer, Strandhagen, & Chan (2018) implementation of lean manufacturing tools, principles have a lot of benefits especially towards performance that have been proven by many researchers and include a big variety of performance metrics. Lean production impact measures of performance have been classified into five groups by Marodin and Saurin (2013). The five groups can be seen in Table 2.

Table 2. Performance groups (created by author)

Performance groups	**Measures**
Operational	Includes such measures as stock levels, setup time, quality metrics, productivity.
Financial	Includes such measures as cost, revenue, profit.
Human	Includes employee stress and commitment, safety at work.
Market	Includes such measures as market share.
Environmental	Includes such measures as pollution, resource efficiency.

Industry 4.0 impact measures of performance have been classified as well into five categories by Moeuf, Pellerin, Lamouri, Tamayo-Giraldo, & Barbaray (2018). The catogeries are:

1. Flexibility
2. Costs
3. Productivity
4. Quality
5. Lead time

Khanchanapong et al. (2014) has analyzed some of the performance measures focusing on four out of the five previously mentioned: costs, quality, lead time and flexibility. The mentioned research has been done reviewing lean practices and manufacturing technologies. Manufacturing technologies in this case stand for computer-aided design, engineering, manufacturing, computer numerical control machines, robots and enterprise resource planning (ERP) systems. Which are seen as part of industry 4.0 technologies as well. Some of the possible relationships have been identified in this case between performance measures and digital technologies, lean. The relationship diagram can be seen in Figure 6. Findings of this research concluded that optimization of each of the systems, especially when they are synergized, can have positive impact on manufacturing company performance.

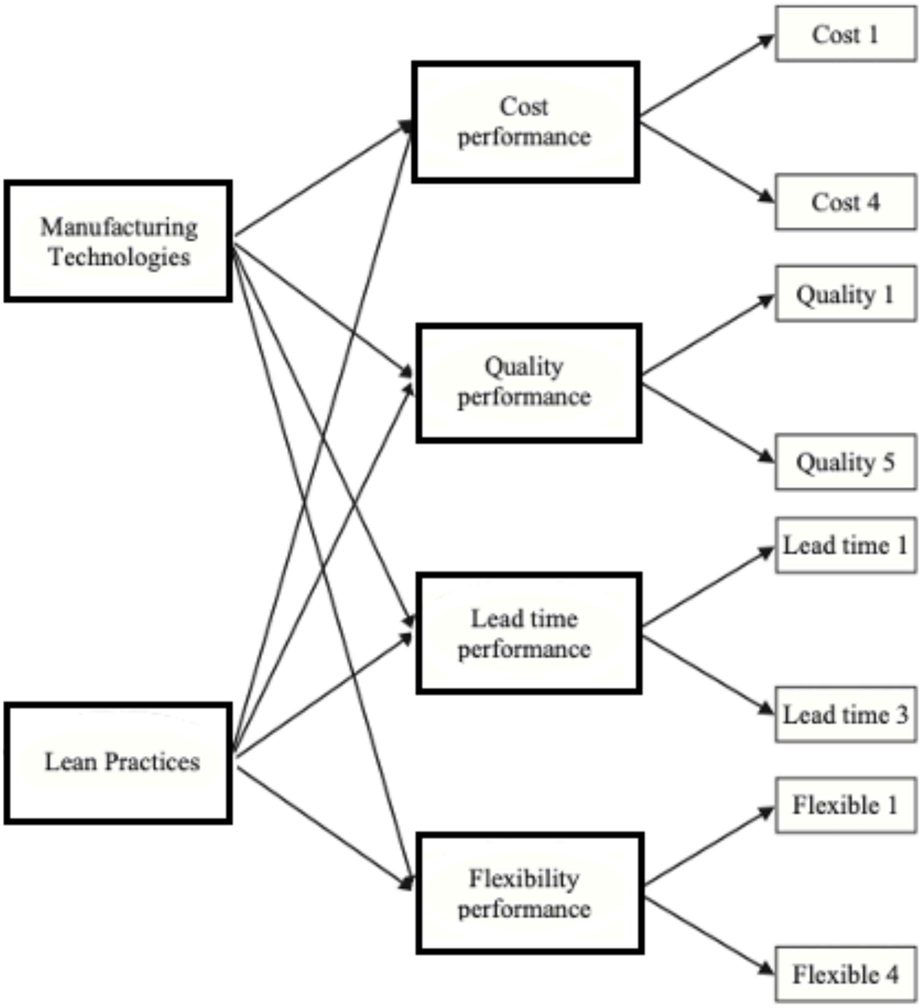

Figure 6. Structural relationship diagram with performance measures (created by author adapted from Khanchanapong et al. (2014))

There are few possible types of relationships that lean and digital technologies could have. First is the possibility of **digital manufacturing supporting lean production** in scientific literature. According to Sanders, Elangeswaran, & Wulfsberg (2016) research every problem that lean manufacturing has in implementation can be solved by digital tehnologies used in Industry 4.0. The research was based of ten different dimesnions of lean manufacturing and challenges that have come up while implementing lean methodology. It is found that Industry 4.0 could solve challenges in supplier, control, customer, process and human factors.

Kolberg & Zühlke (2015) also support the idea that implementing industry 4.0 digital technologien in lean companies could be promising and beneficial. The integration of digital improvement systems can help especially in the ares where lean cost-saving and simple methods lack the fullfilment of current requirements. Their implementation is also seen as being easier in companies that have already implemented lean because of their simplicity and standardized processes. However, there are still no concrete knowledge of how it should be done in most structural and easiest way. The research is missing for which practices can be combined, which contradict one another and which of them complement one another. This way it is not easy to implement it in specific cases with full certainty due to companies using different lean tools and practices.

The other possible relation is **lean production methodology supporting digital manufacturing technologies** and their implementation. Saxby, Cano-Kourouklis and Viza (2020) have cncluded that some elements of lean show positive support for implementation of Industry 4.0 technologies. However, some other elements can be seen as providing neutral or even negative relationship to Industry 4.0. From the authors research it can be seen that lean methods and tools used might need updating to better support Industry 4.0. Buer, Strandhagen and Chan (2018) aknowledge that waste-free, streamlined processes of lean manufacturing can simplify the efforts of a company to digitalize and automate manufacturing processes. The authors have also developed a framework which can be seen in Figure 7.

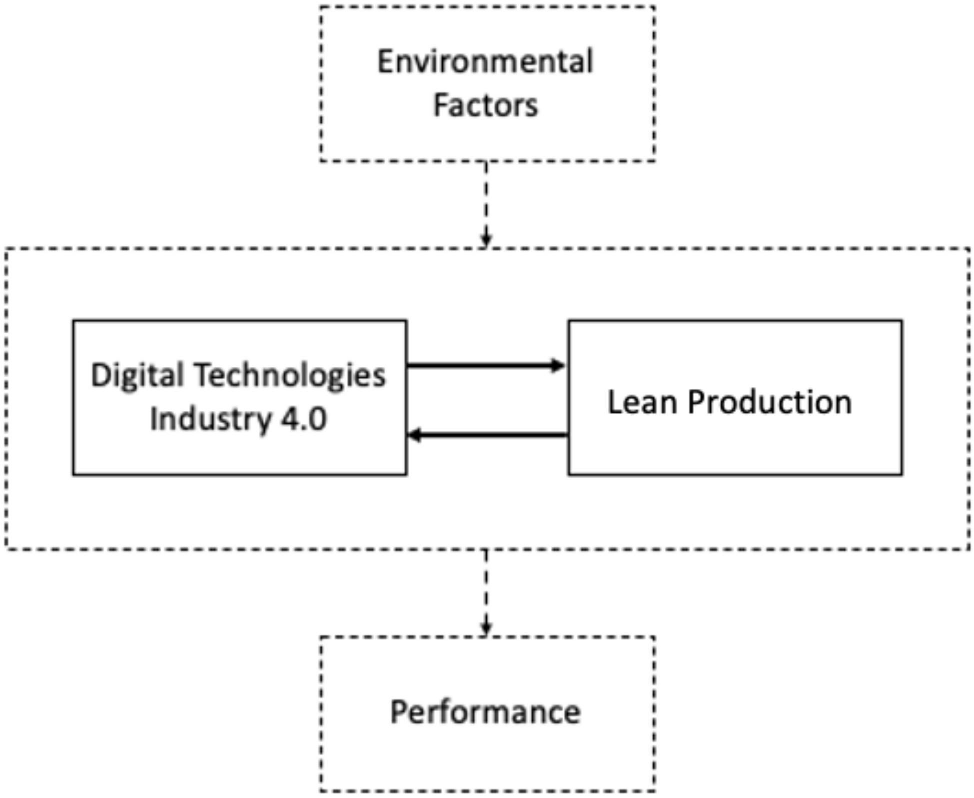

Figure 7 Framework of relationship of lean and digital technologies (created by author adapted from Buer, Strandhagen and Chan (2018))

The framework shows the possible support of lean on digital technologies and vice versa. It also shows the impact which environment can have on Industry 4.0 digital technologies and lean manufacturing. The framework acknowledges the possible impact lean and Industry 4.0 can have on company performance.

On the other hand, Cianoa, Dallasega, Orzes, & Rossia (2020) recognize through their research that rather than one of the improvement methods supporting the other there is potential both ways **relationship between Industry 4.0 and lean methodology**. In the research the effects of Industry 4.0 digital technologies recognized on lean, such as: empowering effect of Autonomous Robots and IoT on SMED and Standardised Work or Big Data and Analytics on Employees Commitment. Also, effects of lean on digital technologies is aknowledged, such as: enabling effects of One Piece Flow and just-in-time on Vertical Integration. Aswell impact on soft lean tools is recognized. However, the authors discuss that more reaserch is needed to fully prove the interrelation of Industry 4.0 and lean methodology. The framework has been developed to support this view and can be seen in Figure 8.

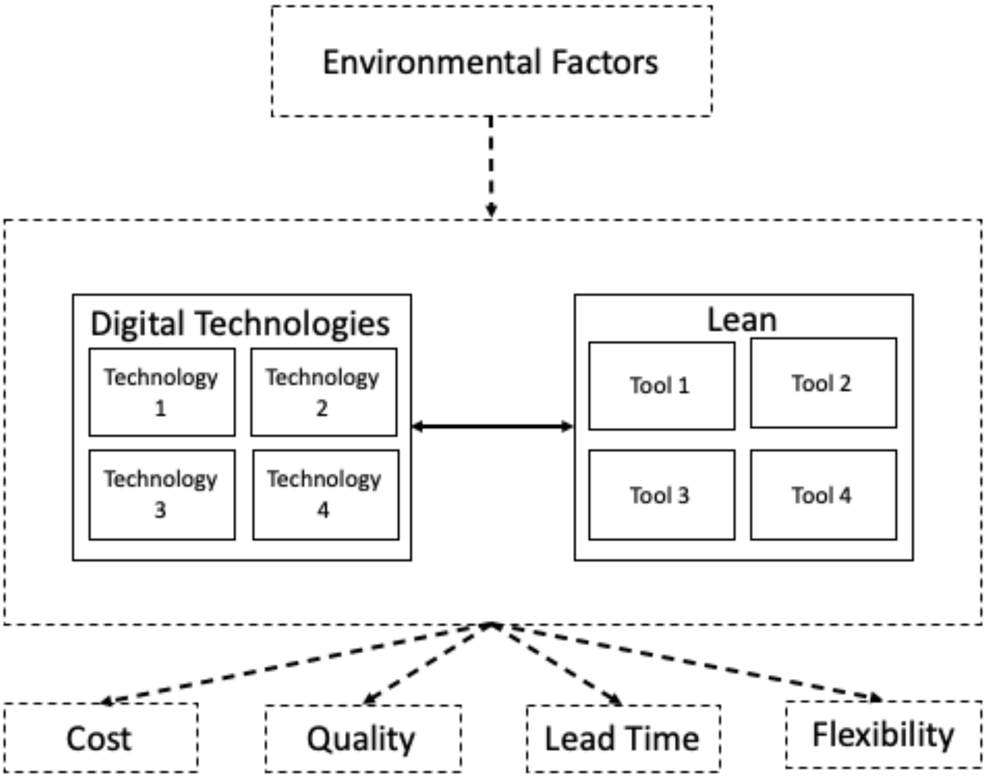

Figure 8. Effect of interrelation of Lean and digital technologies on performance (created by author)

To sum up, lean methodology has been important part of manufacturing companies as for decades it has been implemented to minimize waste and improve production performance. While Industry 4.0 digital technology implementations is more of a recent topic it has been proved to have a positive effect on company performance, their flexibility, costs and quality. Industry 4.0 technology implementation has also big focus on manufacturing companies and can be seen as very beneficial. The main questions arise about the implementation and merging both: Industry 4.0 and lean. The theoretical research has shown different views of authors. Some acknowledge leans support for industry 4.0 digital technologies while others also see a negative relationship. Other authors see digital technologies as support for lean. More recently the interrelation has been noticed between different technologies of industry 4.0 and different tools of lean. However the topic of interrelation of lean and Industry 4.0 is quite a new topic and lacks theoretical support.

2.4. Business performance concept

For companies in order to review their accomplishments and strategy there is a need to measure their different decision impact to the business. Depending on the area of the activity it could be more easy or difficult to measure the accomplishments. Most definitions regarding business performance emphasize the importance of effectiveness and efficiency (Zsidó, 2015). Both effectiveness and efficiency can be hardly separated from the meaning of business performance. Companies are always seeking to provide best results for their customers. Providing a certain level of customer satisfaction, effectiveness refers to the extent to which customer requirements are met, whereas efficiency measurement defines how economically resources of a company are used (Neely & Platts, 2005). Other terms are very frequently associated with definition of business performance are:

- Productivity;
- Efficiency;
- Economic efficiency;
- Profitability;
- Effectiveness.

There is no clear single definition of business performance. One clear definition cannot be found as each business can determine what performance means to them by making certain choices. According to Neely (2004) a lot of firms were unsatisfied with their performance measurement systems as usually they were only about past data of the company accounting. They would not measure customer satisfaction, product quality or what helps them to grow their market share. For company managers there are a few requirements described which should be fulfilled when considering perfomance measures:

1. There should not be too many measurements for managers to keep track of. It should be limited in order to always closely follow the changes and to not get confused in many different metrics. It should be limited to certain number of financial and non-financial measures. It is reccomended up to three measures for each of these two groups.
2. Biggest attention should be paid to non-financial measures. The financial measures would act as more of the secondary information and additional measures to support findings by the non-financial group.
3. Same choice of measurements should be considered through out the company and not differ. It would help to have clear overview for the company as well as look into them more closely to the details if some clarification or more information would be needed.
4. The chosen performance measurements should not be changed quickly. It is best for the company to keep track of the same measurements. In case changes need to be made they should be done slowly and with caution. This would give stability and clarity to the employees.
5. Including a reward system in the company would be beneficial as it would increase employee morale to perform as best as it is possible and tracking the performance measures would be more important to them.

These are the criteria as described by Neely (2004) which should be followed when deciding what to implement. However, to say exactly which measurements are the best for some type of company is not suitable. There are quite a few reasons why every firm should choose them differently according to their situation.

First of all, the choice of measurements is quite big. This means that a company needs to specific their goals and needs in order to choose the best ones. Secondly, each company faces the decision and difficulties to find measures which could clearly state their current situation as well as help to forecast future results for the firm. Third, measures should be always looked at closely as they can lose their value in case of changes in the company and sticking to certain measures is not always the best scenario if such example would be described.

Currently, there is more than a few performance measurement systems. It is critical to measure business performance for development of the company. According to Neely, Gregory & Platts (1995) the system of performance measurement can be divided into three different dimensions:

1. Individual performance measurements;
2. Set of performance measurements;
3. As a relationship between performance measurement system and environment in which it operates.

The framework was created to visually show the concept of it. It can be seen in figure 9.

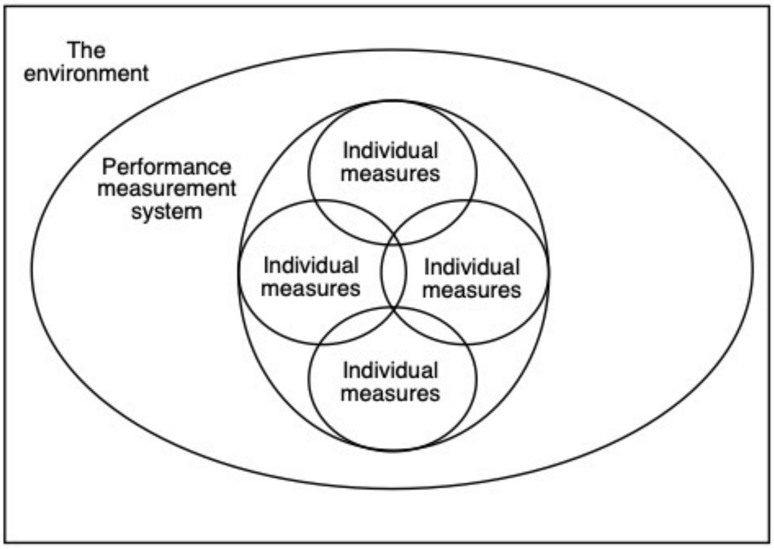

Figure 9. Performance measurement system

According to David and Joseph (2014) there are seven main purposes for performance measurement:

1. Look back;
2. Look ahead;
3. Roll up;
4. Cascade down;
5. Compare;
6. Motivate;
7. Compensate.

This shows that when considering the choices for performance measurements they should be used to either review past results, forecast future results show impact inside the company or make comparisons in the firm. The framework can be seen in figure 10.

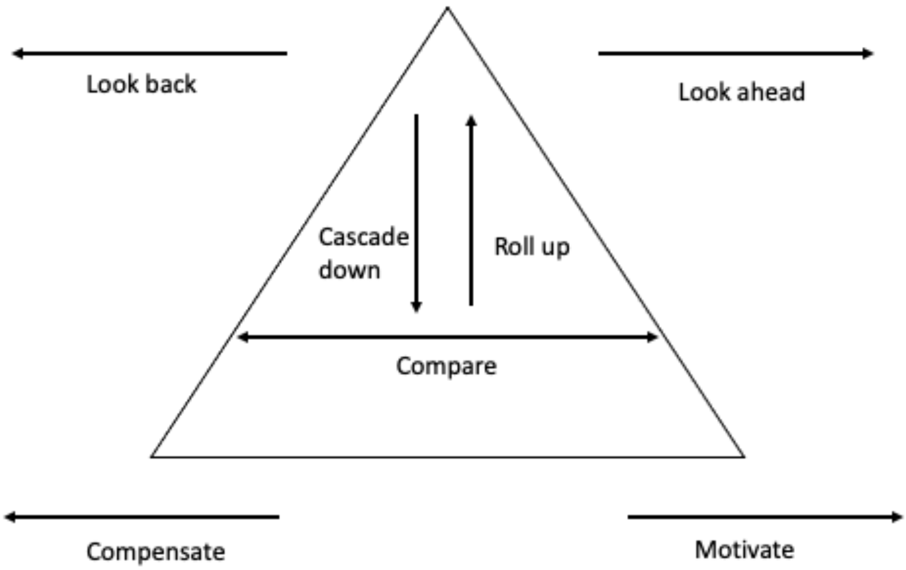

Figure 10. Seven main purposes of performance measurement

Throughout the years many different proposals for best performance measurement systems have been suggested. Some of the most widely used and mentioned are: SMART, the performance measurement matrix, the balanced scorecard and the integrated dynamic PMS and others. Oztaysi (2009) has reviewed the most commonly know models or frameworks of performance management. They can be seen in figure 11.

Models / Frameworks	Focus of the model	Individual Evaluations	Look Back	Look Ahead	Balanced Performance	Alignment with	Flexibility / Dynamism
Traditional Performance Measurement	Financial ratios	-	+	-	-	-	-
Time based performance measurement system.	Time based measurement of the processes	-	-	+	-	-	-
Time based Costing	Time based costing of products	-	+	-	-	-	-
Theory of Constraints (TOC) and throughput accounting	Efficiency, activities, inputs, inventory and money-time	-	+	+	+	-	-

Theory of Constraints (TOC) and throughput accounting	Efficiency, activities, inputs, inventory and money-time	-	+	+	+	-	-
Tableau de Bord	Corporate performance	+	+	+	+	+	□
Performance Pyramid	Identification of the performance improvement areas	-	-	-	+	-	-
Performance Prism	Considers the perspectives: Shareholder satisfaction, strategies, processes, capabilities	+	+	□	□	+	□
Activity-Based Costing	Costing of activities and resources	-	+	+	□	-	-
SMART System	Performance indicators for different levels of the company.	-	+	-	□	□	+
Performance Measurement Survey	Preparation for the prior performance improvement areas.	-	-	-	+	-	-
Performance Measurement Matrix	Groups the corporate performance indicators as financial, non-financial, exterior and interior.	-	+	-	-	-	□
Performance Measurement Framework for Service	Analyzes the performance indicators with a cause and effect relation	-	+	+	□	□	□
Balanced Scorecard	Defines a corporate performance system with, financial, customer, process and learning and growth perspectives.	+	+	+	+	+	+
Macro Process Model	Models the processes as inputs, production system, outputs, outcomes and goals.	-	+	-	□	-	-
Consistent performance management system	Defines the steps for implementing performance measurement.	-	+	□	□	□	+
Cambridge Performance Measurement Process	Design and tracing of the performance indicators	□	+	-	□	□	+
Quality Frameworks	Standard and corporate performance	-	+	□	□	-	-

Figure 11. Performance measurement frameworks and their performance purpose evaluation (Öztayşi, 2009)

From the figure above it can be seen that the most performance measurement frameworks do not fulfill all of the performance measurement purposes. The methods that cover the most aspects are: Tabbleu de bord, performance prism. However, the one that fully covers all of the points is balanced scoreboard.

The individual performance measurements have been conceptualized with two dimensions in the present study: financial performance (e.g., profit margin, return on sales, return on assets, and return on investment) and market performance (e.g., market share, sales, and sales growth).

As it can be seen business performance can be defined through many different measurements. Some of important factors that can be evaluated in many different companies are: sales growth, market share of the company and their product quality.

- Sales growth – it is the increase of sales in a specified period of time. It can be measured in different periods of time depending on each companies preference. This measurement shows the capability of business to increase their revenue, which ultimately can improve their other aspects such as profits, customer loyalty.
- Market share – for company this defined as the total revenue of its products or services. It focuses on a specific market and is counted over certain period of time. By analyzing this measurement company can see how it is doing overall with the competition in the market. It helps for the decision making as the picture can show if business is ahead of the competitors or certain changes need to be made if it is falling behind.
- Product quality – this measurement shows how the companies products are meeting the expectations of the customers. It can consider such parts as features of the product, safety, reliability and other attributes which can be specific to different products. Product quality is as well an important part for companies performance as it can increase loyalty of the customers, increase their product sale and improve brand image.

Overall, business performance tracking is very important for a manufacturing company due to several reasons. First of all, manufacturing company is highly affected by its financial stability and profitability. Sales, quicker production, waste management and overall control of key company activities can increase business profitability. This opens more doors for the company as it can expand their manufacturing lines, invest in R&D, and sustain long-term growth.

Secondly, company can gain competitive advantage by tracking and improving their business performance. Companies which are reviewing their current status, client expectations effectively, maintaining product quality and evaluating their next steps according to chosen business measurements have a higher possibility of gaining competitive advantage. While increasing its market share company can even start to be seen as the industry leader if continuously outperforming other competing businesses.

Thirdly, manufacturing process inefficiencies can be found by tracking and enhancing business performance. A business can spot bottlenecks, reorganize processes, lower their expenses, and boost productivity by monitoring performance indicators like production time, scrap number, and inventory use. This way resources can be assigned in more effectively, shorter production times can be found, and customer satisfaction could be increased.

In summary, monitoring and improving business performance are crucial for a manufacturing company as they contribute to their success. By focusing on performance measurements, a manufacturing company can improve their position, their brand name as well as gain competitive advantage and be profitable.

2.5. Lean production and digital manufacturing matching for business performance hypothesis grounding

Based on scientific literature research the model for matching lean production and digital manufacturing for business performance has been created. The model contains four main parts: digital manufacturing, lean production, lean and digital manufacturing matching and business performance. Four hypothesis have been raised which will be described in more detail.

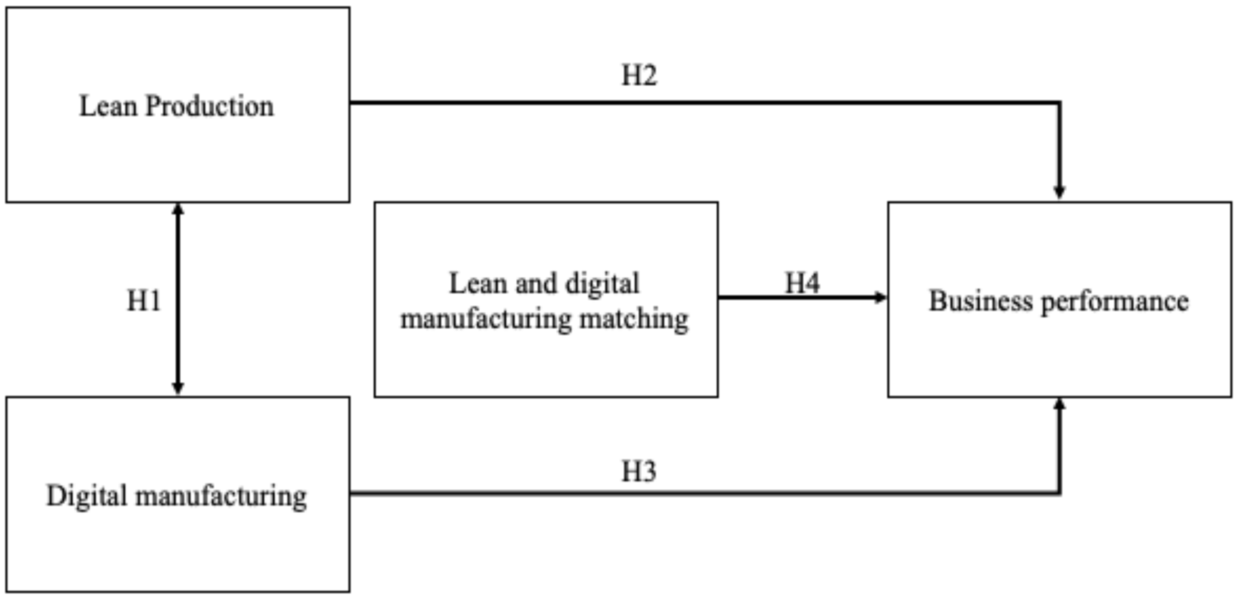

Figure 12. Lean production and digital manufacturing matching hypothesis (created by author)

Hypothesis 1 – Lean production and digital manufacturing reinforce each other and correlate positively.

This hypothesis states that there is a relation between lean production and digital technologies. They are seen as complimentary to one another in order to minimize waste and cost, improve efficiency and improve company processes. This means digital manufacturing technologies would be supporting lean production and lean production would be supporting digital manufacturing technologies. Sanders, Elangeswaran, & Wulfsberg (2016) research has stated that problems which cannot be solved by lean production can be solved by digital manufacturing tehnologies. While Saxby, Cano-Kourouklis and Viza (2020) state that some elements of lean production can positivily support for implementation of digital manufacturing technologies.

Hypothesis 2 - Lean production has positive effect on business performance.

The hypothesis states that lean production has a positive effect on business performance. Buer, Strandhagen, & Chan (2018) state that implementation of lean production practices and priciples can have a lot of benefits especially for performance of the company. This would show that companies which pay attention to implementation of lean practices results in such areas as costs, market share, productivity would be seen positively.

Hypothesis 3 - Digital manufacturing has positive effect on business performance.

Similar to previous hypothesis the same effect would be seen if implementation of digital manufacturing is strongly viewed in the companies. Digital manufacturing could help increase company performance when implemented at a high rate in manufacturing firm.

Hypothesis 4 - Lean and digital manufacturing matching has positive effect on business performance.

Lean production and digital manufacturing matching have a positive relationship to business performance. This would mean that when implemented on the same pace both lean production and digital manufacturing can have an impact on business performance measurements. On the contrary if implemented at separate paces, for example: lean production practices are implemented at a high level in the company and no attention is paid to digital manufacturing, the effect for business performance would not be seen.

3. Lean production and digital manufacturing matching for business performance methodological solutions

Research goal is to answer what kind if lean and digital technologies have a relationship with different business performance measures and if there is one between them. To further analyse and prove the interrelation of lean and digital technologies research methods have been selected which have been conducted in manufacturing companies.

Quantitative research strategy has been done to find out and evaluate what kind of relationship there is between lean and digital technologies. Analysis has been done from European manufacturing survey data of 250 Lithuanian companies collected in Lithuania. This would help get the big picture of manufacturing companies in Lithuania on lean and digitalization. However, there are some limitations as not every aspect can be included in the survey and no additional data can be collected if needed.

The secondary publicly unavailable empirical data was used for this master thesis. The empirical data was collected as part of the European Union’s Horizon 2020 research and innovation programme, project title “Industry 4.0 impact on management practices and economics (IN4ACT)”, (No 810318). The sample (N=250) contains data collected in Lithuania (Vilkas et al., 2023) as part of European manufacturing survey in 2023.

In Lithuania there are 2034 manufacturing companies which have more than 20 employees. With the confidence level of 95% the sample size should be 324. As mentioned previously the survey has been answered by 250 companies.

For the survey there have been also set targets which should be reached. The results of the distribution can be seen in the table below.

Table 3 Survey target and reached answer values

Employees	**Target**	**Reached**
20-49	57,2	57,2
50-249	35,7	34,4
250+	7,1	8,4
Region	**Target**	**Reached**
East	32,0	37,6
North	16,3	17,6
West	19,8	19,2
South	32,0	25,6
Manufacturing production area	**Target**	**Reached**
Manufacture of food products	13,9	13,2
Manufacture of beverages	1,2	1,2
Manufacture of tobacco products	0,0	0,0
Manufacture of textiles	4,2	4,4
Manufacture of wearing apparel	7,3	9,2
Manufacture of leather and related products	0,4	1,2

Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	13,6	15,2
Manufacture of paper and paper products	2,0	1,6
Printing and reproduction of recorded media	2,3	2,4
Manufacture of coke and refined petroleum products	0,2	0,0
Manufacture of chemicals and chemical products	2,4	2,0
Manufacture of basic pharmaceutical products and pharmaceutical preparations	0,4	0,0
Manufacture of rubber and plastic products	5,3	4,4
Manufacture of other non-metallic mineral products	3,9	4,4
Manufacture of basic metals	0,3	0,0
Manufacture of fabricated metal products, except machinery and equipment	13,6	13,2
Manufacture of computer, electronic and optical products	2,9	2,0
Manufacture of electrical equipment	2,6	2,8
Manufacture of machinery and equipment n.e.c.	3,1	3,6
Manufacture of motor vehicles, trailers and semi-trailers	0,9	1,6
Manufacture of other transport equipment	2,4	1,2
Manufacture of furniture	9,5	12,8
Other manufacturing	3,2	2,8
Repair and installation of machinery and equipment	4,1	0,8
Total	**100,0**	**100,0**

From distribution results it can be seen that most of the manufacturing companies as expected were reached that have from 20 to 49 employees. The regions that were expected to give most answeres were East and South both with 32%. However, most manufacturing companies have answered from the East region – 37%, while in the South 25,6% have answered which means it was less answers than expected. Regarding the manufacturing production type the companies that had the highest target groups have answered the most of the surveys while smaller targer groups such as manufacture of basic metals and also manufacture of basic pharmaceutical products and pharmaceutical preparations have not answered at all.

3.1. Lean production and digital manufacturing matching for business performance quantitive research questionnaire

The quantitive research questions cover main four parts: company overview, lean and digital innovation implementation in the company and their performance changes over the past few years. The question groups can be seen in table below. The questions related to the topic of the research have been described below.

Table 4. Justification of the survey research questions (prepared by the author)

Question group	**Question purpose**	**Questions**
Current company lean implementation analysis	To determine if lean methods are used in the company and what kind of methods are used.	5

Current company digital innovation implementation analysis	To determine what kind of digital innovations are used in the company.	6
Business performance measure change assesment	To find out if the company has seen changes in any of their business performance measures.	11
Demographic questions	To find out about the business environment and their characteristics.	1, 2, 3, 4, 7, 8, 9, 10

The questionnaire starts with questions about demographic features. Next questions are about used lean methods and digital innovations used by the company. And the last part of the questionnaire is about their business performance changes and measurements. The questions can be seen in the table below.

Table 5. Questionnaire survey questions (prepared by the author)

No.	Question	Measurement scale
1.	Is your factory a part of multi-site company?	Nominal Scale
2.	Please indicate your company sector.	Open Question
3.	To which countries are the products sold to?	Open Question
4.	To which industries are your products sold to?	Nominal Scale
5.	Which of the organizational methods listed below are used in your company? (Customer related, supplier related and internal)	Nominal Scale
6.	Which of the following technologies are currently used in your company? (Production management software, remote data transfer, automation and robotics, additive manufacturing technologies, simulation modeling and data analysis)	Nominal Scale
7.	Describe your company: annual turnover, 2021.	Open Question
8.	Describe your company: employee number, 2021.	Open Question
9.	Describe your company: return on sales (before tax), 2021.	Nominal Scale
10.	Describe your company: establishment year.	Open Question
11.	Evaluate your company's achievements compared to the achievements of competitors in your sector over the last 3 years? (Sales growth, market share, product quality)	Ordinal Scale

The questions which are related to the characteristics of the company are short and mostly with open style question. The questions regarding business performance, lean production and digital manufacturing are more broad with sections in the questions regarding different groups of practices or implementation tools.

3.2. Lean production, digital manufacturing and business performance reliability analysis

As previously mentioned lean methods can be divided into three different groups: customer related, supplier related and internal. Digital innovations were formed into groups: production management software, remote data transfer, automation and robotics, additive manufacturing technologies and simulation modeling and data analysis.

	Groups	Cronbach alpha
Lean production	Customer Related	-
	Supplier Related	0,346
	Internal	0,768
Digital manufacturing	Production management software	0,663
	Remote data transfer	0,546
	Automation and robotics	0,654
	Additive manufacturing technologies	0,605
	Simulation modeling and data analysis	0,458
Business performance measurement		0,714

According to the results lean practices can are reliable for the internal group of practices. This set of questions will be used in further research. Digital manufacturing has been reviewed by the groups overall was included with all of the groups seen in the table as the Cronbach alpha of it was more than 0,60. Business performance measurement Cronbach alpha has also reached more than 0,60 and can be concluded as reliable to use in further research.

4. Lean production and digital manufacturing matching for business performance results

European manufacturing survey data has been collected in Lithuania out of 250 Lithuanian manufacturing companies. The data has been processed and analyzed using *IBM SPSS Statistics* software. The results have been analyzed using reliability analysis, factor analysis. If needed new variables were created or combined for better overview of the possible relationships.

4.1. Lithuanian manufacturing company characteristics

As mentioned before the survey has been filled by 250 respondents. The results from different manufacturing companies in Lithuania have been collected. First of all, the characteristics of the respondent companies are being described. The questions are related to the size of the company, its establishment year, industry and other descriptive.

One of the questions were about companies year of establishment. Year of establishment can tell the companies age, how many years has it been in business. Companies age can have an impact on lean production or digital manufacturing technology implementation. However, research results are mixed with few contradicting views. Some authors conclude that older companies can be slower to implement the needed changes or have much more difficulties while doing so. But the implementation of different practices depends on many different factors as well. This was also tested to see if the factor of company age has any effect on the Lithuanian manufacturing company digital manufacturing and lean production implementation. The results are described in the table below.

Table 6. Company age and lean prodction, digital manufacturing relationship

	Linear regression between company age and digital manufacturing	Linear regression between company age and lean production
R	0.126	0.105
R Square	0.016	0.011
Sig.	0.069	0.133
Beta	0.126	0.105

From the results it can be seen that in this scenario age of the company does not have any significant impact as the results of p are in both cases higher than 0.05 (digital manufacturing – 0.069, lean production – 0.133). In picture 9 the overview of respondents company age can be seen.

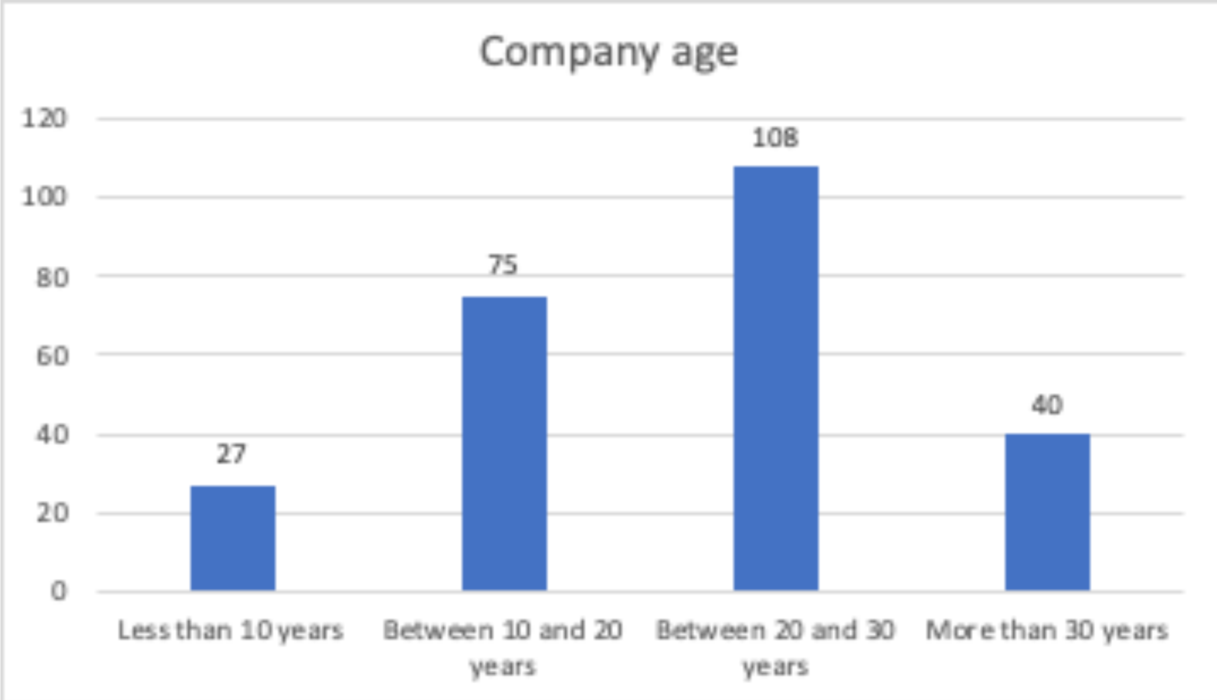

Figure 13. Company age (created by author)

Most of the companies are between 20 and 30 years old, it is about 40% of the respondents. The second highest result answer is companies between 10 and 20 years in business (75 answers). 40 companies have been in business for over 30 years, the oldest company being in business for 33 years. The lowest number of answers if for companies that are in business for less than 10 years (27 answers) with the youngest established for 2 years.

The next question was "if the company is a part of a multi-site company?". As mentioned in the literature research environmental factors can have an influence on lean implementation and digital technologies as well as the impact on the performance of a company. Corporations or multi-site companies can have more resources and know-how which could help companies improvement and increase their performance. However, decision making can be more complex and abide by the corporations expectations. Companies which are not multi-site can have a problem with resources or knowledge but may have quicker change implementation. The results for the question seen in figure 14.

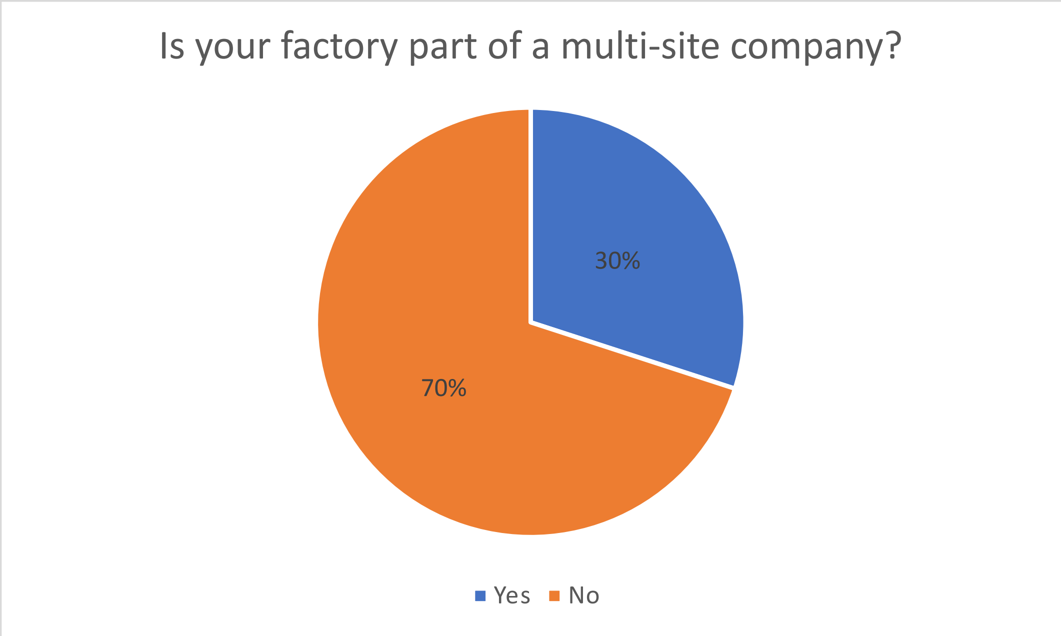

Figure 14. Manufacturing company results for question “if the factory is part of a multi-site company?” (created by author)

Most of the manufacturing companies questioned in Lithuania have answered that they are not a part of multi-site company. 70% of the companies have one factory. The rest 30% are a part of bigger company group or corporation. The results show that much more companies in Lithuania are acting on their own and are independent businesses.

Next characteristic of surveyed companies was what kind of industry they are in as a manufacturing company. The results had 20 different answers among the companies the lowest answers which take up from 3% to 1% have been combined to “other manufacturing”. This group consist of such manufacturing industries: manufacture of paper, manufacture of textiles, manufacture of beverages, manufacture of chemicals and chemical products, manufacture of motor vehicles, trailers and semi-trailers, manufacture of electrical equipment.

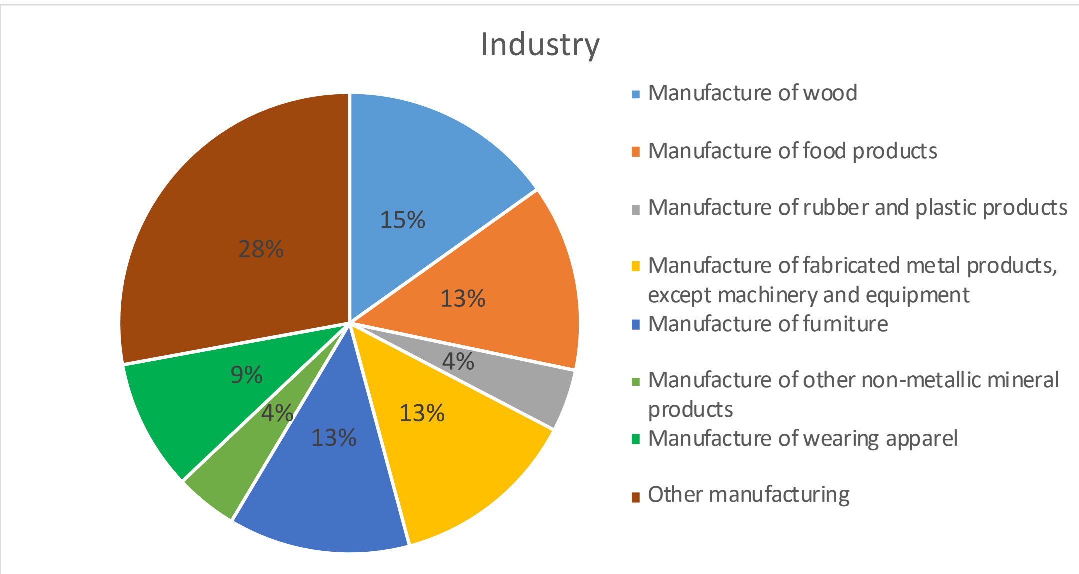

Figure 15. Indursty of respondent company (created by author)

Of described industries the highest percentage belongs to other manufacturing industries with 28%. As it was described previously it consists of other small percentage manufacture answers. The overall highest result from the chart is manufacture of wood industries with 15%. Then three industries have the same number of percentages 13% which belongs to manufacture of food products, manufacture of fabricated metal products, except machinery and equipment and manufacture of furniture. Manufacture of wearing apparel industries has only 9%. The lowest number of industries, only with 4% which are manufacture of other non-metallic mineral products and manufacture of rubber and plastic products.

Next question is regarding the annual turnover of the manufacturing company. Annual turnover is also an important factor as it has an impact on decision making in the company. It influences the ability to implement certain practices or technologies. In our example it could affect lean production and digital manufacturing implementation in the business. Limited investments can result in difficult decision making. Below are the results of annual turnover in Lithuanian manufacturing company.

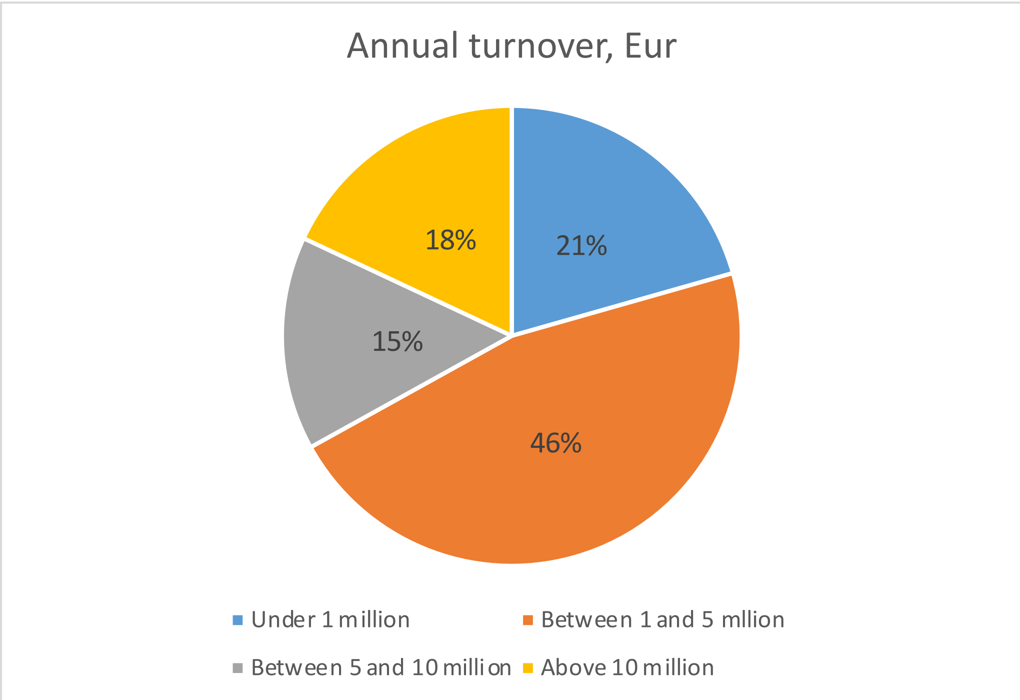

Figure 16. Annual turnover of surveyed company (created by author)

The chart above describes annual turnover of a company. The most annual turnover is between 1 and 5 million which is almost half percentage of companies with 46%. Second highest score is under 1 million with 21% percentage of companies. Next annual turnover is above 10 million with only 18% percentage of companies. Lowest percentage of companies choose that their annual turnover is between 5 and 10 million.

Next question of the survey was regarding how many employees work in the company. This helps to show the size of the company as well as how many resources it has available. Smaller companies might have a less possibilities for implementation of certain lean production and digital manufacturing.

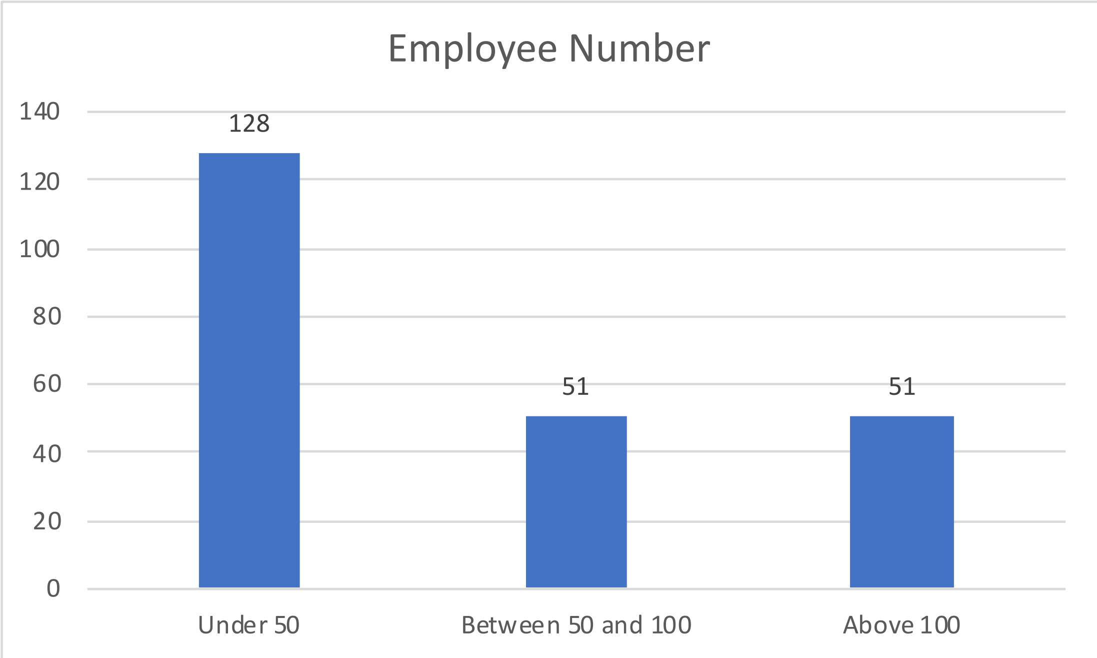

Figure 17. Employee number in surveyed company (created by author)

Most of the companies have under 50 employees working which has the highest score in the chart - 128. Companies that have between 50 and 100 employees or above 100 employees working in their companies have the same number of responses – 51. This concludes, that most of the manufacturing companies in Lithuania are small sized with having under 50 employees.

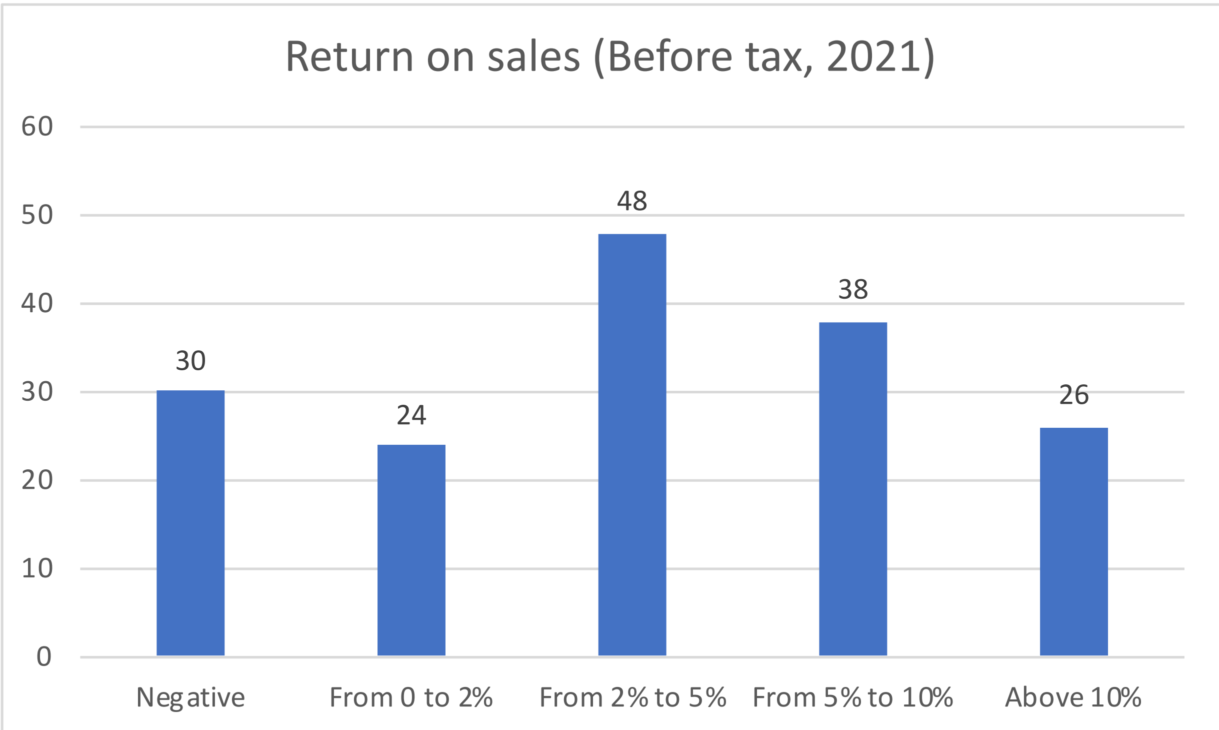

Figure 18. Company return on sales (before tax, 2021) (created by author)

From the chart above 30 companies choose that they have a negative percentage return on sales. 24 companies choose that theirs return on sale has from 0 to 2% which is smallest number on the chart. The return on sales from 2% to 5% is the highest number chosen by the companies with 48 score points. The second highest score of return on sales is with 38 score points, which is from 5% to 10%. Last result of the chart is above 10% which has been chosen by 26 companies.

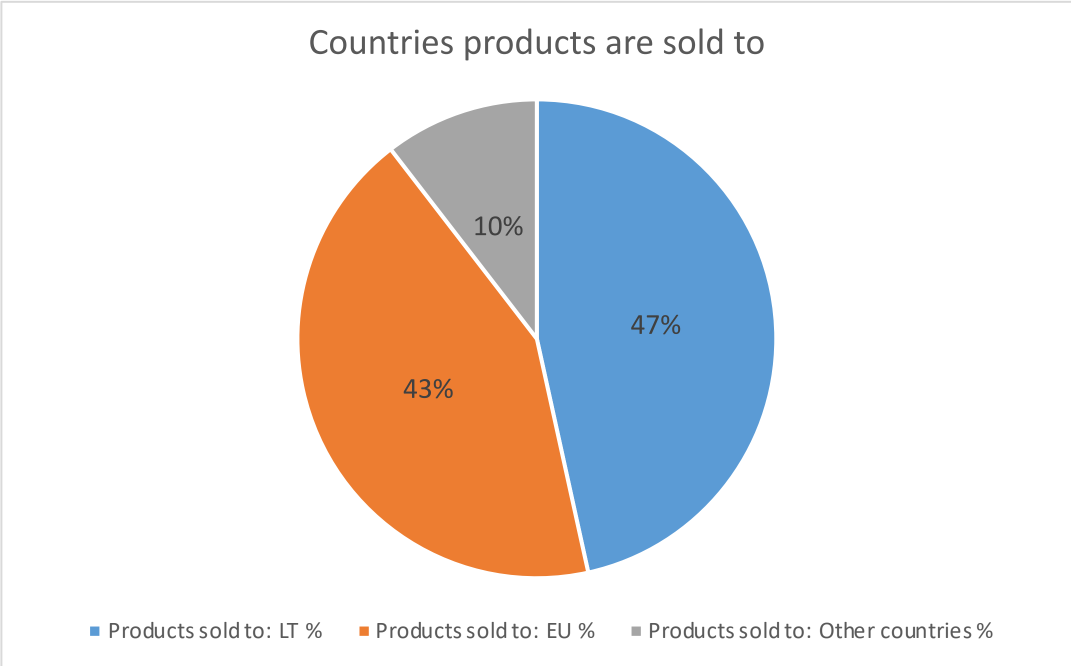

Figure 19. Countries to which manufacturing company products are sold to (created by author)

Chart above describes to which countries companies sell their products. Highest percentage of 47% are products sold to Lithuania. Very similar percentage of 43% are sold to European countries. Lowest percentage of products are sold to other countries with only 10%.

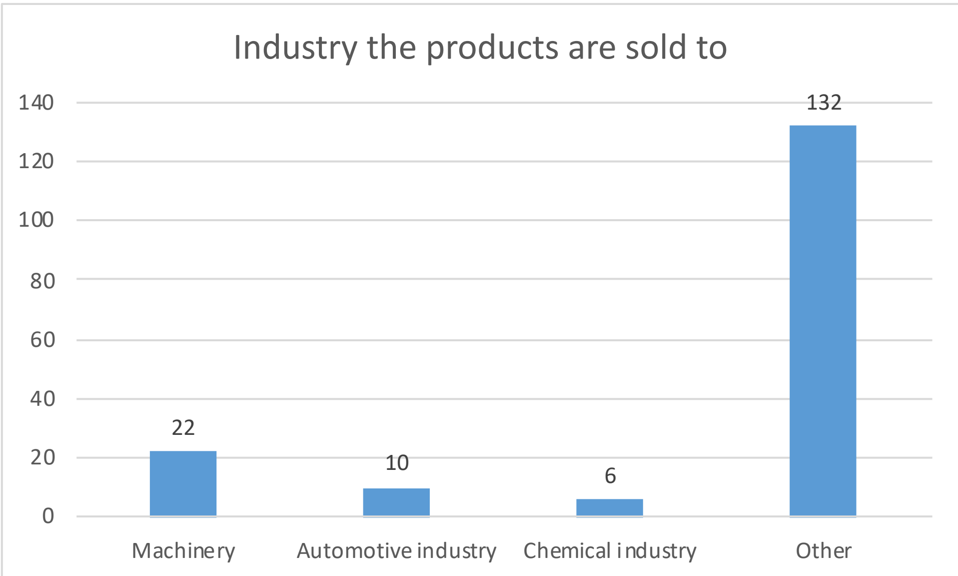

Figure 20. Industries to which manufacturing company products are sold to (created by author)

Chart above describes to which industry products are sold to. 132 companies chose that they sell products to other industries, which is highest number of answers. Second highest number of products sold is to machinery industry with 22 companies. Only 10 companies selected that they sell their products to automotive industry. Lowest number got chemical industry with only 6 companies.

4.2. Diffusion of lean production practices

First of all, analysis was done of what lean production methods are used in manufacturing companies. This shows what methods are most common for implementation in companies as well as which are least popular. The results can be seen in figure 21.

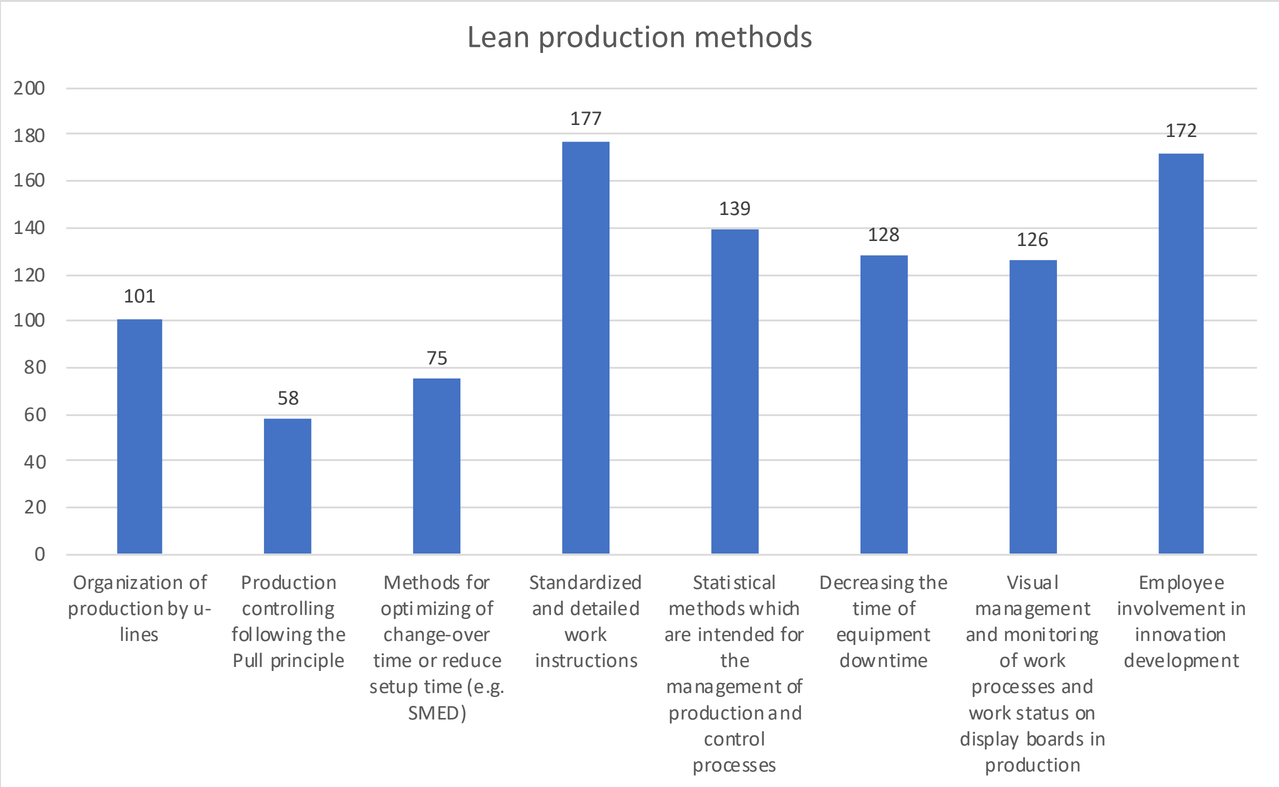

Figure 21. Lean production methods implemented in Lithuanian manufacturing companies

From the bar chart it can be seen that most commonly implemented lean production methods are regarding the standardization of work instructions, which have are used by 177 companies, and employee involvement in development, which has been implemented by 172 companies. This concludes that approximately 70% of questioned manufacturing companies implement mentioned lean production methods. The lowest implementation rate is regarding production controlling following the pull principle with only 58 respondents using this method. Methods for optimizing of change-over time or reduce setup time was also one of the lowest use level with positive answers from 75 of the respondents.

4.3. Diffusion of digital manufacturing innovations

Five groups of digital manufacturing innovations have been analyzed. The following groups are: production management software, remote data transfer, automation and robotics, additive manufacturing technologies, simulation modeling and data analysis.

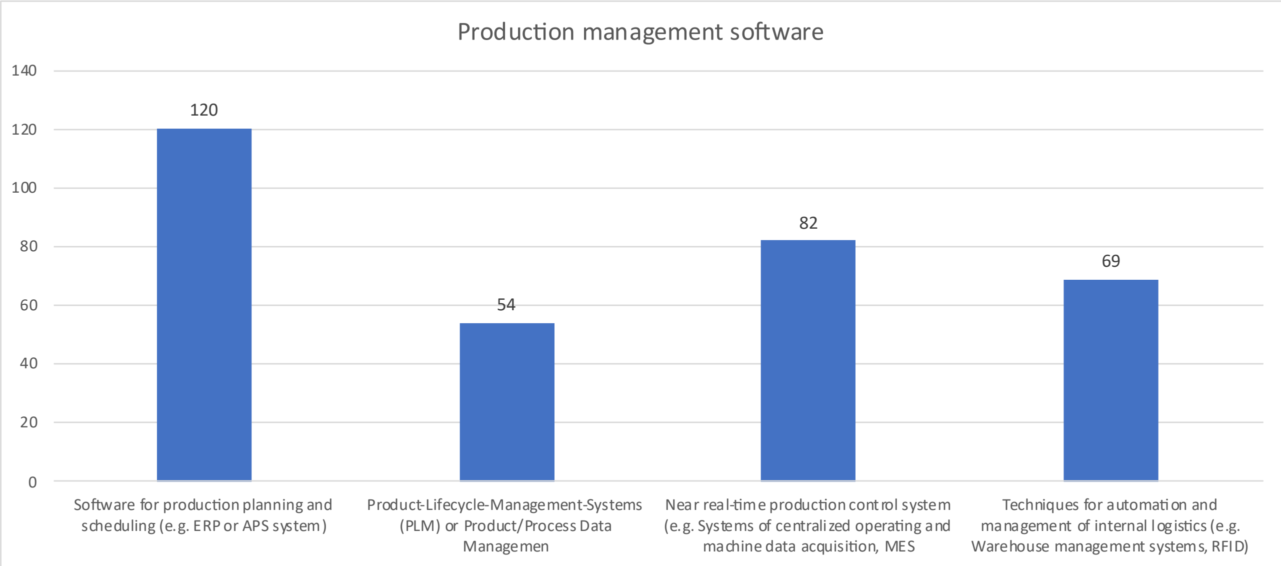

Figure 22. Production management software implementation rate in Lithuanian manufacturing companies

The most popular digital manufacturing method of production management software is software for production planning and scheduling (e.g. ERP or APS system). Almost half of the respondents (120) have it implemented in their manufacturing companies. The least popular is Product-Lifecycle-Management-Systems (PLM) or Product/Process Data Management software with 54 positive responses.

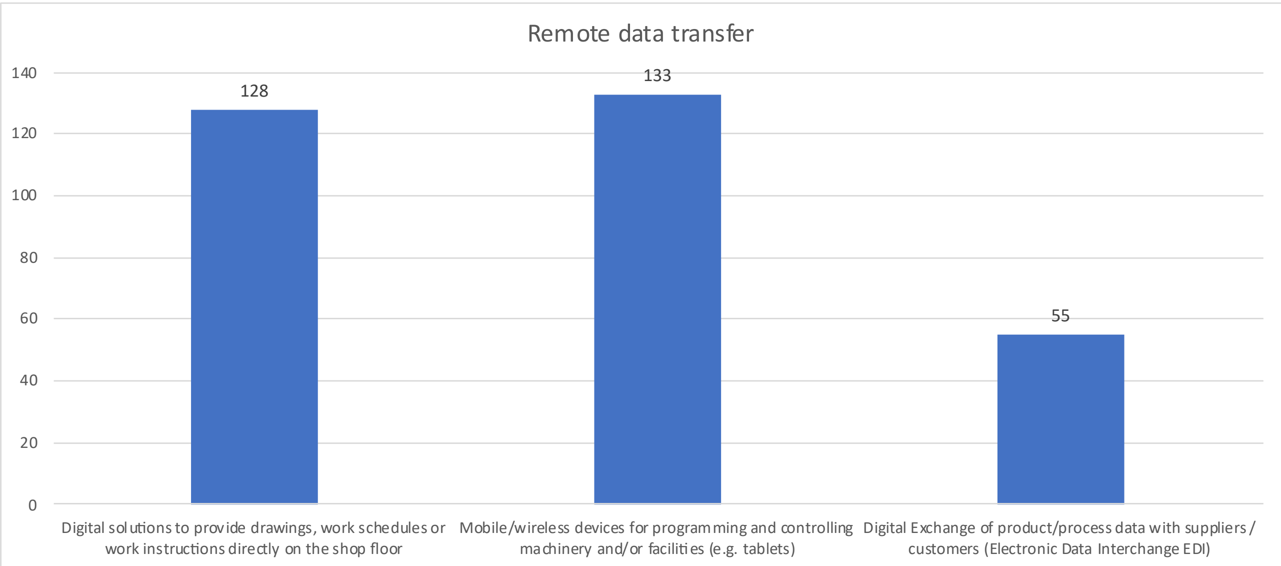

Figure 23. Remote data transfer innovation implementation rate in Lithuanian manufacturing companies

The biggest number of positive responses have come for implementation of remote data transfer technologies. Mobile/wireless devices for programming and controlling machinery and/or facilities (e.g. tablets) had the biggest response rate with 133 answers. 128 manufacturing companies also implemented digital solutions to provide drawings, work schedules or work instructions directly on the shop floor. The lowest rate for remote data transfer was for digital exchange of product/process data with suppliers / customers (Electronic Data Interchange EDI) with 58 manufacturing companies implementing this digital manufacturing tool.

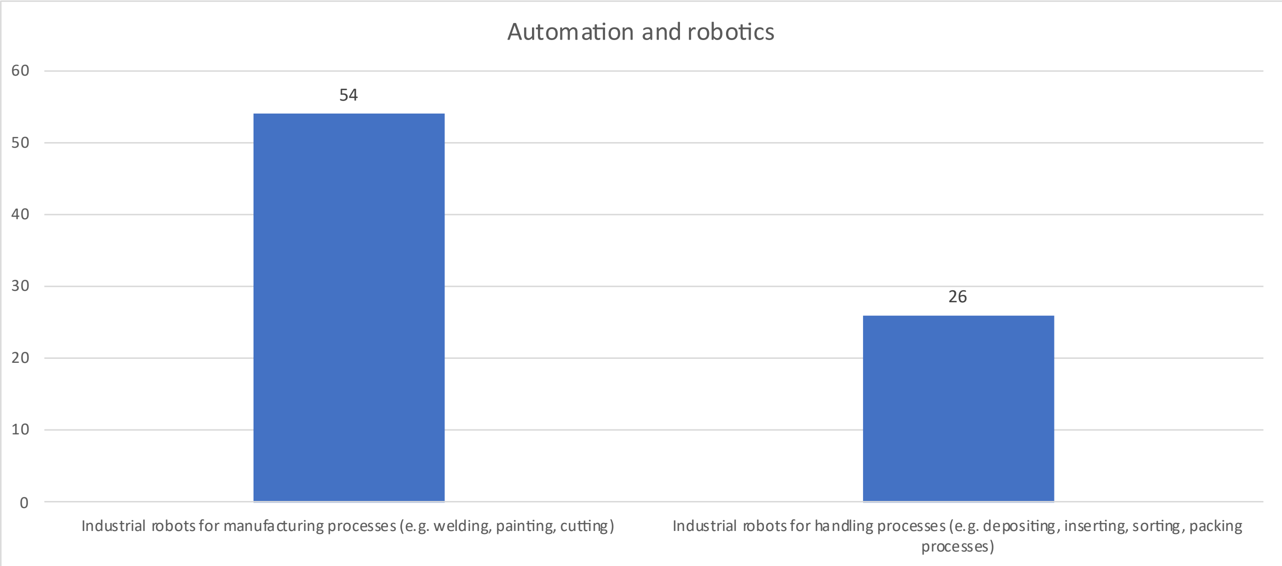

Figure 24 Automation and robotics implementation rate in Lithuanian manufacturing companies

Automation and robotics digital manufacturing technologies can be seen as having lower implementation rate comparing to the previous groups. 54 companies use industrial robots for manufacturing processes (e.g. welding, painting, cutting) and only 26 manufacturing companies use Industrial robots for manufacturing processes (e.g. welding, painting, cutting).

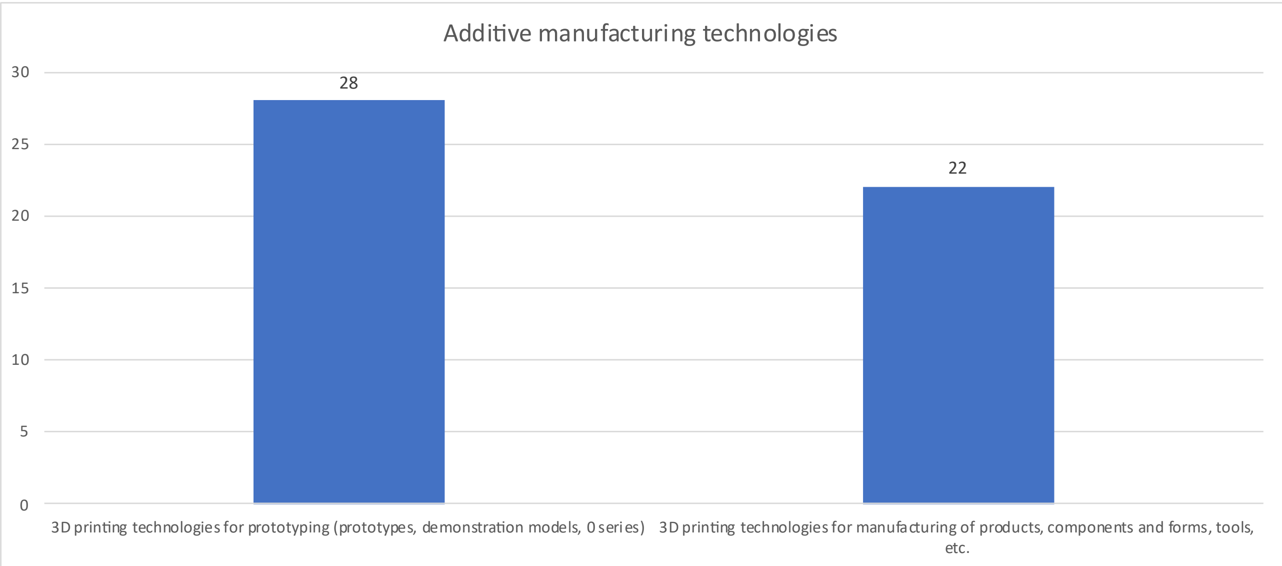

Figure 25 Additive manufacturing technologies implementation rate in Lithuanian manufacturing companies

One of the lowest response rates for additive manufacturing technologies. The highest implementation rate for this group is 28 companies. They are using 3D printing technologies for prototyping (prototypes, demonstration models, 0 series). Only 22 companies are using 3D printing technologies for manufacturing of products, components and forms, tools, etc. This shows that usage of 3D technologies is not popular among Lithuanian manufacturing companies.

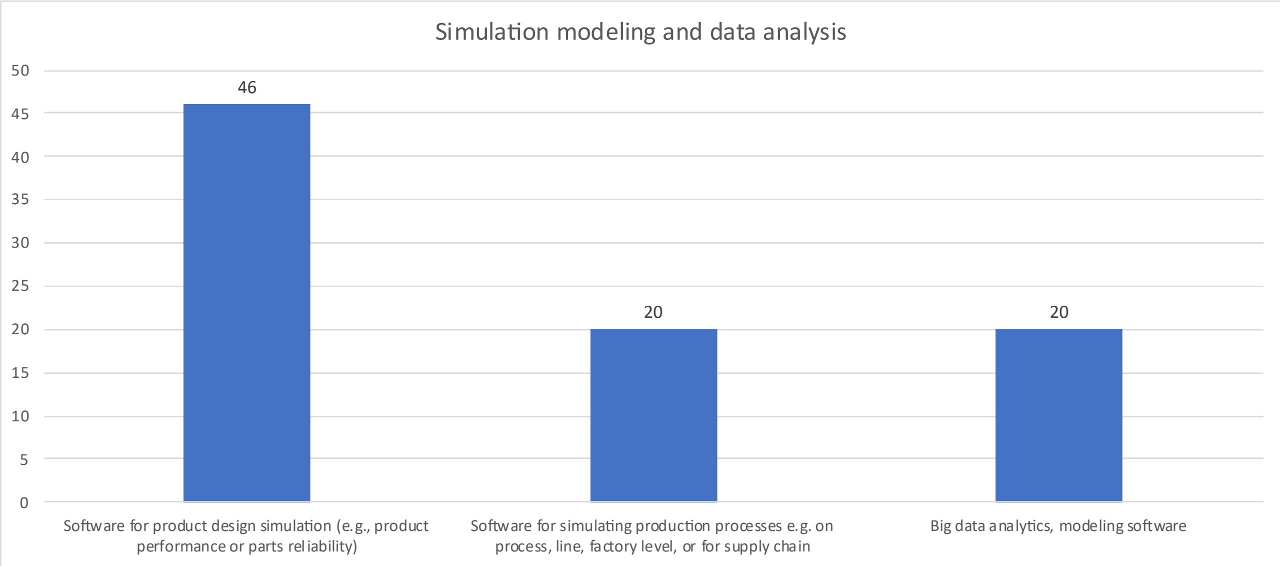

Figure 26 Simulation modeling and data analysis implementation rate in Lithuanian manufacturing companies

Simulation modeling and data analysis technologies also are not commonly used in Lithuanian manufacturing companies. Software for product design simulation (e.g., product performance or parts reliability) is the most popular amongst them with positive response of 46 respondents. Overall the least popular digital manufacturing technologies are: Software for simulating production processes e.g. on process, line, factory level, or for supply chain and big data analytics, modeling software. Only 20 companies have implemented them.

To sum up, it can be seen that lean production methods have a higher implementation rate in Lithuanian manufacturing companies with the highest being standardized and detailed work instructions (177) and lowest - Production controlling following the Pull principle (58). Digital manufacturing technology most popularly used is mobile/wireless devices for programming and controlling machinery and/or facilities (133) and least popular - software for simulating production processes (20) and big data analytics, modeling software (20).

4.4. Hypothesis testing

4.4.1. Interrelation of lean and digital manufacturing (H1)

First hypothesis states that there is a relationship between digital technologies and lean production. To confirm it Spearman correlation coefficient was chosen as it is recommended when the distribution is not close to normal. In the table below the results of correlation check can be seen.

Table 7 Interrelation of lean and digital manufacturing

		Lean Production	Digital Technologies
Lean Production	Correlation Coefficient	1.000	.663*
	Sig. (2-tailed)	.	.000
	N	207	179
Digital Technologies	Correlation Coefficient	.663*	1.000
	Sig. (2-tailed)	.000	.
	N	179	207

* Significant when p<0.01

Relationship between Lean production and Digital technologies is statistically significant (p value less than 0.01). The relationship between this variables is positive and strong (*r* = 0.663) according to the authors Sarstedt and Mooi (2019), Stockemer (2019). Their description of relationship interpretation can be seen in table below.

Table 8. Sarstedt and Mooi (2019) and Stockemer (2019) interpretations of relationships

Stockemer (2019)		Sarstedt and Mooi (2019)	
Correlation coefficient	Interpretation	Correlation coefficient	Interpretation
Below 0.30	Weak relationship	0.30 – 0.45	Weak relationship
0.30 – 0.49	Moderate relationship	0.45 – 0.60	Moderate relationship
Above 0.49	Strong relationship	Above 0.60	Strong relationship

This would mean lean production reinforce digital technologies and digital technologies reinforce internal lean production. Further linear regression has been used to analyze the effects of lean production and digital technologies. The main results can be seen in the table below.

Table 9. Linear regression of lean production and digital manufacturing

	Linear
R	0.672
R Square	0.452
Sig.	0.000
Beta	0.672

R = 0.672 and proves a strong relationship between lean production reinforce digital technologies. The determination coefficient (R Square) R2 = 0.452, which means that almost a half of the variance can be explained by the model. Beta shows that the effect is positive. Which means that lean production strongly can improve implemented digital technologies and vice versa. To sum up, there is an interrelation between lean production and digital technologies and the H1 has been proven.

4.4.2. Lean production effect on business performance (H2)

Next lean production effect on business performance has been reviewed. Spearman correlation coefficient was used to review if there is a relationship between the two variables. The results are shown in table 9.

Table 10. Lean production effect on business performance correlation

		Lean Production	Business performance
Lean Production	Correlation Coefficient	1.000	.239*
	Sig. (2-tailed)	.	.001
	N	207	207
Business performance	Correlation Coefficient	.239*	1.000
	Sig. (2-tailed)	.001	.
	N	207	207

* Significant when p<0.01

The results indicate that there is a relationship between lean production and business performance. The relationship between the variables is positive, however it is below moderate (r = 0.239). This shows that lean production has some effect on business performance. To further analyze the results linear regression has been done.

Table 11. Lean production effect on business performance linear regression

	Linear
R	.241
R Square	.058
Sig.	.000
Beta	.241

From the linear regression the Beta coefficient confirms there is a positive impact of lean production on business performance. This means that implementation of lean production tools can improve the performance of a company in such areas as: sales increase, market share and quality of the production.

4.4.3. Digital manufacturing effect on business performance (H3)

The third raised hypothesis has been concerning the positive effect of digital manufacturing on business performance.

Table 12. Digital manufacturing effect on business performance correlation

		Digital manufacturing	Business performance
Digital manufacturing	Correlation Coefficient	1.000	.250*
	Sig. (2-tailed)	.	.000
	N	208	208
Business performance	Correlation Coefficient	.250*	1.000
	Sig. (2-tailed)	.000	.
	N	208	208

The results show that there is a significant relationship between digital manufacturing and business performance. It is positive but is quite weak (r = 0.250). Comparing lean production relationship with business performance and digital manufacturing relationship they have quite similar values. Next linear regression has been also done to get more insights in the relationship.

Table 13. Digital manufacturing effect on business performance linear regression

	Linear
R	.244
R Square	.060
Sig.	.000
Beta	.244

Beta coefficient is positive and is equal to 0.244. This means that the hypothesis is proved and digital manufacturing has an effect on business performance. It can be concluded that both lean production and digital technologies have similar effects on business performance. Their effect is positive and digital manufacturing, same as lean production, can improve business performance areas - sales increase, market share and quality of the production.

4.4.4. Lean and digital manufacturing matching effect on business performance (H4)

Fourth hypothesis states that digital manufacturing and lean production matching can affect business performance. This would indicate that companies should implement both lean production and digital manufacturing technologies at a similar rate for the possible best increase for business performance. The results of matching can be seen in table 13.

Table 14. Lean and digital manufacturing matching effect on business performance correlation

		Digital manufacturing and lean production matching	Business performance
Digital manufacturing and lean production matching	Correlation Coefficient	1.000	.100
	Sig. (2-tailed)	.	.182
	N	179	179
Business performance	Correlation Coefficient	.100	1.000
	Sig. (2-tailed)	.182	.
	N	179	179

From the results it can be concluded that digital manufacturing and lean production matching has no significant effect on business performance. This means there is no important influence to it if both lean and digital manufacturing tools and technologies are implemented at the same rate. From previous analysis it was confirmed that both have influence on business performance, however they can be implemented separately with regard to Lithuanian manufacturing companies preference.

To sum up the results of the hypothesis – three out of four have been verified. In the table below the overall results of the hypothesis can be seen.

Table 15. Hypothesis results

Hypothesis	**Result**
H1 - Lean production and digital manufacturing reinforce each other and correlate positively	Accepted
H2 - Lean production has positive effect on business performance	Accepted
H3 - Digital manufacturing has positive effect on business performance	Accepted
H4 - Lean and digital manufacturing matching has positive effect on business performance	Rejected

The fourth hypothesis has not been proved and thus concludes that lean production and digital manufacturing tools do not need to be implemented at the same rate. However, from first three hypothesis we can make several positive remarks. Lean production and digital technologies positively correlate and can improve each other if implemented correctly. Lean production does have an effect on business performance measurements as well as digital manufacturing does too.

First hypothesis was accepted. According to the findings a positive significant relationships has been determined between lean production and digital technologies. Which means that lean production and digital manufacturing can improve one another if the right tools and technologies are chosen.

Second hypothesis has been also accepted. This shows that lean production has a positive significant relationship with business performance. Through lean method implementation companies can improve their activities or processes which results in better performance.

Third hypothesis has been accepted as well and digital manufacturing has a positive significant relationship with business performance. The results have proven that attention to the technologies and practices of this methodology can have a significant improvement in firms overall results. This as well as lean production can gain better business performance results for a firm.

However, the fourth hypothesis has been rejected. This shows that there is no need to implement both lean production and digital technologies on the same level in order to affect business performance. Firms can choose if they implement only lean methods or digital manufacturing methods as they improve business performance but there is no additional effect if they are implemented on the same level.

Conclusions

1. The current situation of lean production and digital manufacturing effect on business performance has been reviewed and their matching effect on business performance. Currently there are few researches regarding lean production or digital manufacturing effect on business performance and the field is not fully analyzed. From the current researches it was found that some of the practices can have a positive impact on business performance while others might not. The effect of matching lean production and digital manufacturing in order to increase business performance is unclear in having a positive impact.

2.From scientific literature analysis and research it was found that lean production first emerging in automotive companies has been widely used in manufacturing and other industry companies. Many different authors have acknowledged benefits of lean and lean tools implementation which can result in improvements of production, quality, waste management and other benefits. Digital manufacturing technologies have been found to have increasing attention for implementation in manufacturing companies due to Industry 4.0. Implementation of the digital manufacturing technologies can be split into two groups: “front-end technologies” and “back-end technologies”. According to the authors, the industry can benefit from the integration of digital manufacturing. The technologies can increase productivity, better resource use and quality of the products. Regarding the matching of lean production and digital technologies few contradictory views have been discovered by separate researchers: lean production methodology supporting digital manufacturing technologies; lean production methodology supporting digital manufacturing technologies; lean production and digital manufacturing support each other and have a positive impact on performance when implemented together. However, some authors have also indicated that digital manufacturing and lean production do not have any effect on performance if implemented together. Following the findings a framework has been developed to which specifies how lean and digital manufacturing effect each other as well as business performance and if their matching has an effect on business performance.

3. The secondary publicly unavailable empirical data was used for the master thesis. The empirical data was collected as part of the European Union’s Horizon 2020 research and innovation program. The sample (N=250) contains data collected in Lithuanian manufacturing companies. The questions relating to the company characteristics, lean production, digital manufacturing and business performance have been selected. The reliability analysis has been done and found that internal lean production and digital manufacturing technology Cronbach alphas are according to the standards and can be used for further analysis.

4. The results of empirical data analysis have indicted the characteristic of manufacturing companies in Lithuania. Most of the companies are smaller size with under 50 employees (128), the annual turnover of the companies are from 1 to 5 million euros (46%) and most of the products are sold in Lithuania or European Union countries with the sum of 90% answers stating it. Lean production practices have a higher implementation rate in Lithuanian manufacturing companies with the highest being standardized and detailed work instructions (177) and lowest - Production controlling following the Pull principle (58). Digital manufacturing technology most popularly used is mobile/wireless devices for programming and controlling machinery and/or facilities (133) and least popular - software for simulating production processes (20) and big data analytics, modeling software (20). The result of regression testing have proved three out of four hypothesis.

First hypothesis was proved and it can be stated that according to the findings in this paper a positive significant relationships has been determined between lean production and digital technologies. Which means that one can improve the other if the right tools are chosen. By evaluating the best tools and practices from both methodologies manufacturing industry companies can choose to fill the gaps that one of the methods does not cover.

Second hypothesis has confirmed that lean production has a positive significant relationship with business performance. This shows that lean production fulfills one of the main goals of their methodology, which is improving performance. Through lean method implementation companies can eliminate waste, lower production time, organize their work and this way improve their performance which can gain them a competitive advantage.

Third hypothesis has confirmed digital manufacturing having a positive significant relationship with business performance. Although digital manufacturing is quite more recent topic it has been widely reviewed by companies. The results have proven that attention to the technologies and practices of this methodology can have a significant improvement in firms overall results. This as well as lean production can gain company competitive advantage, better business performance results.

However, the fourth hypothesis has been denied and it can be concluded that there is no need to implement both lean production and digital technologies on the same level in order to affect business performance. This means that the company can choose if they want to implement only lean methods or digital manufacturing methods as they can improve business performance on their own. There is no additional effect if lean production and digital are implemented step by step on the same extent.

Recommendations

Based on the analysis of the scientific literature and the conclusions of the conducted research, the following recommendations could be made:

- After data analysis it was confirmed that both lean production and digital technologies have a positive impact on business performance when implemented in manufacturing companies. However, the scientific research has shown that due to big number of different choices presented for companies to get the best results from implementation of these practices the tools and methods have to be carefully considered and even adjusted if needed keeping in mind the goals and capabilities of each business.
- Empirical data analysis has proved that there is no need to match lean production and digital manufacturing technologies in order to get a positive effect on the business performance indicators. It shows that manufacturing companies can choose if they would be implementing more lean production practices or digital manufacturing practices. However, it has also shown that implementation of both methodology tools can have a significant positive impact on other tools that are already being used of lean production or digital manufacturing no matter the implementation level.

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Appendices

Appendix 1. European manufacturing company survey

Is your factory a part of multi-site company?
-Yes
-No

Please indicate your company sector.
-Open Question

To which countries are the products sold to?
-Lithuania
-European Union
-Other countries

To which industries are your products sold to?
-Product manufacturing
-Chemistry
-Automotive manufacturing
-Other sectors

Measures of lean methods
Which of the following organizational concepts are currently used in your factory? 0 – No; 1 – Yes.
If Yes, what is the extent of the used potential of the method? 1 – Low; 2 – Medium; 3 – High.
(Extent of the used potential - Extent of actual utilization compared to the most reasonable maximum potential utilization in your factory: Extent of the utilized potential 'low' for an initial attempt to utilize, 'medium' for partly utilized, and 'high' for extensive utilization.)
- Standardized and detailed work instructions (e.g., standard operation procedures SOP, MOST);
- Measures to improve internal logistics (e.g., Value Stream Mapping/Design, changed spatial arrangements of production steps);
- Fixed process flows to reduce setup time or optimize change-over time (e.g., SMED, QCO);
- KANBAN, Internal zero-buffer principle);
- Customer- or product-oriented lines/cells in the factory (instead of task-/operation-structured shop floors);
- Detailed regulations on the arrangement and setting of the work equipment and storage of intermediary products (e.g., Method of 5S);
- Decreasing the time of equipment downtime (Total Productive/ Preventive Maintenance);
- SPC, process capability analysis);
- Display boards in production to illustrate work processes and work status (e.g., Visual Management);
- Involvement of employees into improvement (e.g., A3, KAIZEN, PDCA, etc.);
- Integration of tasks (planning, operating or controlling functions with the machine operator);
- Involvement of customers into production (e.g., sharing demand information, joint product development);
- Inventory managed by suppliers, exchange of cost structure information);
- Collecting supplier feedback (e.g., sharing information on quality and delivery problems).

Measures of digital manufacturing innovations
Which of the following technologies are currently used in your factory? 0 – No; 1 – Yes.
If Yes, What is the extent of the used potential of the method? 1 -Low; 2 - Medium; 3 – High.
Extent of used potential - Extent of actual utilization compared to the most reasonable maximum

potential utilization in your factory: Extent of utilized potential “low” for an initial attempt to utilize, “medium” for partly utilized and “high” for extensive utilization.

- Mobile/wireless devices for programming and controlling facilities and machinery (e.g., tablets);
- Digital solutions to provide drawings, work schedules or work instructions directly on the shop floor;
- Software for production planning and scheduling (e.g., ERP system);
- Digital Exchange of product/process data with suppliers/ customers (Electronic Data Interchange EDI);
- Near real-time production control system (e.g., Systems of centralized operating and machine data acquisition, MES);
- Systems for automation and management of internal logistics (e.g., Warehouse management systems, RFID);
- Virtual Reality or simulation for product design or product development (e.g., FEM, Digital Prototyping, computer models);
- Industrial robots for manufacturing processes (e.g., welding, painting, cutting);
- Industrial robots for handling processes (e.g., depositing, assembling, sorting, packing processes, AGV);
- 3D printing technologies for prototyping (prototypes, demonstration models, 0 series);
- 3D printing technologies for manufacturing of products, components and forms, tools, etc.).

Measurement of business performance

Indicate how well your factory performed compared to its competition within your industry along these different performance dimensions, 1 – Much worse, 2 – Somewhat worse, 3 – About the same, 4 – Somewhat better , 5 – Much better.

-Sales growth
-Market share
-Product quality

Please characterize your factory:

Annual turnover

- in 2021 XX million €

Number of employees

- in 2021 XX number

Return on sales (before tax, 2021)

- negative
- 0 up to 2%
- >2 up to 5%
- >5 up to 10%
- >10%

-**Establishment year**

-Open question.

* - European manufacturing survey (EMS, 2021)