Process innovation is like riding a Tandem:

Complementarities between organisational and technological process innovation and their effects operational efficiency in the manufacturing industry

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Abstract

This study assesses the relationship between technological process innovation and organisational process innovation and their combined effect on operational efficiency. Additionally, where other studies often ignore the direction of the relationship between technological and organisational innovation this study tries to identify whether organisational and technological process innovations interact sequentially or simultaneously. The empirical data was collected through the European Manufacturing Survey (EMS) and five interviews with production managers in manufacturing firms. The results show no significant complementary effect of technological and organisational process innovation on operational efficiency. Also no direct effects were identified. The interviews showed that manufacturing firms can adopt new technological and organisational process innovations simultaneously and sequentially in the industry 4.0 context. The results imply that managers should pursue both technological and organisational innovation in congruence.

Keywords: technological process innovation, organisational process innovation, manufacturing firms, complementarities, synergies, operational efficiency.

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Chapter 1 - Introduction

At the moment one of the most prompting challenges for the manufacturing industry is the digital transformation (Chiarello et al., 2018). This digital transformation is captured under the umbrella concept industry 4.0 (Culot et al., 2020). This concept is described as the integration of several new concepts and technologies and has smart manufacturing at its bases. Industry 4.0 has an enormous complex technological architecture, which causes various problems for manufacturing companies. Therefore the effective adoption of industry 4.0 technologies is an important subject for research. The core of industry 4.0 are new, highly digitalised manufacturing systems (i.e, smart manufacturing technologies). Smart manufacturing technologies lead to cost reduction, increased productivity (Schroeder et al, 2019), less failures and down time (Davies, 2015) and increased quality (Moeuf et al., 2017). A report from McKinsey (2016) stated that switching to smart manufacturing methods can increase productivity by 45%-55%. Logically, firms invest heavily in the implementation of these new production technologies (Frank et al., 2019). There is no doubt amongst researchers that these technological process innovation are essential for a manufacturing firms future competitiveness (Duman & Akdemir, 2021).

Innovation researchers have suggested that a firms competitiveness does not only rely on technological innovation, but also on organisational innovation (Evangelista and Vezzani, 2010; Mol and Birkinshaw; 2009; Hamel, 2006). Organisational innovation such as lean or total quality management practices also enhance firm performance (Walker et al, 2011; Hamel, 2006; Armbruster et al, 2008; Mol & Birkinshaw, 2009). In contrast to technological innovation, organisational innovation research has received limited attention due to a lack of established definitions and measurements, complexity and ambiguity (Damanpour, 2014; Cerne et al., 2016; Sapprasert & Claussen, 2012).

Historically, research on innovation types has followed a technological trajectory (Damanpour & Arravind, 2012). Assuming that organisations mainly gain competitive advantage with new technological product or process innovations (Damanpour, 2020). Even though researchers have emphasized that a technological-centric view of innovation is insufficient and that organisational aspects are essential for sustainable competitive advantage and to make technological innovations work (Mol & Birkinshaw, 2006; Hamel, 2006; Arranz et al., 2019), the technological determinism continues to prevail (Kopp et al., 2016). To some extent this is a logical development because industry 4.0 is linked to groundbreaking technological innovations and is foremost a technological centric development (e.g., Frank et al, 2019). Consequently, scholars and practitioners often forget or underestimate the impact of organisational innovations (Khosravi et al., 2018). However, innovations seldom function in isolation (Rosenberg, 1979). Organisations that introduce new technological innovations, without considering the changes in the organisational side of the organisation, often face problems and fail to capture the full value (Mol & Birkinshaw, 2009). Implying that organisational innovations and technological innovations cannot be researched as separate departments but need to be researched in an integrative manor (Damanpour, 2020). Therefore, innovation research has shifted its focus to studying various types of innovation and their combined effects on firm performance (e.g. Camison & Villar-Lopez, 2014; Evangelista & Vezanni, 2010; Tavassoli & Karlsson, 2016; Arranz et al, 2019; Battisti & Stoneman, 2010, 2023; Doran, 2012; Lee et al., 2019). This is in line with the socio-technical approach which challenges the technical imperative. The socio-technical approach emphasizes the need to align the 'technical core' and 'social core' of the organisation. The social core refers to employees that work in the organisation and the relationships between them. The technical core embodies the production of goods (Trist, 1981). In this research, I build on this perspective by measuring whether a firms operational efficiency increases when they adopt both organisational process innovations and technological process innovations. Thereby, adding to the still under researched literature of the joint adoption of innovation types and their effects on firm performance measures (Khosravi et al., 2018; Damanpour, 2020). As Damanpour (2020, p. 269) states, 'Yet research on complementarities of technical and nontechnical innovations is in an early stage'. In this research I focus on process innovation instead of for example product innovation because the literature still shows some contradicting empirical findings (e.g. Schmidt & Rammer., Ballot et al., 2015). This research distinguishes between technological process innovation and organisational process innovation, in line with (Edquist & Meeus, 2006; Damanpour et al., 2009). Technological process innovation is defined as new technological elements introduced into an organisations manufacturing process (Meeus & Edquist, 2006). In contrary organisational process innovations, refers to the implementation of a new organizational method in the firm's business practices and workplace organization (OECD, 2005). This research is focused on innovation in the production process, therefore measuring performance with operational efficiency.

Additionally, while other studies often confirm a synergetic relationship between organisational process innovations and technological process innovations, they do not mention how these synergies are formed. Innovation research has discussed sequential and simultaneous interactions between technological process innovations and organisational process innovation (Hollen et al., 2013). The debate about how organisational process innovation and technological process innovation interact is still ongoing and shows conflicting findings (Damanpour., 2020; Arranz et al., 2019). Increasing our understanding on the interplay between technological process innovation and organisational process innovation in the industry 4.0 context becomes increasingly important due to the difficulties that manufacturing firms experience regarding the adoption of smart manufacturing technologies into their workplace (e.g. Raj et al., 2020; Stentoft et al., 2021). Moreover, the average Small and Medium Enterprise (SME) in the manufacturing industry is still in the early stages of adopting smart manufacturing technologies (Van Helmond et al., 2018; Frank et al., 2019). This makes it very interesting to study how these organisations deal with the tensions between technological and organisational factors. Not unsurprisingly, several researcher have called for additional research on the relationship between organisational innovation and technological innovation (Volberda et al., 2013;

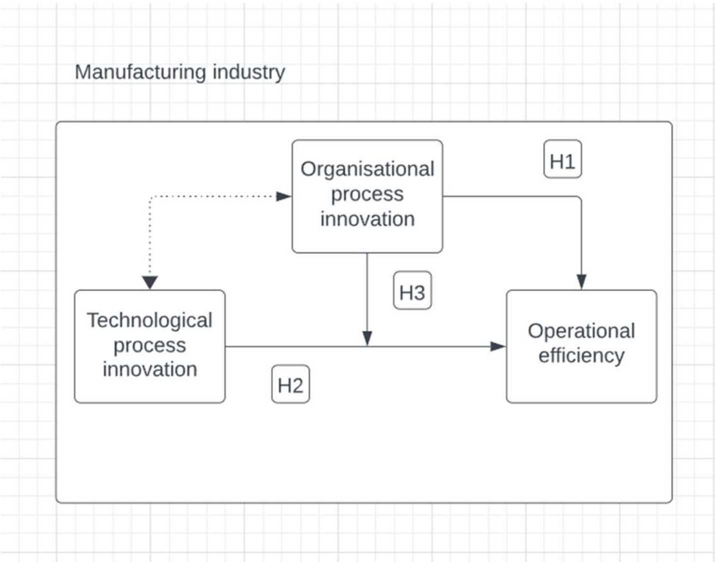
Damanpour, 2020, 2017; Hollen et al., 2013).

So this research has two objectives. First, quantitatively researching if organisational process innovation and technological process innovation have synergetic effects on operational efficiency. Thereby, adding to the still under researched literature of the joint adoption of innovation types and their effect on firm performance measures (Khosravi et al., 2018; Damanpour, 2020). This analysis was done with the EMS innovation survey. This is an innovation survey among 186 Dutch manufacturing firm. Second, additional interviews were held to get a deeper understanding on how synergies between organisational process innovation and technological process innovation are formed in Dutch manufacturing firms. This leads to the following research question: *what is the effect of the joint adoption of technological process innovation and organisational process innovation on operational efficiency, and how is this effectively organised by Dutch manufacturing firms?* This thesis is structured as follows. Chapter 2 includes a relevant review of the literature and provides fitting hypotheses. The method section describes data collection and analysis methods. In the results chapter the findings are presented. And in the discussion and conclusion section the findings are discussed.

Chapter 2 - Theoretical framework

This chapter starts with an extensive elaboration of the general concepts: innovation in general, organisational process innovation, technological process innovation and industry 4.0. Following this, hypotheses will be formulated. The model below shows the conceptual model for this research, which will be elaborated on in the hypotheses development.

Table 2.1 Conceptual model



Note: the dotted line shows the part of the conceptual model that is researched qualitatively.

2.1 What is innovation

The focus of this research is on innovation, however innovation is a very broadly used concept and has different meanings in different contexts. Therefore it is essential to discuss what innovation actually means in this research. Innovation is a complex phenomenon, which received countless definitions. Innovation can be defined as the development and use of new ideas and behaviours (Damanpour et al., 2009). This idea can relate to different unit of analysis: it can be new to the society, industry, organisation, team or individual. In this research the focus is on innovation at organisational level and therefore defines innovation as 'new to the firm'. This definition is still very broad, therefore innovation researchers have created several typologies for innovation. For example OECD (2005) distinguishes between organisational innovation, marketing innovation product innovation and process innovation. Damanpour and Evan (1984) differentiate between technological innovation and administrative innovation. There are many taxonomies for innovation, in the next paragraph I will discuss this in more depth.

2.2 Innovation and firm performance

Innovation and firm performance are complex constructs. Innovation can enhance firm performance in multiple dimensions. Generally, the literature distinguishes between four different firm performance dimensions for measuring innovation outcomes: innovative performance, production performance, market performance and financial performance (Gunday et al., 2011). This research focuses on innovation in the production process, making the production performance dimension most applicable for measuring performance. To measure production performance this research uses operational efficiency, which refers to achieving the same output with fewer resources or achieving higher output with the same resources in production (Ichniowski et al., 1997).

2.3 Technological process innovation and organisational process innovation

Innovation researchers have distinguished between technological innovation and organisational innovation for a long time (Damanpour & Evan, 1984; Daft, 1978). This differentiation is firmly established in the extant literature (Damanpour & Aravind, 2012). Damanpour and Evan (1984) differentiated between technological process innovation which is associated with the 'technical core' of the firm and administrative process innovation which is related to the 'social core' of the organisation. Edquist and colleagues distinguished between two types of process innovation; technological and organisational (Edquist et al, 2001; Meeus and Edquist, 2006). Technological process innovation refers to new technological elements introduced into an organisations manufacturing process. It refers to all activities that are focused on transforming inputs into products (e.g. new production machinery). So technological process innovation is directly associated with the production process. On the other hand organisational process innovation is associated with new organizational methods in the firm's business practices and workplace. It has no technological elements and is more indirectly related to the production process (Edquist, 2001). In practice this distinction is difficult to sustain because nowadays many processes incorporate both technological and organisational aspects. For example, lean often involves the use of new material processing technologies as well as new work procedures (Womack et al., 1990). Nonetheless, in theory building this conceptualisation has proven to be useful (Edquist, 2001).

It is noteworthy that organisational process innovation has received numerous definitions and conceptualisations, see appendix 1 for an overview. (Damanpour, 2014). This is because the literature on organisational innovation is scattered (Cerne et al., 2016). It was first referred to as administrative innovation, defined as new approaches and management practices to motivate employees, change strategy and structure of tasks and units and modify organization's processes (Daft, 1978, Damanpour & Evan, 1984; Damanpour et al., 1989). More recent research refer to management innovation (Hamel, 2006; Mol & Birkinshaw, 2009; Damanpour, 2020), managerial innovation (Damanpour & Aravind, 2012) or organisational innovation (OECD, 2005; Armbruster et al 2006,2008; Camison & Villar-lopez, 2014; Arranz et al 2019; Battisti & Stoneman 2023). According to Damanpour and Aravind (2012) these definitions have significant overlap. In this study I follow the definition and typology from Edquist and Meeuw (2006), which relates to managerial and management innovation (Damanpour & Arravind, 2012). The primary difference from other definitions provided by OECD

(2005), Armbruster et al., (2008) and Battisti & Stoneman (2010) is that they include inter-organisational innovations. While this is very useful, it is not the focus of this research.

2.4 Defining Industry 4.0

Industry 4.0 is an initiative from the German government to develop advanced manufacturing production systems to increase productivity and efficiency of the manufacturing industry (Kagermann et al., 2013). This concept embodies a new phase in the manufacturing industry, characterized by the incorporation of new technologies that enhance the value throughout the entire product life cycle (Kagermann et al., 2013). Industry 4.0 requires a socio-technical development of the human role in production systems (i.e. Smart working), where activities are performed in cooperation with smart manufacturing systems. Industry 4.0 is based on the concept of advanced manufacturing technologies, or also known as Smart Manufacturing technologies (Frank et al., 2019). Zheng et al (2018) refer to smart manufacturing as 'fully integrated and collaborative manufacturing systems that respond in real time to meet the changing demands and conditions in factories and supply networks and satisfy varying customer needs' (Zheng et al.,2018; p.139).This enhances productivity and flexibility (Schroeder et al., 2019). Some examples of smart manufacturing technologies are; cloud, internet of things, machine to machine learning, sensors and artificial intelligence and flexible lines for a more extensive overview look at (e.g. Frank et al, 2019).

2.5 Effect of organisational and technological process innovation on operational efficiency

Organisational process innovation is one of the most important sources for sustainable competitive advantage (Mol & Birkinshaw, 2009). This is because non-technological innovations are harder to replicate (Teece, 2007). The argument for organisational innovation as competitive advantage finds it theoretical grounds in the resource based view (RBV). According to the main assumption of RBV only firms with rare, valuable, durable, non-substitutable and inimitable resources will gain sustainable competitive advantage (Barney, 1991). New process technologies can often be bought of the shelve, however organisational innovations are often related with organisational capabilities which have to be build and are hard to replicate. Regarding the impact of organizational process innovation on firm performance, the literature emphasizes the strong relationship between organizational process innovation and productivity outcomes. It suggests that implementing organizational innovations leads to the optimization of resources that are used in production process. This is confirmed by empirical data, for example Black and Lynch (2004) have concluded that around 30% of the productivity improvements in the US manufacturing industry in the 1990s was linked to organisational innovations. Hamel (2006) uses anecdotal evidence, to demonstrate that examples like Toyota lean and the Ford production line have had enormous effects on the productivity of manufacturing firms. Additionally a Dutch institute for applied research showed an increase in productivity of up to 16% for firms who implemented organisational process innovation like lean or autonomous teams (Tottendil et al., 2002).

There is also a very large body of literature that shows the effect of a single organisational innovation or a group of organisational innovations on productivity. For example Belekoukias et al (2014) links certain lean methods such as JIT and kaizen to better operational performance. Kaynak (2003) finds a positive relationship between TQM practices and productivity. Whereas, Staw and Epstein (2000) find no effect of the implementation of TQM in fortune 500 firms on performance. The impact of organisational process innovation on firm performance measures is still under discussion in the literature, however most researchers conclude that organisational innovation has significant impact on productivity (e.g. Mol and Birkinshaw, 2009; Mazzanti et al, 2006; Arranz et al, 2019; Camison & Villar-Lopez, 2014; Armbruster et al., 2008). Some contradicting studies are (Atalay et al., 2013; Abrahamson, 1996; Staw & Epstein, 2000; Wang, 2010). These studies emphasize the technological dominance in innovation. However, Walker et al (2015) analysed empirical data from 44 peer-reviewed journal articles, revealing a positive impact of organisational process innovation on firm performance. In combination with the other studies this should ease the discussion on the impact of organisational process innovation on firm performance, therefore I hypothesize:

Hypotheses 1: Organisational process innovation has a direct positive effect on operational efficiency

There exists a general consensus amongst researchers on the positive effect of new technologies on competitiveness and growth (Koellinger, 2008). There are countless studies that show the effect of TPI on operational performance. Technological advances in production increase quality, costs, flexibility and speed (E.g. Jaikumar & Hayes, 1988). More recent papers show that for example Cyber-physical systems can reduce set-up times, labour and material costs and processing times (Jeschke et al.,2017). Or machine to machine communication can reduce downtime (Mortensen and Madsen, 2018). The relationship between technological advancements and operational efficiency seems straightforward. Nonetheless, TPI does not automatically lead to greater productivity (Brynjolfsson & Hitt, 1998). In the late 1990's the computers did not lead to great productivity improvements. It first needed an extensive restructuring period before the results were visible (Brynjolfsson & Hitt, 1998). Indicating that organisational changes were necessary to make the technological innovation work. If these organizational innovations are not implemented, the implementation of technological process innovations can even lead to productivity losses (Brynjolfsson et al., 1997). However, most evidence points to a positive relationship between technological process innovations and efficiency.

Hypotheses 2: Technological process innovation has a direct positive effect on operational efficiency

2.6 synergetic effect of technological and organisational process innovation on operational efficiency

Researchers have emphasized the importance of innovation types as complements. In line with Milgrom and Roberts (1990) synergies or complements refer to the situation where the combined implementation of different types of innovations (such as technological and organizational innovations) results in greater overall benefits than the sum of their individual parts. The integrative view of innovation types has two different theoretical bases. First the socio-technical approach, which finds its roots in the work of Trist (1981) and Damanpour & Evan (1984). The socio-technical approach emphasizes the need to align the technological core and social core of the organisations. Socio-technical theory sees the relationship between technology and the social systems as interrelated parts, where if one undergoes major changes the other part has to change accordingly. So according to the socio-technical perspective when there is significant innovation on the technological side the organisational side has to innovate accordingly and the reverse. But why is the joint adoption of technological innovation and organisational innovation beneficial for organisations? According to strategic management perspectives the answer lies in the resource based view (Barney, 1991). An integrative innovation strategy allows for synergetic use of internal resources, competences and knowledge (e.g. technological process and organisational process knowledge) resulting in distinctive competencies that are hard to replicate, therefore resulting in sustainable competitive advantage (Damanpour et al, 2009; Hervas-oliver & Sempere-Ripoll 2015). Several studies report the potential synergistic effects between technological (process) innovation and organizational process innovation and their combined effect on firm performance (e.g. Arranz et al., 2019; Doran, 2012; Tavassoli & Karlsson, 2016; Camison & Villar-Lopez, 2014). For example Camison & Villar-Lopez find evidence for that organisational innovations combined with technological process innovations increase efficiency in the production process. Additionally Tavassoli & Karlsson (2016) find that Firms that choose to implement multiple types of innovation tend to achieve better future productivity. Arranz et al (2019) Finds that the effect of organisational process innovation along with technical process innovation is greater than when organisational and technical process innovation are implemented alone. In contrary, Ballot et al (2015) finds evidence for technological and organisational process innovation complementarity in UK firms, but not French firms. Schmidt and Rammer (2007) only find evidence for complementarity between organisational and product innovation not for technical process innovation and organisational innovation. However most empirical evidence leans towards a complementary relationship of these process innovation types on productivity, therefore I hypothesize:

Hypotheses 3: The effect of technological process innovation on operational efficiency is stronger when it is moderated by organisational process innovation.

2.7 Interrelation between technological process innovation and organisational process innovation in the industry 4.0 context

In the literature, both sequential and simultaneous (reciprocal) interactions between technological and organizational process innovation can be found. A sequential pattern refers to that either technological process innovation or organisational process innovations has to be completed, before the other type takes place (Hollen et al., 2013). So, the first innovation sets the bases and creates conditions that facilitate or enable the subsequent innovation. In the simultaneous perspective organisational process innovation and technological process innovation are interdependent for their implementation and are therefore introduced combined over time in an orchestrated way (Hollen et al., 2013). In this perspective innovations are designed to be integrated from the beginning, allowing for immediate interaction and mutual enhancement.

So, conflicting perspectives emerged on how synergies are formed between technological and organisational process innovation, see table 2.2 for an overview (Damanpour, 2020). Some argue that organisational innovation is a necessary condition for technological process innovation (e.g. Lam, 2006; Damanpour et al., 1989; Mol and Birkinshaw, 2013; Camison & Villar-lopez, 2014). This perspective suggests that organisational innovation is essential for creating a culture of learning, creativity and change, which in turn stimulates technological innovation. Lam (2006: p.3) posits that 'the ability of an organisation to innovate is a pre-condition for the successful inventive resources and new technologies'. She argues that organisational structure and knowledge creation practices are necessary conditions for the creation and implementation of TPI, especially in fast changing environments. Camison and Villar-lopez (2014) find through path analysis that organisational process innovations like use of lessons and knowledge practices and temporary cross functional working groups favours the development of technological process innovation capabilities which in turn favourably influences firm performance. Thus indicating that organisational innovation is a necessary condition for the development of technological process advancements. Hervas-Oliver et al., (2012) found a sequential relationship, where the implementation of organisational innovation increases the probability of introducing technological process innovations. This perspective is rooted in organisational (re)structuring and knowledge management theory. Its relevance is evident today in the in the non-technological barriers manufacturing companies are experiencing to adopting industry 4.0 technologies. For example resistance to change, lack of internal digital culture and training, lack of digital skills, lack of understanding of the interplay between technology and human beings (Raj et al, 2020; Stentoft et al, 2021). All these barriers prevent manufacturing companies from enabling technological process innovations. This indicates that organisational process innovations like employee training or organisational restructuring are a necessary condition for implementing new industry 4.0 technologies.

Others assume that organisational actions are determined predominantly by technological innovation. This perspective proposes that technological process innovations drive organisational process innovations. Organisational changes are seen as supportive to technological innovations and are implemented to facilitate the implementation of production technologies or to unlock the full potential (Damanpour, 2014). Schmidt & Rammer (2007) showed that firms are stimulated to implement organisational innovations when technological innovation are introduced. Arranz et al (2019) found that synergies only occur when technological innovation precedes organisational innovation and did not find any evidence for the other way around. Hervas-Oliver and Sempere-Ripoll (2015) find that the adoption of technical process innovations increases organisational process innovations effectiveness. This perspective originates in the work of Evan (1966), he suggested that ‘organisational lag’ existed between new technological and organisational actions. Organisational lag is defined as ’the discrepancy in the rate at which new technical and administrative ideas are implemented in an organisation (Evan, 1966; p.52). This theory states that technological innovations are often more observable, are perceived as more advantageous and are perceived as less complex than organisational innovations. Resulting in that organisational process innovations tend to lag behind technological innovations (Damanpour & Evan, 1984). Increased organisational lag is linked to lower firm performance. Evidently, industry 4.0 is a technological oriented trend with a great variety of emerging technologies (Frank et al, 2019). Thus industry 4.0 is primarily motivated by a technological imperative, suggesting that in this new industrial phase, technological process innovations are likely to drive organisational alterations in most cases because the most short-term competitive advantage is to be gained by adopting new smart manufacturing technologies (Mckinsey, 2016).

The third perspective posits an interdependent relationship between organisational innovation and technological innovation (e.g. Damanpour & Aravind, 2012; Hollen et al, 2013; Damanpour et al, 2009; Ettlie, 1988). This view argues that organisational innovations and technological innovations are interrelated and should be implemented simultaneously. This perspective finds its basis in the works of work of for example Ettlie (1988), who argues that manufacturing firms become most successful when organisational and technical innovations are implemented simultaneously, especially in highly competitive environments. Moreover, Damanpour (2010) argues that it is difficult to differentiate between technical and organisational process innovations, therefore underlining their interdependence. For instance, quality management practices are directly supported by real time information provided by the ERP system, without the information provided by the IT systems it is hard for employees to successfully complete quality tests. This line of arguing corroborates with research from Claussen et al (2019) on the applicability of the socio-technical approach in the industry 4.0 context. In which they argue that the distinctions between the social core and technical core of the firm become blurred in the industry 4.0 Context. As they are interlinked an interact in various ways. Many tasks performed by individuals and teams are enhanced by technologies in multiple ways. Thus when a change in either administrative or technical part of the firms takes place the other part has to change accordingly right away to maintain a balanced fit.

In summary, the relationship between technological and organisational process innovation in the industry 4.0 context is unclear and is in need for clarification. Due to the conflicting perspectives and limited research on the relatedness between technological and organisational innovation this research has formulated an exploratory question.

Exploratory question*: how are Organisational process innovation and technological process innovation related in the context of industry 4.0?*

Table 2.2: different perspectives on the relationship between Organisational process innovation (OPI) and technological process innovation (TPI)

Perspectives	Type of relation	Illustrative Sources
OPI→TPI	Sequential	Lam (2006): Mol & Birkinshaw, (2013); Camison & Villar-lopez (2014); Mothe et al., (2015); Hervas-Oliver (2012)
TPI→ OPI	Sequential	Evan (1966); Arranz et al. (2019); Passmore et al. (1982); Battisti & Stoneman (2010)
TPI←→OPI	Simultaneous	Hollen et al. (2013); Damanpour et al. (2009); Ettlie (1988); Damanpour & Aravind (2012); Damanpour (2010)

Chapter 3 - Methodology

3.1 Research Design

The research questions consists of a descriptive part and an exploratory part. Therefore a mixed methods approach was used. A mixed methods research is a comprehensive approach that combines qualitative and quantitative research methods within a single study (Malina et al., 2011). This methodological framework enables researchers to gain a deeper and more holistic understanding of research questions by leveraging the strengths of both qualitative and quantitative data collection (Malina et al., 2011). The mixed methods approach allows for triangulation by comparing the quantitative and qualitative results. This is particularly useful for this study because the research question consists of two parts. First, a descriptive question: *what is the effect of the joint adoption of technological process innovation and organisational process innovation on operational efficiency?* This can be effectively researched with a quantitative research method. Second, *how is this effectively organised by Dutch manufacturing companies?* This a more open research question, which fits a qualitative approach.

3.2 Data collection

For the quantitative part the data was drawn from the international European manufacturing survey (EMS) 2022. This is an international research network that generates a research about innovation in European manufacturing firms every three years. The sample comprises 186 Dutch manufacturing firms across the following industries: Metal, Food, Textile, Construction, Machinery and Electronic. This survey incorporates questions about the use of organisational and technological process innovations and is therefore suitable for this research. Furthermore, additional operational efficiency information was requested. Access to this database was acquired through Radboud University.

For the qualitative research method, five in-depth interviews were held with production managers in Dutch manufacturing firms. It makes sense to perform interviews because the interrelation between organisational process innovation and technological process innovations needs to be researched at project level, which is not possible with the EMS survey. Instead of interviewing multiple interviewees per firm, this researcher performed a single interview for five organisations. This way the reliability of the results are increased. However this does result in less in depth insides. To increase the validity the interviews were semi-structured. The purpose of this study is to better understand already existing and described phenomenon's rather than develop grounded theory, therefore semi-structured interviews are preferred over open interviews (Miles & Huberman, 1994). The interview questions are based on reliable dimensions and measures found in the literature (e.g. OECD, 2005,2018; Armbruster et al.,2008). This ensures the content validity and construct validity of this study. All the interviewees were asked approximately similar questions, making it easier to compare the results (Gilham, 2005). Moreover the interviews were recorded, if permission was granted, to guarantee accurate transcripts.

To ensure the privacy of the interviewees and the company, they are anonymized. The researcher used his network to find suitable interviewees.

3.3 Operationalization

The operationalisation aims to measure the concepts and relations discussed in the theoretical framework (Vennix, 2019). The operationalisation table can be found in Appendix 2.

3.3.1 Independent variables

The selection of the items was based on (Armbruster et al., 2008). According to Armbruster et al. (2008) organisational innovation comprises of both inter- and intra-organisational innovations. This research takes an intra-organisational approach, therefore inter-organisational innovations are not included. The items are measured on a dichotomous scale. For each organisational process innovation item was asked if it was applied, not applied or planned to be applied in 2025. This has been transformed into a more simple yes or no questions. So the extent of organisational innovativeness was measured by counting the number of implemented organisational practices. In total there are 11 items for organisational process innovation.

Technological process innovation is operationalised based on the OSLO manual (OECD, 2005; Frank et al., 2019). 14 digital process technologies make up the measurement scale. The items represent to what extent manufacturing firms are using new digital process technologies. Technological process innovation is also measured on a dichotomous scale. For each technological process innovation item was asked if it was applied, not applied or planned to be applied in 2025. This has been transformed into a yes or no questions. So the extent of technological process innovations was measured by counting the number of implemented technological innovations.

3.3.2 Dependent variable

This research included four operational efficiency measures: product lead time, not on time, scrap rate and quality complaints (Ichniowski et al., 1997). Scrap rate, not on time and quality complaints are measured in percentages of the total produced products. Product lead time was measured in hours and days, this has been log transformed to make it more suitable for the regression analysis.

3.3.3 Control variables

This research controls for firm size and type of industry as these variables could have considerable impact on the outcome of this research., this is in line with previous research (e.g. Armbruster et al., 2008; Sapprasert & Claussen, 2012). First, type of industry is included to control for the influence of industry heterogeneity on the adoption of technological and organisational process innovations and on its effects on operational efficiency. The type of industry is divided into different categories; metal, food, construction, chemical, machinery and electronic (see appendix 2). Second, firm size is included as this could influence the amount of technological process innovations implemented by firms (Frank et al.,2019; Stentoff et al., 2021). Firm size is measured in amount of employees. This variable has been transformed into a log variable.

3.4 Case selection

This study focuses on innovation in the production process in the Dutch manufacturing industry. Therefore the data was collected at Dutch manufacturing firm. Initially the plan was to interview firms in the machinery sector, to increase comparability. However due to limited time and connections other sectors were also included. The firm itself had to have at least 50 FTE, to ensure enough complexity. Within the organisation, the interviewee must be directly linked to the production process. Therefore all interviewees are production managers, or sometimes called operations managers. The cases (anonymised) along with the, sector, number of employees and role of the interviewee can be found in table 3.1

Table 3.1: Case studies

Case/Name	Number of employees	Sector	Role interviewee
R, manager metal manufacturer	Around 400	Metal	Production manager
L, flight simulator manufacturer	113	Machinery	Operations manager
N, manager water technology	Around 400	Machinery	Production manager
P, manager screw factory	53	Machinery	Production manager
H, manager coating	Around 150	Chemical	Production manager

3.5 data analysis methods

This study will conduct a quantitative analysis and five interviews. For the statistical analysis the study uses the multiple regression analyses. Regression analyses is particularly useful to test the relationship between multiple independent variables and a single dependent variable (Hair et al, 2018). This research involved two independent variables and one dependent variable, making regression analysis the most suitable method. Prior factor analysis was not necessary as the measures for the variables were already created (Field, 2013). Operational efficiency is operationalised into four different items, so for every item a regression analysis was performed. For a multiple regression analysis, the minimum sample size should be 5 cases per variable (hair et al., 2019). This research includes 2 independent variables and 2 control variables making the minimum sample size 20. The EMS survey includes 186 firms, which is more than sufficient.

The interviews were transcribed with AI and then manually checked. For the coding, Excel was used. This research has a deductive nature, therefore the deductive coding approach was used (Blijenbergh, 2015). This means that the codes are mainly based on the existing literature. This is possible because various research efforts have been made to conceptualize the different types of innovation (e.g. OECD, 2005; Armbruster et al., 2008; Frank et al., 2019) and the interrelationship between organizational process innovation and technological process innovation (Hollen et al., 2013; Battisti et al., 2015). This enhances the validity of the qualitative research by ensuring that the codes align with existing theoretical frameworks.

3.6 research integrity

The researcher has to take into account multiple ethical standards. This study will follow the rules described in the Dutch code of conduct on scientific practices (*Nederlandse Gedragscode Wetenschapbeoefening*). First the interviews were recorded and transcribed, after permission of the interviewee. This increases the transparency of the acquired data and mitigates the risk of fabricating fake data. Moreover the researcher gave the option to anonymize the interviewees and cases. This way the interviewee and companies cannot be identified.

Chapter 4 – Results

This research comprises of both quantitative data and qualitative data. First the quantitative data will be discussed. Multiple regression analyses were used to test how operational efficiency measures are affected by new technological or organisational process innovations.

4.1 Descriptive statistics dependent variables

First I shortly discuss the descriptive statistics, an overview can be found In table 4.1. Most of the participating manufacturing firms operate in the metal, chemical and machinery sector. The median number of employees is 45, indicating that most participants in the survey are SMEs. The minimum amount of employees is 10 and the maximum is 30.000. On average manufacturing companies use 3.96 digital process technologies (stdev 2.56) out of 14, which seems somewhat low. This means that firms often only have a few digital process technologies implemented. Software for production planning (63.4%) and digital solutions for work instruction (50.5%) were among the most used technological process innovations. The least used process technologies are software for simulating production (10.8%) 3D printing (15.6%). Organisational process innovation were adopted more, on average 5.12 out of 11 (stdev 2.53). The most used organisational process innovation is customer or product oriented lines (81.2%) the least used is energy management certificates (9.7%).

Table 4.1 descriptive statistics dependent variables:

Indepedent variables	Mean	Stdev	Min	max
Size (Employees)	246.89	2197.56	10	30.000
Size (median)	45			
Inudstry (Base; Metal)	26.3%			
Food	7.5%			
Textiles	16.1%			
Construction	4.3%			
Chemical	20.4%			
Machinery	18.8%			
Electrical	6.5%			
Organisational process innovation	5.12	2.53	0	11
Technological process innovation	3.96	2.56	0	10

4.2 Measurement model

To measure the reliability of the independent variables Cronbach's Alpha is used Cronbach's Alpha displays the internal correlation between the items (Hair et al., 2018). In general the threshold for an acceptable reliability is 0.7 (Hair et al. 2018). Technological process innovation consists of 14 items with a Cronbach's Alpha of 0.66, which is questionable (hair et al., 2018). Technological process innovation is a very broad and heterogeneous construct, therefore a lower Cronbach's Alpha can be expected (Nunnally, 1978). This is because the items are capturing different aspects of a broad and complex construct. constructs shows a moderate level of common variance. Almost all items score above 0.2 which is often seen as moderate.

Table 4.2: Reliability statisctics

Here a lower Cronbach's Alpha (above 0.6) is still acceptable (Nunnally, 1978). Similar studies with

Innovation types	proportion used	Corrected item-total correlation	Reliability coeffcient
Technological process innovation			0.656
Mobile devices for programming	0.376	0.193	
Digital soluition technologies	0.505	0.316	
Prodution planning software	0.634	0.401	
Internal logistics systems	0.296	0.216	
Digital exchange of data technologies	0.333	0.258	
Product life cycle systems	0.161	0.328	
Real time control systems	0.242	0.297	
Manufacturing robots	0.226	0.163	
Robots for processes	0.274	0.282	
3D printing for prototyping	0.220	0.318	
3D printing for product components	0.156	0.304	
Software for product design simulation	0.280	0.305	
Software for advanced computations	0.151	0.235	
Software for simulating prodcutionprocess	0.108	0.254	
Organisational process innovation			0.716
Integration of tasks	0.688	0.282	
Customer or product oriented lines	0.812	0.228	
Poduction controlling pull principle	0.344	0.352	
Change-over-time concepts	0.279	0.478	
Workinstructions	0.489	0.432	
Displayboard	0.462	0.397	
Quality management measures	0.731	0.516	
Employee involvement	0.602	0.359	
Employee bonussystems	0.296	0.362	
Enviromnetal certificates	0.323	0.207	
Energy certificates	0.097	0.367	

similar conditions have also accepted a Cronbach alpha between 0.6 and 0.7 for technological innovation (e.g., Damanpour et al., 2009). The corrected item-total correlation for both

4.3 Regression analysis

For this analysis three different models were created. Model 1 includes the control variables; size and industry. Model 2 adds technological process innovation and organisational process innovation. In this model the direct effect of the previously mentioned constructs on operational efficiency is measured. Model 3 adds the moderation effects and represents the fully specified model. The regression analysis has been repeated four times for every indicator of operational efficiency. Prior to evaluating the data, the assumptions of the regression analysis are analysed.

4.3.1 Assumptions

Linearity

The assumption of linearity is satisfied. The linearity was tested by analysing the scatterplot of the standardized predicted value (Appendix 3.8 to 3.12). The scatterplots for product lead time, not on time, scrap rate and quality complaints reveal a reasonably linear relationship between the independent and dependent variables. The residuals are randomly scattered and show no specific pattern. There are some outliers that score above the threshold of the standardized residual of 2.5 (Rousseeuw & Leroy, 2007), although there are very few.

Multicollinearity

The assumption of multicollinearity has been met. To assess the collinearity the VIF scores and tolerance values were analysed. The highest VIF statistic is 3, which is below the general rule of thumb of 4 and the Tolerance values are all above 0.2 (Field, 2013).

Normality

The assumption of normality of the residuals distribution has been met. A histogram of standardized residuals and a normal probability plot were used to evaluate the normality of the residuals distribution. The histograms show that especially scrap rate and quality complaints are somewhat right skewed. However this is not seen as problematic because the linear regression analysis is relatively robust to violations of the normality assumption (Hair et al., 2019)

Independence of error terms and homoscedasticity

there is no dependence of the residuals as assed by the Durbin-Watson statistic which is around 2 in every regression analysis. This falls within the acceptable range of 1 to 3. To assess the presence of unequal variances, the scatterplot of standardized predicted values was evaluated. The scatterplot indicated that the data met the assumption of homogeneity of variance, as there was no clear pattern indicative of heteroscedasticity (Hair et al., 2019).

4.3.2 Hypothesis

Multiple regression analyses were used to test how operational efficiency measures are affected by new technological or organisational process innovation (see Table 4.3). The results show that organisational process innovation has no significant effect on any of the operational efficiency measures (see table..). This means that hypotheses 1: *Organisational process innovation has a direct positive effect on operational efficiency* is not supported. In the complete model (model 3) technological process innovation has no significant effect on product lead time, not on time, scrap rate and quality complaints, thus indicating no direct relationship. However in model 2 technological process innovation significantly decreases scrap rate (B= -0.082) and quality complaints (B= -0.059). This shift can be explained by the addition of the interaction effect, which allows for more complexity. The direct effect of technological process innovation on scrap rate and quality complaints in model 2 give a slight indication for a significant relationship however it is very weak. Thus the hypotheses that technological process innovation has a direct effect on operational efficiency is not supported. Finally I predicted that operational efficiency would increase when technological process innovation is moderated by organisational process innovation. However the results show no significant effect. Hence, hypothesis 3 is not supported

Table 4.3 regression coefficients

	Product lead time		Not on Time		Scrap rate		Quality complaints	
Indepedent variables	Model 2	Model 3	Model 2	Model 3	Model 2	Model 3	Model 2	Model 3
Organisational process innovation	-0.055	-0.055	0.030	0.030	0.033	0.033	-0.023	-0.024
Technological process innovation	0.085	0.093	0.000	0.028	-0.082*	-0.56	-0.059*	-0.018
Moderation effect TPI, OPI	-	0.003	-	0.011	-	0.010	-	0.016
Size (in employees)	0.010	0.008	-0.013	-0.019	0.085	0.080	0.086	0.078
Industry (base metal)								
Food	-1.117**	-1.116**	-0.668	-0.665	-1.185***	-1.183***	-0.522*	-0.518*
Textile	-0.481	-0.480	-0.347	-0.345	-0.468*	-0.465*	-0.065	-0.061
Construction	0.024	0.029	-0.692	-0.675	0.240	0.255	0.389	0.414
Chemical	-0.369	-0.363	-0.105	-0.083	-0.449*	-0.428*	-0.198	-0.163
machinery	1.164***	1.168***	0.307	0.323	-0.041	-0.026	0.215	0.239
Electronic	-0.461	-0.455	0.413	0.438	-0.057	-0.035	0.176	0.213
Model statistics								
Adjusted R square	0.203	0.199	0.047	0.038	0.098	0.097	0.072	0.084
F statistics	1462	0.033	0.369	0.652	3353	0.926	4958	3317
P value	0.235	0.857	0.674	0.421	0.037*	0.337	0.008**	0.070

***** p<0.001; **p<0.01; *p<0.05**

4.3.3 Control variables

Firm size appears to have no significant effect on operational efficiency (table 4.3). The negative effects of most industry types indicates that firm in the metal industry experience lower levels of operational efficiency. Firms in the machinery sector show significant higher product lead time. Firms in the food sector score better on product lead time, scrap rate and quality complaints, but not on scrap rate, compared to the other industry types.

4.4 Qualitative results

In the following section, the qualitative results will be discussed. First, the core constructs; technological process innovation and organisational process innovation will be described. Once these constructs have been thoroughly analysed the interactions between those two will be outlined.

4.4.1 Technological process innovation

Technological process innovations refers to new technological elements introduced into an organisations manufacturing process (Edquist & Meeus, 2006). Various technological process innovations were described in the case studies. First these technological advancements were classified into several categories (Based on Frank et al; 2019). The most frequently mentioned technological process innovations were related to vertical integration (digitalisation) and automatization. Examples of vertical integration technologies mentioned in the cases include implementation of ERP system, CAD integration, tablets and phones used in production, shopfloor control systems and product life cycle systems. The overarching goal of these technologies is to integrate and digitalise information streams in the entire organisation, thereby providing more control over the production process and ultimately improving decision making on the shop floor level. Some illustrative quotes:

> 'That is the complete CAD integration. So, the moment an engineer starts designing, they immediately have their bill of materials generation, as well as all the backend order information and customer contact details.' (P, manager screw factory)

> 'The implementation of shop floor control is still ongoing, so we're still working on it. We're gradually implementing it. Shop floor control is essentially an extension of the ERP system. It manages the order process through the factory, instead of the current paper-based system. Soon, everything will be managed through the system.' (H, manager coating).

Moreover, the interviewees described multiple automatization/robotisation projects. In these projects the goal is mainly to increase quality, efficiency and decrease human interaction. For intance, R, manager metal manufacturer described:

> 'when you talk about those production automations, it's about improving quality and reducing dependence on employees. You've probably heard often that it's difficult to find employees. Additionally, the quality standards are becoming increasingly higher. If you can automate or robotize such processes, you become more agile and less dependent on manpower.'

The technological process innovations have been further classified into: incremental process innovations and radical process innovations. This distinction was made because incremental and radical technological process innovations show differential interaction patterns in relation with organisational process innovation.

Incremental process innovations involves making gradual improvements to existing processes (Damanpour & Aravind, 2012). Many incremental technological process innovations were mentioned an example is:

> 'It involves automating the laser engraving and marking process. All implants receive a mark so they can be traced later, indicating who made them and from which production batch they come. They are 100% engraved with a laser. We have automated this process with a robot to increase output and also to improve quality.' (R, manager metal manufacturer)

While radical process innovations focus on introducing significant and transformative changes that disrupt the current paradigms (Damanpour & Aravind, 2012). Some illustrative examples:

> 'From a smaller location with a powder line, we have transitioned to this. First we had separate processes and production lines now we have actually integrated those into one large production line. This allows for many combinations in a product, meaning you can choose a combination of products or a whole combination of treatments without the product needing to move from one department to another, thus no human intervention is required. This is something that is not present in our market' (H, manager coating)

> 'When it comes to technological process innovation, we indeed transitioned to the new ERP system, SAP, in 2023. And then you realize that it has a very significant impact'(L, manager flight simulators).

4.4.2 Organisational process innovation

Organisational process innovation refers to new organizational methods implemented into the firm's business practices and workplace (OECD, 2005). Multiple organisational process innovation were described in the interview. They were categorised into different groups based on Armbruster et al (2008). The most common organisational process innovation discussed were: methods to ensure quality in production (e.g. Total Quality Management, continuous improvement), job enrichment/enlargement and standardisation of work instructions/procedures. Organisational process innovations were implemented for various reasons: continuous improvement, supportive to technological innovations, increasing efficiency and increasing quality. First, tools like BI dashboards were used to visualise and stimulate continuous improvement of the production process.

> 'We work very intensively with dashboards, Power BI dashboards, using available information to present in a meaningful way what is going wrong. What is going wrong can include reliability in delivery, how many deliveries arrive on time, how many are late, whether the issue is specific to one customer or affecting all customers, allowing us to zoom in and address specific issues with individual customers.'(R, manager metal manufacturer)

Additionally, organisational process innovations has an existence right on its own. Managers mentioned that they used risk management practices to prevent downtime and malfunctions thereby decreasing product lead time and scrap rate.

> 'It's a standardized method called Failure Mode and Effect Analysis (FMEA) to assess risks in processes and evaluate their effects. How significant is the risk? What are the consequences? What is the likelihood of something occurring on a scale of 1 to 10? And how likely am I to detect it? We apply this to all our standard processes and review it annually based on errors or deviations observed in the past year.' (R, manager metal manufacturer)

Finally, organisational process innovations were used supportive to technological process innovations. This was mainly the case with adjusting the work procedures/instructions to the new technology. This I will elaborate on further in the following paragraph.

4.4.3 Relation between technological process innovation and organisational process innovation

In the interviews several combinations between technological process innovation and organisational process innovation were described. Therefore this section is structured based on the different interactions observed between technological process innovation and organisational process innovation. First the sequential patterns are described, then the simultaneous patterns.

> *Want welke organisatorische activiteiten hebben jullie dan? Uitgevoerd om je organisatie voor te bereiden op deze grote stap richting de nieuwe productielijn? H: Nou ja, dan hebben ze eigenlijk niet gedaan, zal ik maar zeggen, dus We hebben eigenlijk en ze hebben eigenlijk daar mij voor en en aangenomen zal ik maar zeggen om te gaan regelen, zal ik maar zeggen. Dus organisatie. Ja die organisatie op poten te zetten en zorgen dat de goede mensen op de juiste plek komen en het implementeren van de juiste processen zal ik maar zeggen*

Sequential patterns

A sequential pattern refers to that either technological process innovation or organisational process innovations has to be completed, before the other type takes place (Hollen et al., 2013). With regard to sequential patterns there are two possibilities. First technological process innovation can enable organisational process innovations or organisational process innovation is a prerequisite for technological process innovation. This study observed that technological innovations mainly enable organisational innovations, however in some cases organisational process innovations serve as preparatory to technological advancements. First, the results show that technological process innovation can lead to organisational process innovation, suggesting that adopting new process technologies can stimulate firms to further implement innovations in their workplace. As described before I distinguished between incremental and radical technological process innovations. The results show that radical technological innovations process innovations tend to lag behind. H, the manager of the coating line mentioned that they had implemented a complex new production line, In essence they integrated three different production lines into one. this increased the possible modifications and decreased the transport of the product from line to line. However this also increased the organisational complexity. The challenge at the moment was to fine tune the new work procedures, task and responsibilities and quality procedures. See illustrative quotes below:

> ‘There were quality processes that essentially disappeared due to the absence of personnel. People who had left, who were not able to handle the demands of the new factory. They came to work here from smaller factories and would then quickly quit, leaving gaps in the processes. It took some time to find the right people to fill these positions. We had to gain a clear understanding of what kind of employees we needed. Eventually, we found someone who seemed to be a good fit. This applies to all the roles we have added recently.’ (H, manager coating line)

> ‘T: What organizational activities have you undertaken to prepare/support your organization for this significant step towards the new production line? H: Well, they haven't really done any, I would say. That's why they hired me, to organize everything, so to speak. My role is to set up the organization, ensure the right people are in the right positions, and implement the appropriate processes.’ (H, manager coating line)

Moreover, L the manager of the flight simulator manufacturer implemented a new ERP system into their operations. He mentioned that this had considerable impact on their organisation. A large barrier for the implementation of this new ERP system was that their work processes were not aligned with the new ERP system.

> ‘The second hurdle was that our work processes were not aligned at all, and we realized this later on. Many processes were based on the old ERP system and did not work with the new one, creating gaps in the process. Questions arose like, Who is going to do that?" Tasks and responsibilities changed for people, which we had not anticipated’ (L, manager flight simulators).

Thus, it seems that organisational process innovations tend to lag behind more radical technological process innovations. This results in significant problems for the firms, regarding an increase in quality complaints and delayed deliveries. For example L, the manager of the flight simulator manufacturer described a decrease in on time delivery of 40% as result of implementing the new ERP system.

> ‘Yes, we call that on-time delivery to the customer, right? So, the commitment to deliver as promised was declining. We saw our on-time delivery rate drop from about 90%, which we were very proud of, down to 50% all of a sudden.’ (L, the manager flight simulators).

‘We are now experiencing that while the production line is operational, our employees and work processes around it are not yet running smoothly, which causes issues related to quality complaints and delayed deliveries’ (H, manager coating line)

Thus, indicating that organisational process innovations are necessary to make the radical technological process innovations work. The cause of that organisational process innovations lagged behind the radical technological process innovations seems to be that managers were uncertain about the exact nature of the forthcoming changes. Therefore making it hard to prepare the social core of the organisation for the technological change.

‘Yes, it was really like innovating with a blindfold on. Because you simply don't know. I always said, I don't know what the possibilities are, so I need to make a choice. But out of what, right?’ (L, manager of the flight simulators).

The results imply that when technological process innovation precedes organisational process innovation (sequentially) problems occur. Therefore I find no support for the argument that synergies arise when technological process innovation precedes organisational innovation. On the other hand organisational process innovations are an important basis for technological process innovations. R, manager metal manufacturer, explained that they started a new procedure in which key technical players in the holding discuss what technological innovations their firm is implementing (i.e quality circle).

‘We are now working on what we call an innovation café. We regularly meet with the technical key players from various companies to discuss what is happening at each company in the holding and what projects we are working on. While we centralize some aspects, it’s mainly about knowing what each other is working on. This way, we can learn from each other. For example, I might find something interesting and ask, "Can I come by next week to see what you’re doing? It might be useful for me too. (R, manager metal manufacturer)

This shows that new formalized meetings, in which employees discuss their innovations can enable new technological innovations. Thereby setting a basis for new innovation efforts. Additionally, organizational process innovations create a fertile ground for the implementation and utilization of new technological advancements. In other words, changes in an organization's administrative procedures, human resources or structure are essential to prepare for new technological innovations. For example employees need to be trained to be able to effectively utilize the new process technologies.

‘If it's a robot for engraving implants, then the people who currently engrave the implants must be trained in handling automated systems. They need to acquire the necessary knowledge. So, they have to perform their work in a completely different way. Instead of manually engraving

> products, they need to learn how to set up a robotic machine.'(R, manager metal manufacturer)'

N, manager water technologies stated that it is essential to provide insight on what organisational tasks and functions are changing as a consequence of the adoption of new production technologies.

> 'We created a comprehensive map of how the factory will look, with the new machines. Including the placement of machines and the logistics process. Essentially, we mapped the entire construction process from start to finish. For example, how will items be received? Do we have warehouses to connect to the lasers? So that our incoming goods can be received and immediately placed on the shelves, only to be taken out when they are ready to be cut. In line with this we are trying to map what functions and tasks will change as a consequence of this new machinery.' (N, manager water technology)

This thus indicates that job creation/enlargement can be done as preparatory work to make sure that the work processes are aligned with the new technologies.

Proposition 1: Technological and organisational process innovation show sequential interactions

Proposition 1b: Organisational process innovations tend to lag behind radical technological process innovations

Proposition 1c: Organisational process innovations can be a prerequisite to technological process innovations.

Simultaneous patterns

In the simultaneous perspective organisational process innovation and technological process innovation are interdependent for their implementation and are therefore introduced combined over time in an orchestrated way (Hollen et al., 2013). In the attempt to innovate technological processes, improvements can be obtained by combining this new technological process with new organisational advancements. This could be the other way around so that technological innovations are implemented to support new organisational activities, however this is rarely the case in this study. Important to note is that the simultaneous perspective does not mean that organisational innovation and technological innovations are implemented at the exact same time. It means that while working on the technological process innovation (or organisational process innovation) complementary organisational process innovations (or technological process innovations) are also implemented. The results imply that in most cases manufacturing firms show simultaneous innovation patterns. Additionally, it seems that simultaneous adoption patterns are often seen with more incremental technological process innovations. For example R, manager metal manufacturer explains that new technological process innovation always need to be supported with new work instruction standardization and documentation:

> ‘If I refer back to our activities for our medical products, it's quite straightforward because everything you do and change in terms of technology must also be documented. It has to be documented in your procedures and work instructions. It must literally state that H is allowed to do something, like wash or blast something. It also needs to be clear that I am trained for that task, and this must be documented. So, if I implement a new innovation, I also need to describe and document that process, provide training, and conduct control practices. And these new procedures have to be digitalised again into the ERP systems’ (R, manager metal manufacturer).

So, when a new technology is implemented the new process and control practices need to be documented. Thereafter, these new work procedures, instructions and control practices need to be digitalised again into the ERP system. Thus implicating that new technological innovations lead to changes in the social core of the organisation which then have to be digitalised again. This happens in a short time span to make sure that there is a fit between the new technological advancement and the administrative organisation around it.

Furthermore P, explained that during the implementation of new sensors and lasers into their production it was essential to include the operational employees into the development and implementation phase, and that inherent to the introduction of these new technologies, new work instructions/procedures were written.

> ‘Part of the process involves including the people who will eventually be working with it in the development phase. I think this is wise for two reasons. First, it allows us to incorporate the knowledge and experience that these floor workers and users have into the new process technology, which I believe is important. Additionally, it creates a foundation for those who will be using it, helping them understand what’s coming and building their familiarity with it from the start. That’s the first step. Then we usually have a fairly long phase where we just get to work. This involves trial runs and assessments, without necessarily being fully in production. During this period, manuals are written, agreements are made, and fine-tuning is done. The users who will be working with it are also involved in this stage. After that, it moves into full production and becomes integrated into the workflow. Depending on the results and the input or output requirements, small working groups are created around it, again involving the users, to ensure everything runs smoothly.’ (P, manager screw factory)

This indicates that synchronous to the implementation of these new sensors and lasers new work instructions were written to align the work procedures with the new production activities. Additionally, the operational workforce is part in the development and implementation phase to incorporate their knowledge and familiarize them with the new technologies. Finally small cross-functional work groups are created if necessary to support the implementation of the new technology. So, clear synergies arise from aligning the new technology with the social core by concurrently implementing organizational innovations (i.e. cross-functional workgroups, involvement employees in innovation) to support the adoption of the new technology.

Finally it is very hard to practically differentiate between organisational and technological process innovation because they are intertwined. P, manager screw factory described that they had implemented a new procedure due to an increase in validation and quality insurances asked by their customers. To facilitate this they created the ITP-process which was linked to enormous streams of documents and quality tests.

> ‘We call that the ITP process, which stands for Inspection Testing Protocol. We clearly agree on these things with the customer in advance. Then, we embed it entirely into the process. For instance, if the customer says that roughness needs to be tested because everything must be smooth, we say, "Okay, fine, that's a test. We have a detailed written description of how the test will be conducted. We've also written work procedures for it, together with the people on the shop floor who will carry out the tests. And we've now set up that entire process flow. Currently, it's still managed with Excel and separate paperwork. Parallel to this we are now in the process of integrating it into our ERP system.’ (P, manager screw factory)

This quote implies that new quality practices and work instructions are directly interrelated with digitalisation. So in this case changes in the administrative part of the organisation are almost directly supported by digitalisation. Making sure that the last real-time information is available for the shop floor employees, through their ERP systems.

Proposition 2a: Technological and organisational process innovations interplay in a simultaneous way

Proposition 2b: Simultaneous adoption patterns are often seen with more incremental technological process innovations

Chapter 5- Discussion/conclusion

5.1 Conclusion

This research intended to answer the following research question: *what is the effect of the joint adoption of technological process innovation and organisational process innovation on operational efficiency, and how is this effectively organised by Dutch manufacturing firms?* This was researched by executing a multiple regression analysis and five interviews with production managers in Dutch manufacturing firms. The quantitative results show that the joint adoption of technological process innovation and organisational process innovation have no complementarity effect on operational efficiency (H3). Furthermore, organisational process innovation and technological process innovation have no direct impact on operational efficiency (H1 & H2). So, contrary to prior expectations hypotheses 1 to 3 are rejected.

Additionally, this research tried to answer the following qualitative exploratory question: *how are Organisational process innovation and technological process innovation related in the context of industry 4.0?* To answer this five interviews were held with production managers in Dutch manufacturing firms. Thereby answering the call for more research on the interaction between technological and organisational innovation as highlighted by (Damanpour, 2020, 2017; Volberda et al., 2013). The results illustrate that both simultaneous and sequential adoption patterns of technological and organisational process innovation are relevant. Two sequential pattern were found. First, this research illustrated that organisational process innovations tend to lag behind radical technological process innovations, resulting in operational efficiency decreases. Second, organisational process innovation can be an important prerequisite of technological process innovations in two ways. It can serve as preparatory work to create a fertile ground for the adoption of new process technologies. Secondly, it can enable new technological process innovations (e.g. Kaizen continuous improvement). Finally, organisational and technological process innovations can be adopted synchronously. This was mainly the case with more incremental technological or organisational process innovations.

5.2 Theoretical implications

The non-significant effect of technological innovation, organisational process innovation and their combined effect on operational efficiency are not in line with the extant literature. First, the joint adoption of technological and organisational process innovations shows no significant effect on operational efficiency. Thus finding no support for that technological and organisational process innovation are complementary. This in contrast with most prior research (e.g. Camison & Villar-lopez, 2014; Arranz et al., 2019; Polder et al., 2010) but in line with (Schmidt & Rammer, 2007; Ballot et al., 2015). There are several possible explanations for the non-significant effect. First, the research does not find any direct effects, thereby significantly decreasing the likelihood for finding an interaction effect (Hair et al., 2019). However it does not completely rule out the possibility for a significant interaction effect. One reason could be as described Brynjolfsson & Milgrom (2013) that complementary innovation strategies increase coordination efforts and overall complexity, thereby implying that costs of integrating technological and organisational innovation could become higher than the benefits (Ballot et al., 2015), resulting in lower performance outcomes. Additionally, the literature suggests there could be a time lag before the effects of both process innovation types is visible in performance outputs (Arranz et al., 2019; Armbruster et al., 2008). On this I will elaborate on later.

Second, the most surprising result is that technological process innovation shows no significant effect on any of the operational efficiency measures. While this is in contrast to my beliefs and the extant literature it does align with the arguments of the productivity paradox (Brynjolfsson & Hitt., 1998). This theory prompts that new technological process innovations need supportive organisational changes and that a significant restructuring and learning period is necessary before the effects are visible. This line of arguing is also somewhat supported by the interviews. The interviewees mentioned that at first quality complaints increased after the introduction of an entirely new production line (H, manager screw manufacturer) and on time delivery decreased with 40% after the implementation of a new ERP system, this is now back on 80% (L, manager flight simulators). Indicating that a restructuring and learning period is necessary. This is also in line with Ross and Vitale (2000) who found that firms that implemented a new ERP system suffered from an initial 3 year performance dip due to the disruptive effect on the existing processes. Furthermore, on average only 4 out of 14 process technologies are implemented by manufacturing firms in the EMS questionnaire. Indicating that the average manufacturing firm is still in the starting blocks for the adoption of the smart manufacturing technologies, which is in line with (Helmond et al., 2018; Frank et al., 2019). This corresponds with the interviews which indicate that most firms are still in between phase 1 and 2 for the adoption of smart manufacturing technologies. Therefore it is plausible to conclude that most of the productivity gains have not yet been achieved by the average manufacturing firm and are therefore not visible in the results.

Organisational process innovation also shows no significant effect on operational efficiency. There are several possible explanations for this result. First, this research has methodological limitations. According to Armbruster et al (2008), it is likely that the effects of an overall or composite organizational innovation indicator on performance metrics such as productivity, flexibility, and quality may overlap and cancel each other out, leading to no significant impact on these performance indicators. Thus indicating that individual organisational innovations might have different effects on operational efficiency measures. For example Total Quality Management practices might have a positive effect on quality complaints but a negative effect on product lead time. Or a production to order based production line might decrease product lead time but increase perceived quality and flexibility. Moreover, this research does not take into account to what extent organisational innovations are implemented into the firm, which can have considerable effects on the estimation of the performance outcomes. For example, Armbruster et al (2008) illustrated that more than 60% of all firms claimed to have realized task integration, however just 10% had fully realised the potential. Finally, there might be a time lag before the effects of organisational process innovations on firm performance measures are visible (Armbruster et al., 2008; Arranz et al., 2019). The implementation of new organisational activities requires significant changes to structure and processes which can be time consuming. For instance, the implementation of task integration into the production process requires: restructuring of production processes, employee training, rewriting work instructions. New organisational practices take time to build, therefore the performance effects might only be visible after a certain period of time. Finally, it is also possible that organisational process innovation simply has no significant effect on operational efficiency. The extant literature still shows conflicting empirical results, regarding the performance effects of organisational innovations. Some studies find strong effects of organisational innovation (Gunday et al., 2011; Polder et al., 2010) while others find no effects (Atalay et al., 2013). Thus suggesting that the relationship between organisational innovation and performance is contingent on several contextual factors (Ballot et al., 2015)

Next this research set out to investigate the interrelatedness between technological and organisational process innovation in the industry 4.0 context. This research identified both sequential and simultaneous interactions. First, organisational process innovations can lag behind technological process innovations. This was predominantly the case with radical technological innovations. An explanation for this could be that radical innovation involves transformative changes that disrupt the current processes, making the necessary corresponding organisational changes complex and at least partially unpredictable. Thus resulting in their later implementation. These findings support the organizational lag model, which suggests that innovation in the social core can lag behind innovations in the technical core, resulting in diminishing operational efficiency (Evan, 1966; Damanpour & Evan, 1984). Therefore, this research finds no support for the argument that synergies arise when technological process innovation precedes organisational process innovation, which is line with most of the extant literature (Damanpour et al., 1989). Additionally, the findings suggest that organisational process innovation can precede technological process innovations. Mainly serving as preparatory work for the successful introduction of new technologies. This confirms the arguments of various researchers on that organisational changes are necessary to create a positive environment for the adoption of new technological innovations and to enable further technological innovations (e.g. Lam, 2006; Damanpour et al., 1989; Mol and Birkinshaw., 2013).

Second, besides the sequential patterns between the types of innovation, I also identified synchronous emergence. Thereby finding support for the literature stream arguing that manufacturing firms adopt different types of innovation simultaneously (e.g. Ettlie, 1988). Additionally, the results imply that contrary to radical process innovations incremental innovation often occur simultaneously due to easier coordination, predictability and the interrelatedness between organisational and technical activities. Therefore this study adds to the literature by illustrating that both sequential and simultaneous adoption patterns between organisational and technological process innovation are possible. Which is in contradiction to other studies (e.g. Battisti et al., 2015; Arranz et al., 2019; Damanpour et al., 1989). On top of that, this study shows that radical and incremental innovations interact differently, concerning the relationship between technological and organisational process innovation. Thereby, adding to the literature on the interrelatedness between innovation types.

5.3 Managerial implications

Concerning the managerial implications, this research can only give recommendations regarding the interrelatedness between technological and organisational process innovation in the manufacturing industry. The results of this research imply that managers should focus on both organisational and technological process innovation. Only focusing on technological process innovations will have negative effects on performance as illustrated in the interviews. In line with the organisational lag model (Evan, 1966), managers should make sure that the introduction of new technological advancements is accompanied by corresponding organisational changes to maintain a balanced fit. Additionally, managers should be aware of the different interaction patterns between technological and organisational process innovation. Therefore, managers should intentionally design innovation strategies, based on their individual context, to ensure optimal complementary effects between organisational and technological process innovation.

5.4 Future research and limitations.

This study is subject several limitations that should be considered in the interpretation of the findings. This study uses a dichotomous scale to measure the degree of organisational and technological innovativeness. Therefore assuming that the quantity of innovations represents the overall innovativeness of the organization. However, it is possible that organizations have implemented additional innovations beyond those listed in the EMS questionnaire. Furthermore, as already discussed in the previous paragraph this research does not incorporate the extent to which the innovation is adopted, thereby limiting the explanatory power of the data. Future research should add this into their quantitative analysis. Furthermore, the qualitative results have to interpreted with care and should be seen as preliminary. Interviews are not the ideal method to research the interaction between technical and organisational process innovation. To thoroughly research this interrelationship it is essential to gain a deep understanding of how innovation in the production process evolved from the start to the finish. This can only really be effectively achieved through longitudinal studies that examine the development of innovation in the production process. So, future research should address the relatedness between technological process innovation and organisational innovation and their combined effect on firm performance using longitudinal data. This way previously mentioned limitations related to the time lag between innovation and their effect on performance, as well as limitations regarding the link between technological and organisational innovation can be overcome.

Second, as proposed by Armbruster et al (2008), future research could cluster various organisational and technological process innovations and examine the effects of these clusters on different performance measures. This is necessary because different organisational process innovations might have different performance outcomes. For instance, innovation in business practices such as lean or total quality management have different effect than knowledge management practices (e.g. employee involvement in innovation). Lean management may contribute to decreasing product lead time while knowledge management practices might increase technological innovation capabilities (Mothe et al., 2015).

Thirdly, future research on the relatedness between technological and organisational process innovation should differentiate between radical and incremental innovations and explore how this effects the interaction between technological and organisational process innovation. This research carefully suggests that the interaction between technological and organisational process innovation is different for radical innovations than incremental innovations. The degree of innovation radicalness has seldom been included into these studies.

Finally, the various interaction patterns (i.e. sequential and simultaneous) observed between technological and organisational process innovation indicate that there is no one winning strategy for combining technological and organisational process advancements (in line with Ballot et al., 2015). Therefore it might be interesting to study contingencies that impact the relationship between technological and organisational process innovation. Empirical research is necessary to gain a better understanding of when sequential implementation is more beneficial than simultaneous implementation and the reverse.

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Appendices

Appendix 1: different definitions and conceptualisations of organisational innovation

Concept	**Definition**	**Aspects**	Source
Organizational process innovations	'new ways to organize business such as production or R&D and have no technological elements as such. They have to do with the coordination of human resources and work practices'		Edquist et al (2001, p.15);
Administrative process innovations	Refers to new approaches and management practices to motivate employees, change strategy and structure of tasks and units and modify organization's processes		Damanpour et al (2009)
Organisational innovation	Changes in structure and processes of an organisational because of new managerial and working practices	Differentiates between • Inter-organisational or intra-organisational • Procedural and structural innovation	Armbruster et al (2006:2008)
Organisational innovation	organisational innovation refers to the introduction of management practices and structures that are new to the organisation	Differentiates between: • management practices (e.g. teamwork, knowledge mangement • Product approaches (e.g. TQM, Lean) • External relations (e.g. outsourcing)	OECD (2005)
Management innovation	'the generation and implementation of a management practice, process, structure, or technique that is new to the state of the art and is intended to further organizational goals'	Differentiates between: • Practice • Process • Structure • technique	Birkinshaw et al (2008)
Management innovation	New-to-the-firm changes in setting objectives, motivating employees,		Birkinshaw (2012)

	coordinating activities and descision making		
Management innovation	Identifies several subtypes: • knowledge management; innovation in firms internal learning and knowledge sharing through communication technology • workplace organization; new practices with regard to distribution of responsibilities and decision making amongst employees • external relations		Hecker & Ganter (2013)
Business process innovation	Differentiates between 6 types of innovation	• products of goods or services • distribution and logistics • marketing and sales • information and communication systems • administration and management • product and business process development	OECD (2018)
		• business practices • workplace organisation • external relations • knowledge management practices	Mothe ngueyen en Nguyen-th (2015)

Appendix 2: Operationalisation table

Variable	Construct	Dimensions	Items/questions	Scale	Source
Indepedent variable	**Technological process innovation**				
			Mobile devices for programming	Nominal (Yes or no)	Based on armbruster et al (2008)
			Digital soluition technologies	Nominal (Yes or no)	
			Prodution planning software	Nominal (Yes or no)	
			Internal logistics systems	Nominal (Yes or no)	
			Digital exchange of data technologies	Nominal (Yes or no)	
			Product life cycle systems	Nominal (Yes or no)	
			Real time control systems	Nominal (Yes or no)	
			Manufacturing robots	Nominal (Yes or no)	
			Robots for processes	Nominal (Yes or no)	
			3D printing for prototyping	Nominal (Yes or no)	
			3D printing for product components	Nominal (Yes or no)	
			Software for product design simulation	Nominal (Yes or no)	
			Software for advanced computations	Nominal (Yes or no)	
			Software for simulating prodcutionprocess	Nominal (Yes or no)	
Indepedent variable	**Organisational process innovation**				
			Integration of tasks	Nominal (Yes or no)	Based on OECD (2005); Frank et al (2019)
			Customer or product oriented lines	Nominal (Yes or no)	
			Poduction controlling pull principle	Nominal (Yes or no)	
			Change-over-time concepts	Nominal (Yes or no)	
			Workinstructions	Nominal (Yes or no)	
			Displayboard	Nominal (Yes or no)	
			Quality management measures	Nominal (Yes or no)	
			Employee involvement/development	Nominal (Yes or no)	
			Employee bonussystems	Nominal (Yes or no)	
			Enviromnetal certificates	Nominal (Yes or no)	
			Energy certificates	Nominal (Yes or no)	
Dependent variable	**Operational effciency**				
		Product lead time		Metric	

		Not on time	Ratio (0-100%)	Ichniowski et al., (1997)
		Scrap rate	Ratio (0-100%)	
		Quality complaints	Ratio (0-100%)	
Control variable	**Firm size**			
		Number of employees	Ratio (10 to 30.000)	
Control variable	**Industry type**			
		Metal		
		Food		
		Textile		
		Construction		
		Chemical		
		Machinery		
		Electronic		

Appendix 3: SPSS output

3.1 Descriptive statistics

Statistics

		Size number of employees 2021	lnSize number of employees 2017 (log)	Industry Industry sector	Metal	Food	Textile	Construction	Chemical	Machinery	Electronic
N	Valid	186	186	186	186	186	186	186	186	186	186
	Missing	0	0	0	0	0	0	0	0	0	0
Mean		246,8871	3,9287	3,6720	,2634	,0753	,1613	,0430	,2043	,1882	,0645
Std. Error of Mean		161,13299	,07871	,15181	,03239	,01940	,02704	,01492	,02964	,02874	,01806
Median		45,0000	3,8067	3,5000	,0000	,0000	,0000	,0000	,0000	,0000	,0000
Mode		25,00[a]	3,22[a]	1,00	,00	,00	,00	,00	,00	,00	,00
Std. Deviation		2197,56097	1,07349	2,07038	,44169	,26454	,36879	,20343	,40428	,39190	,24633
Variance		4829274,198	1,152	4,286	,195	,070	,136	,041	,163	,154	,061
Skewness		13,561	1,535	-,022	1,083	3,246	1,857	4,542	1,479	1,609	3,574
Std. Error of Skewness		,178	,178	,178	,178	,178	,178	,178	,178	,178	,178
Kurtosis		184,571	6,090	-1,459	-,837	8,629	1,463	18,829	,189	,594	10,892
Std. Error of Kurtosis		,355	,355	,355	,355	,355	,355	,355	,355	,355	,355
Range		29990,00	8,01	6,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Minimum		10,00	2,30	1,00	,00	,00	,00	,00	,00	,00	,00
Maximum		30000,00	10,31	7,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Sum		45921,00	730,74	683,00	49,00	14,00	30,00	8,00	38,00	35,00	12,00

a. Multiple modes exist. The smallest value is shown

3.2: Statistics technological process innovation

Statistics

Digi_Production index of digitalization |

N	Valid	186
	Missing	0
Mean		3,9624
Std. Error of Mean		,18758
Median		4,0000
Mode		3,00
Std. Deviation		2,55823
Variance		6,545
Skewness		,446
Std. Error of Skewness		,178
Kurtosis		-,516
Std. Error of Kurtosis		,355
Range		10,00
Minimum		,00
Maximum		10,00
Sum		737,00

3.3: statistics organisational process innovation

Statistics

ProcessOrganization index of innovativ

N	Valid	186
	Missing	0
Mean		5,1237
Std. Error of Mean		,18582
Median		5,0000
Mode		5,00
Std. Deviation		2,53426
Variance		6,422
Skewness		,240
Std. Error of Skewness		,178
Kurtosis		-,487
Std. Error of Kurtosis		,355
Range		11,00
Minimum		,00
Maximum		11,00
Sum		953,00

3.4 Reliability statistics technological process innovation

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
,652	,656	14

35 reliability coefficient organisational process innovation

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
,714	,716	11

3.4 Item statistics technological process innovation

Item Statistics

	Mean	Std. Deviation	N
ti_MobileDev Technology - Mobile/wireless devices for programming and operation	,3763	,48578	186
ti_DigSolutions Technology - Digital solutions for providing drawings, work schedules or work instructions directly on the shopfloor	,5054	,50132	186
ti_ProdPlanning Technology - Software for production planning and scheduling	,6344	,48290	186
ti_IntLogistics Technology - Systems for automation and management of internal logistics	,2957	,45759	186
ti_DigExchange Technology - Digital Exchange of product/process data with suppliers / customers	,3333	,47268	186
ti_PLCsystems Technology - Product-Lifecycle-Management-System	,1613	,36879	186
ti_RealtimeControl Technology - Near real-time production control system	,2419	,42941	186
ti_manuRobots Technology - Industrial robots for manufacturing processes	,2258	,41924	186
ti_handRobots Technology - Industrial robots for handling processes	,2742	,44731	186
ti_3Dprototype Technology - Additive manufacturing 3D for prototyping	,2204	,41566	186
ti_3Dprint Technology - Additive manufacturing 3D for products components etc	,1559	,36375	186
ti_softProdDesign Technology - Software for product design simulation	,2796	,45000	186
ti_softAdvComp Technology - Software for advanced computations, data analysis High-Performance Edge computing	,1505	,35856	186
ti_softProcess Technology - Software for simulating production processes	,1075	,31062	186

3.5 Item statistics organisational process innovation

Item Statistics

	Mean	Std. Deviation	N
oi_IntegrationTasks Organizational concepts - Integration of tasks	,6882	,46449	186
oi_CustomerLines Organizational concepts - Customer- or product-oriented lines	,8118	,39190	186
oi_PullPrinciple Organizational concepts - Production controlling following the Pull principle	,3441	,47635	186
oi_ChangeOverTime Organizational concepts - Fixed process flows to reduce setup time or optimize change-over time	,2796	,45000	186
oi_WorkInstruction Organizational concepts - Standardized and detailed work instructions	,4892	,50123	186
oi_DisplayBoards Organizational concepts - Display boards in production to illustrate work processes and work status	,4624	,49993	186
oi_QualityMeasures Organizational concepts - Methods of assuring quality in production	,7312	,44454	186
oi_EmployeeInnovation Organizational concepts - Employee involvement in innovation development	,6022	,49078	186
oi_EmployeeBonus Organizational concepts - Employee bonus systems in production	,2957	,45759	186
oi_CertifiedEnvironmentMS Organizational concepts - Certified environmental management system	,3226	,46873	186
oi_CertifiedEnergyMS Organizational concepts - Certified energy management system	,0968	,29645	186

3.6: Item-total statistics technological process innovation

Item-Total Statistics

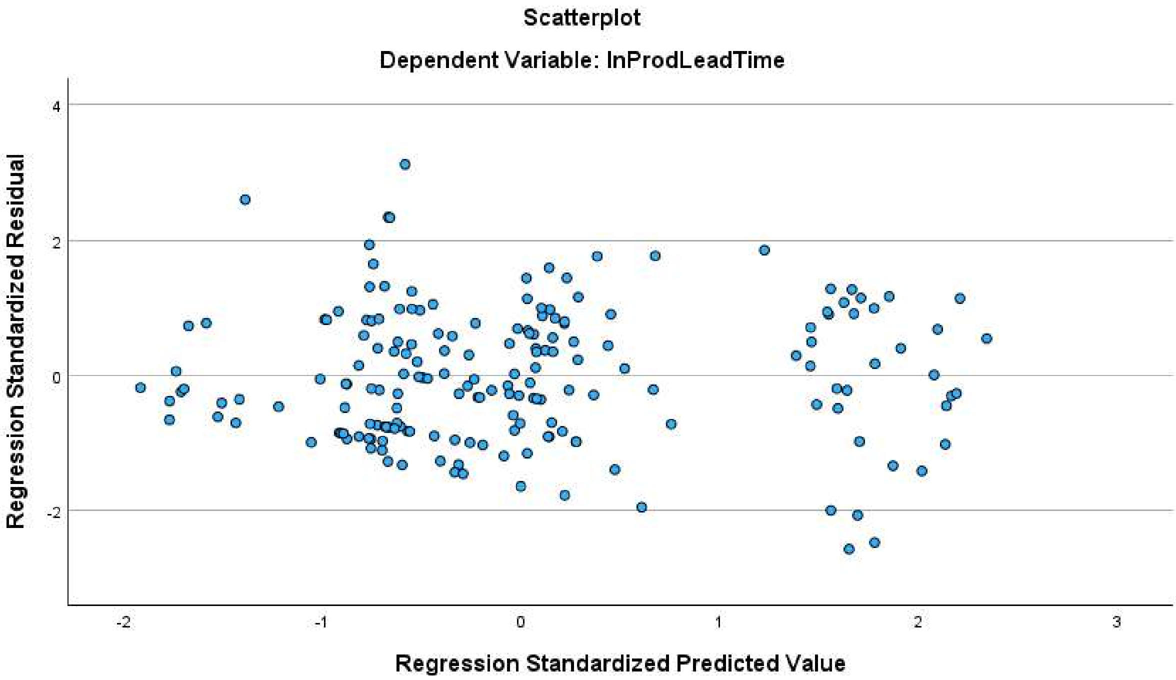
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
ti_MobileDev Technology - Mobile/wireless devices for programming and operation	3,5860	5,855	,193	,093	,649
ti_DigSolutions Technology - Digital solutions for providing drawings, work schedules or work instructions directly on the shopfloor	3,4570	5,547	,316	,212	,628
ti_ProdPlanning Technology - Software for production planning and scheduling	3,3280	5,411	,401	,208	,613
ti_IntLogistics Technology - Systems for automation and management of internal logistics	3,6667	5,856	,216	,134	,644
ti_DigExchange Technology - Digital Exchange of product/process data with suppliers / customers	3,6290	5,737	,258	,108	,638
ti_PLCsystems Technology - Product-Lifecycle-Management-System	3,8011	5,825	,328	,172	,628
ti_RealtimeControl Technology - Near real-time production control system	3,7204	5,748	,297	,203	,631
ti_manuRobots Technology - Industrial robots for manufacturing processes	3,7366	6,033	,163	,281	,651
ti_handRobots Technology - Industrial robots for handling processes	3,6882	5,740	,282	,289	,634
ti_3Dprototype Technology - Additive manufacturing 3D for prototyping	3,7419	5,738	,318	,337	,628
ti_3Dprint Technology - Additive manufacturing 3D for products components etc	3,8065	5,876	,304	,383	,632
ti_softProdDesign Technology - Software for product design simulation	3,6828	5,688	,305	,186	,630
ti_softAdvComp Technology - Software for advanced computations, data analysis High-Performance Edge computing	3,8118	6,002	,235	,176	,640
ti_softProcess Technology - Software for simulating production processes	3,8548	6,060	,254	,132	,639

3.7: Item-total statistics organisational process innovation

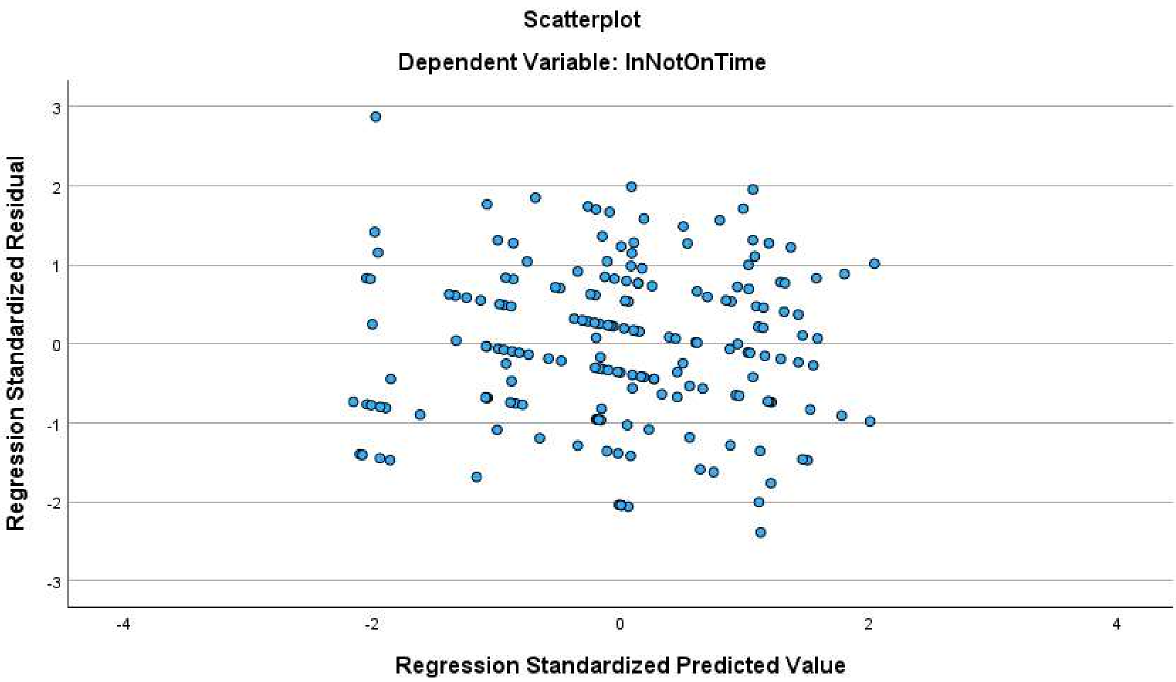
Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
oi_IntegrationTasks Organizational concepts - Integration of tasks	4,4355	5,588	,282	,148	,706
oi_CustomerLines Organizational concepts - Customer- or product-oriented lines	4,3118	5,837	,228	,123	,711
oi_PullPrinciple Organizational concepts - Production controlling following the Pull principle	4,7796	5,416	,352	,169	,695
oi_ChangeOverTime Organizational concepts - Fixed process flows to reduce setup time or optimize change-over time	4,8441	5,235	,478	,262	,675
oi_WorkInstruction Organizational concepts - Standardized and detailed work instructions	4,6344	5,185	,432	,282	,682
oi_DisplayBoards Organizational concepts - Display boards in production to illustrate work processes and work status	4,6613	5,263	,397	,234	,688
oi_QualityMeasures Organizational concepts - Methods of assuring quality in production	4,3925	5,180	,516	,330	,670
oi_EmployeeInnovation Organizational concepts - Employee involvement in innovation development	4,5215	5,364	,359	,244	,694
oi_EmployeeBonus Organizational concepts - Employee bonus systems in production	4,8280	5,441	,362	,165	,693
oi_CertifiedEnvironmentMS Organizational concepts - Certified environmental management system	4,8011	5,739	,207	,205	,717
oi_CertifiedEnergyMS Organizational concepts - Certified energy management system	5,0269	5,810	,367	,258	,697

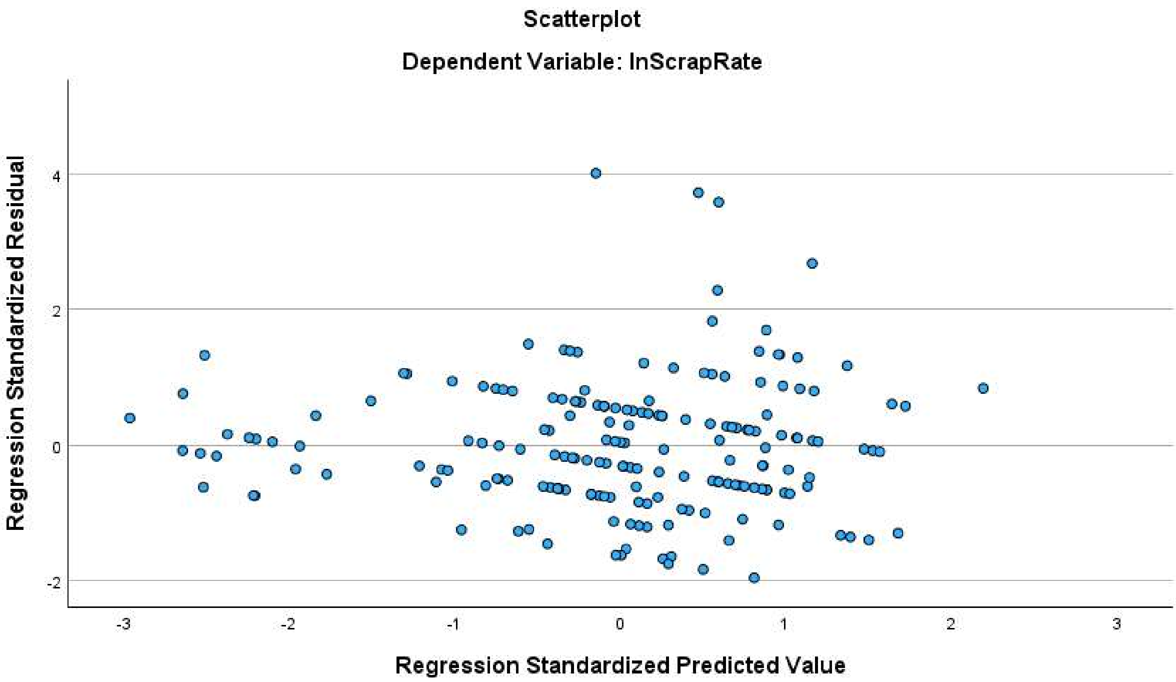
3.8 scatterplot of the standardized predicted value product lead time



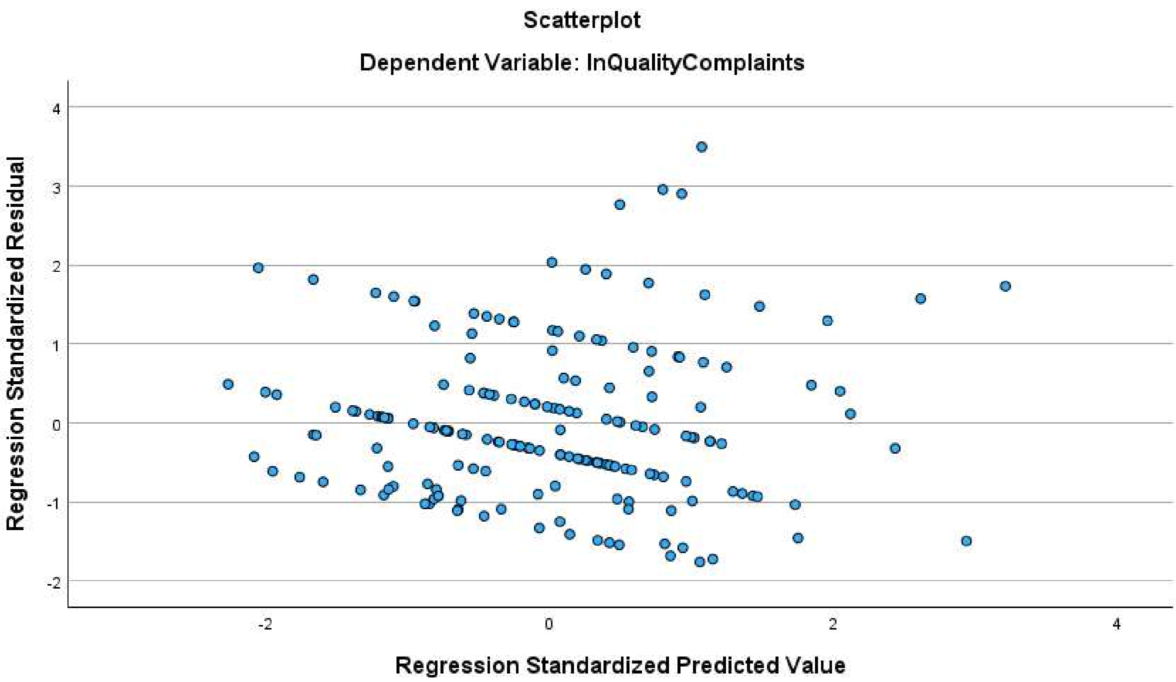
3.9 scatterplot not on time



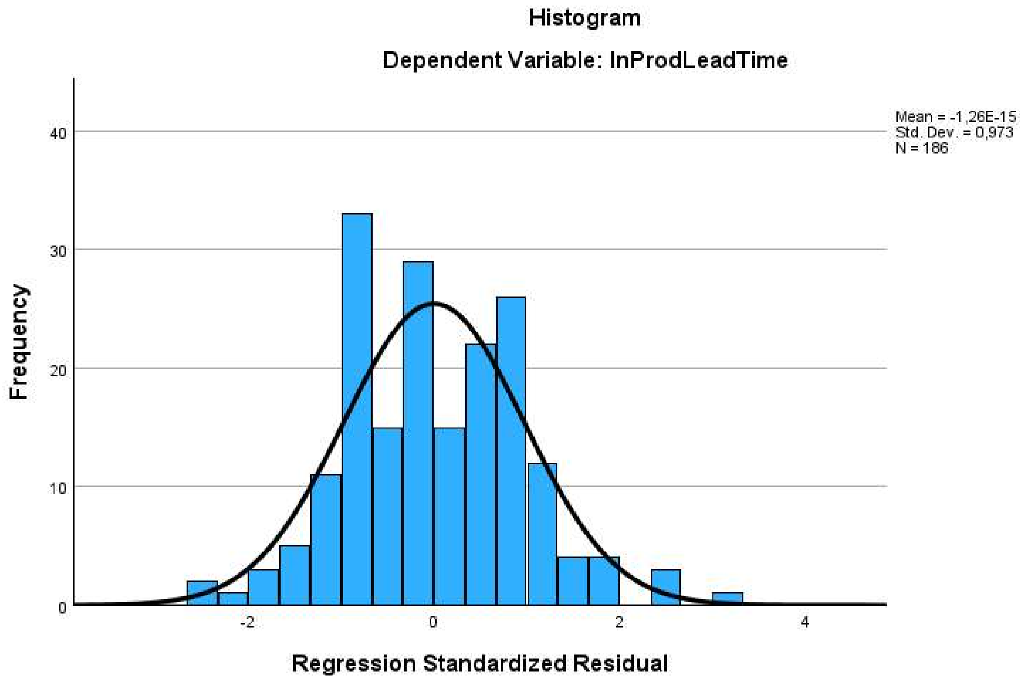
3.10 Scatterplot scrap rate



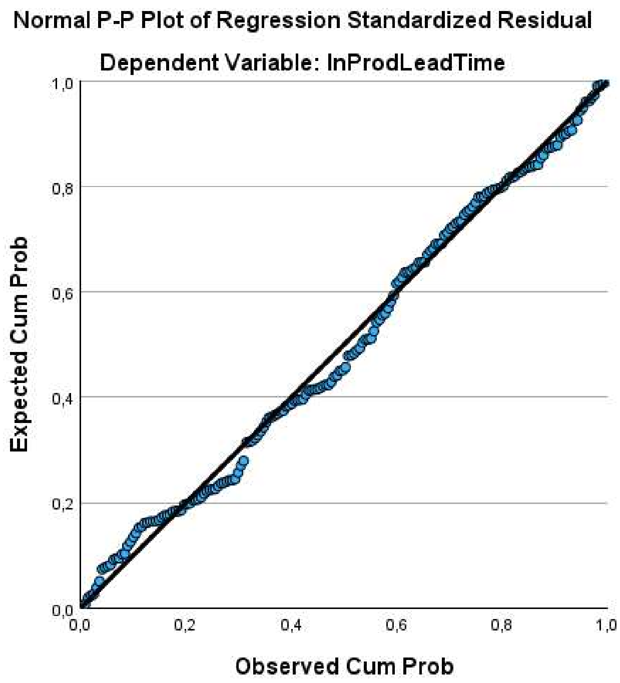
3.11 Scatterplot quality complaints



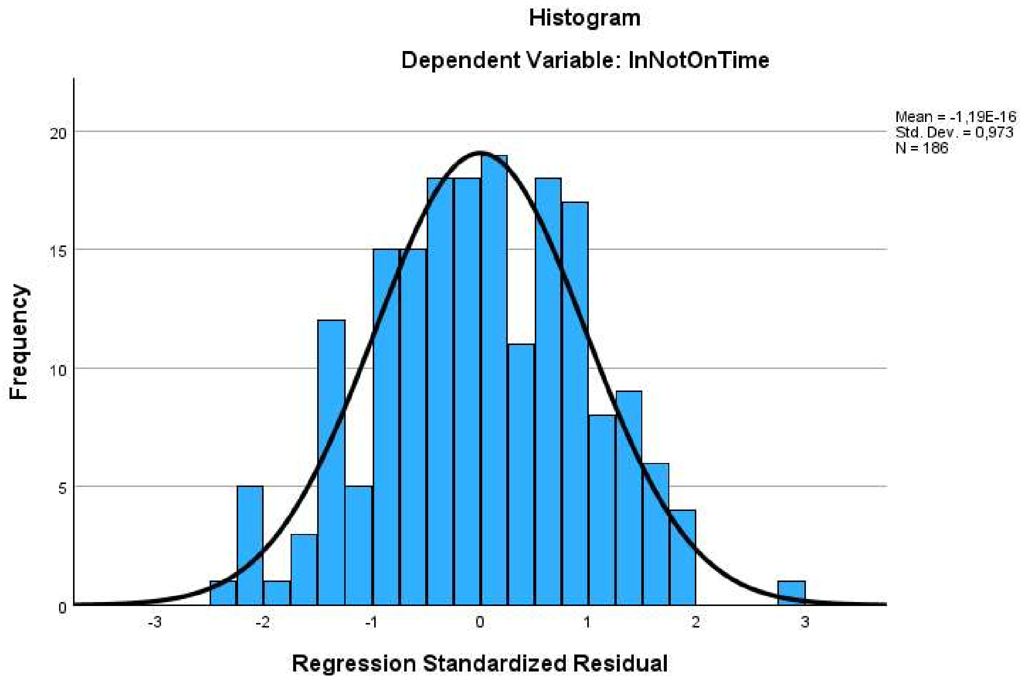
3.12 Standardized residuals histogram product lead time



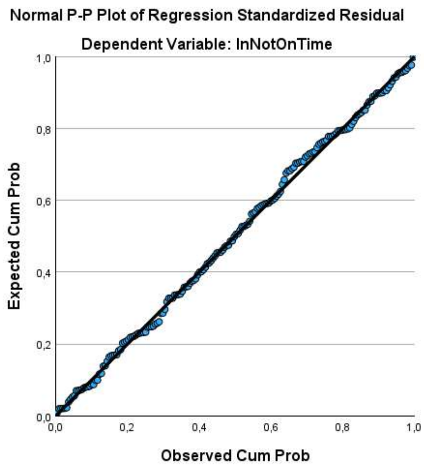
3.13 Normal probability plot product lead time



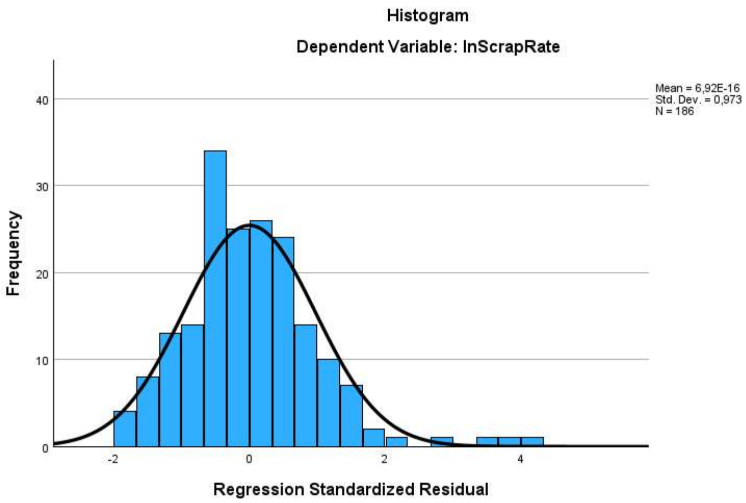
3.13 Standardized residuals histogram not on time



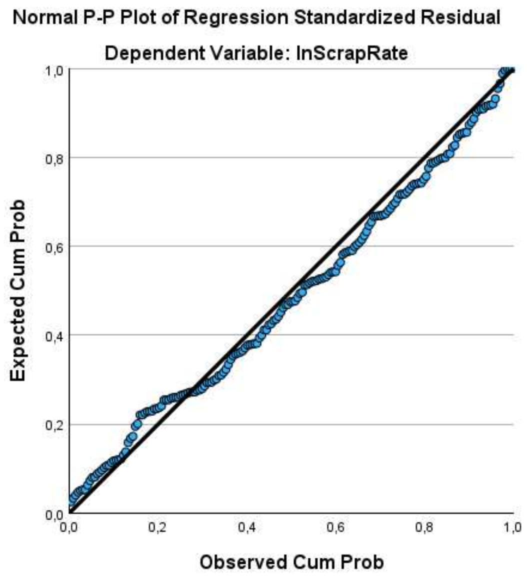
3.14 normal probability plot not on time



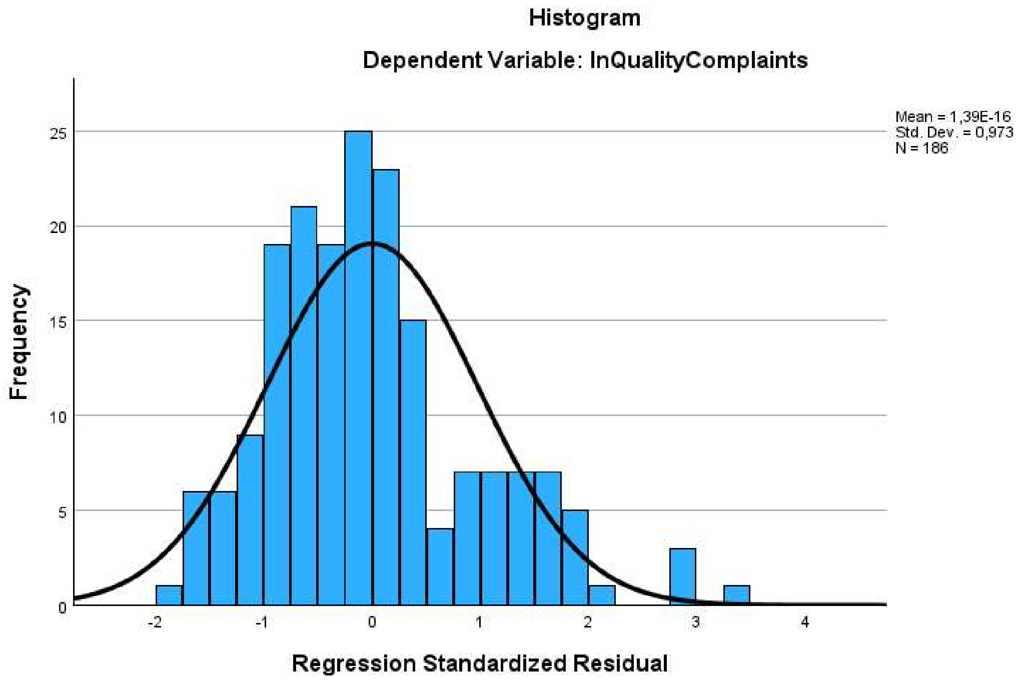
3.15 Standardized residuals histogram scrap rate



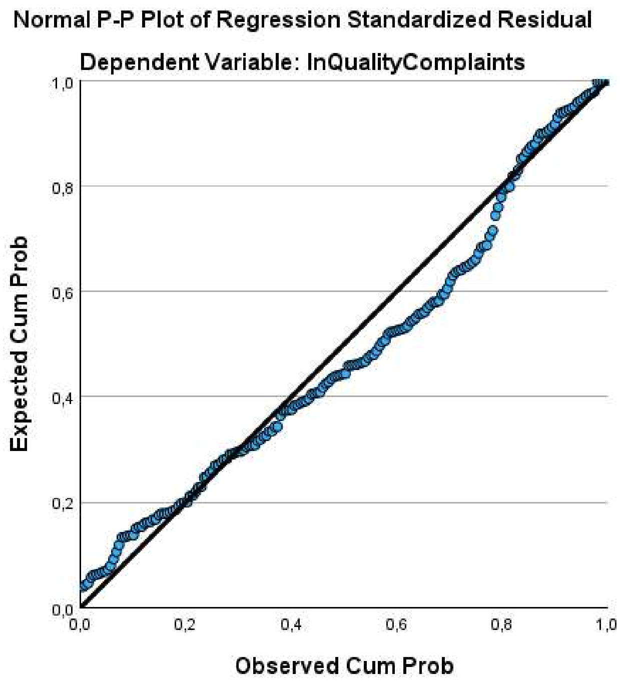
3.16 Normal probability plot scrap rate



3.17 Standardized residuals histogram quality complaints



3.18 Normal probability plot quality complaints



3.18: Regression coefficients product lead time

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics Tolerance	VIF
1	(Constant)	2,094	,405		5,165	<,001		
	lnSize number of employees 2017 (log)	,055	,093	,040	,596	,552	,952	1,051
	Food	-1,324	,408	-,237	-3,249	,001	,812	1,231
	Textile	-,575	,306	-,144	-1,875	,062	,739	1,353
	Construction	-,062	,504	-,008	-,122	,903	,897	1,115
	Chemical	-,556	,286	-,152	-1,943	,054	,706	1,417
	Machinery	1,162	,293	,308	3,973	<,001	,718	1,392
	Electronic	-,500	,426	-,083	-1,175	,242	,858	1,166
2	(Constant)	2,144	,410		5,232	<,001		
	lnSize number of employees 2017 (log)	,010	,104	,007	,093	,926	,749	1,335
	Food	-1,117	,425	-,200	-2,631	,009	,745	1,343
	Textile	-,481	,311	-,120	-1,546	,124	,715	1,399
	Construction	,024	,506	,003	,047	,962	,888	1,126
	Chemical	-,369	,308	-,101	-1,200	,232	,607	1,647
	Machinery	1,164	,292	,309	3,983	<,001	,717	1,395
	Electronic	-,461	,426	-,077	-1,084	,280	,855	1,170
	Digi_Production index of digitalization process innovations used	,085	,051	,147	1,681	,095	,561	1,782
	ProcessOrganization index of innovative practices in process organization used	-,055	,049	-,095	-1,125	,262	,609	1,643
3	(Constant)	2,107	,457		4,608	<,001		
	lnSize number of employees 2017 (log)	,008	,105	,006	,077	,938	,744	1,344
	Food	-1,116	,426	-,200	-2,622	,010	,744	1,343
	Textile	-,480	,312	-,120	-1,540	,125	,715	1,399
	Construction	,029	,508	,004	,056	,955	,886	1,129
	Chemical	-,363	,310	-,099	-1,169	,244	,599	1,668
	Machinery	1,168	,294	,310	3,974	<,001	,712	1,405
	Electronic	-,455	,428	-,076	-1,061	,290	,848	1,179
	Digi_Production index of digitalization process innovations used	,093	,066	,161	1,399	,164	,329	3,042
	ProcessOrganization index of innovative practices in process organization used	-,055	,049	-,095	-1,125	,262	,608	1,644
	i_cDiPoXOrPr	,003	,016	,017	,180	,857	,463	2,161

a. Dependent Variable: lnProdLeadTime

3.19: Regression coefficients not on time

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics Tolerance	Collinearity Statistics VIF
1	(Constant)	2,197	,326		6,738	<,001		
	lnSize number of employees 2017 (log)	,011	,075	,011	,150	,881	,952	1,051
	Food	-,638	,328	-,155	-1,946	,053	,812	1,231
	Textile	-,349	,246	-,118	-1,418	,158	,739	1,353
	Construction	-,687	,406	-,128	-1,695	,092	,897	1,115
	Chemical	-,065	,230	-,024	-,282	,778	,706	1,417
	Machinery	,317	,235	,114	1,350	,179	,718	1,392
	Electronic	,423	,343	,096	1,235	,219	,858	1,166
2	(Constant)	2,151	,331		6,489	<,001		
	lnSize number of employees 2017 (log)	-,013	,084	-,013	-,159	,873	,749	1,335
	Food	-,668	,343	-,162	-1,944	,054	,745	1,343
	Textile	-,347	,251	-,118	-1,380	,169	,715	1,399
	Construction	-,692	,409	-,129	-1,691	,093	,888	1,126
	Chemical	-,105	,249	-,039	-,424	,672	,607	1,647
	Machinery	,307	,236	,111	1,300	,195	,717	1,395
	Electronic	,413	,344	,094	1,201	,231	,855	1,170
	Digi_Production index of digitalization process innovations used	,000	,041	,000	-,003	,997	,561	1,782
	ProcessOrganization index of innovative practices in process organization used	,030	,040	,071	,769	,443	,609	1,643
3	(Constant)	2,020	,369		5,469	<,001		
	lnSize number of employees 2017 (log)	-,019	,085	-,019	-,227	,821	,744	1,344
	Food	-,665	,344	-,162	-1,933	,055	,744	1,343
	Textile	-,345	,252	-,117	-1,369	,173	,715	1,399
	Construction	-,675	,410	-,126	-1,646	,102	,886	1,129
	Chemical	-,083	,251	-,031	-,329	,742	,599	1,668
	Machinery	,323	,237	,116	1,360	,176	,712	1,405
	Electronic	,438	,346	,099	1,266	,207	,848	1,179
	Digi_Production index of digitalization process innovations used	,028	,054	,065	,517	,606	,329	3,042
	ProcessOrganization index of innovative practices in process organization used	,030	,040	,070	,754	,452	,608	1,644
	i_cDiPoXOrPr	,011	,013	,086	,807	,421	,463	2,161

a. Dependent Variable: lnNotOnTime

3.20: Regression coefficients scrap rate

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	1,443	,257		5,623	<,001		
	lnSize number of employees 2017 (log)	,025	,059	,031	,433	,666	,952	1,051
	Food	-1,006	,258	-,306	-3,897	<,001	,812	1,231
	Textile	-,376	,194	-,159	-1,937	,054	,739	1,353
	Construction	,319	,319	,075	,999	,319	,897	1,115
	Chemical	-,296	,181	-,138	-1,635	,104	,706	1,417
	Machinery	-,046	,185	-,021	-,248	,804	,718	1,392
	Electronic	-,026	,270	-,007	-,097	,923	,858	1,166
2	(Constant)	1,425	,257		5,552	<,001		
	lnSize number of employees 2017 (log)	,085	,065	,105	1,305	,193	,749	1,335
	Food	-1,185	,266	-,361	-4,456	<,001	,745	1,343
	Textile	-,468	,195	-,198	-2,401	,017	,715	1,399
	Construction	,240	,317	,056	,757	,450	,888	1,126
	Chemical	-,449	,193	-,209	-2,331	,021	,607	1,647
	Machinery	-,041	,183	-,018	-,221	,825	,717	1,395
	Electronic	-,057	,267	-,016	-,216	,830	,855	1,170
	Digi_Production index of digitalization process innovations used	-,082	,032	-,240	-2,576	,011	,561	1,782
	ProcessOrganization index of innovative practices in process organization used	,033	,031	,097	1,082	,281	,609	1,643
3	(Constant)	1,305	,286		4,564	<,001		
	lnSize number of employees 2017 (log)	,080	,066	,099	1,219	,224	,744	1,344
	Food	-1,183	,266	-,360	-4,445	<,001	,744	1,343
	Textile	-,465	,195	-,197	-2,389	,018	,715	1,399
	Construction	,255	,317	,060	,805	,422	,886	1,129
	Chemical	-,428	,194	-,199	-2,206	,029	,599	1,668
	Machinery	-,026	,184	-,012	-,142	,887	,712	1,405
	Electronic	-,035	,268	-,010	-,130	,897	,848	1,179
	Digi_Production index of digitalization process innovations used	-,056	,041	-,165	-1,352	,178	,329	3,042
	ProcessOrganization index of innovative practices in process organization used	,033	,031	,095	1,065	,288	,608	1,644
	i_cDiPoXOrPr	,010	,010	,099	,962	,337	,463	2,161

a. Dependent Variable: lnScrapRate

3.21: Regression coefficients quality complaints

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics Tolerance	Collinearity Statistics VIF
1	(Constant)	,934	,223		4,196	<,001		
	lnSize number of employees 2017 (log)	,005	,051	,007	,091	,927	,952	1,051
	Food	-,437	,224	-,157	-1,953	,052	,812	1,231
	Textile	,005	,168	,003	,031	,975	,739	1,353
	Construction	,440	,277	,121	1,587	,114	,897	1,115
	Chemical	-,149	,157	-,082	-,946	,345	,706	1,417
	Machinery	,195	,161	,104	1,215	,226	,718	1,392
	Electronic	,184	,234	,062	,788	,432	,858	1,166
2	(Constant)	,992	,221		4,492	<,001		
	lnSize number of employees 2017 (log)	,086	,056	,126	1,535	,127	,749	1,335
	Food	-,522	,229	-,187	-2,282	,024	,745	1,343
	Textile	-,065	,167	-,033	-,389	,698	,715	1,399
	Construction	,389	,272	,107	1,426	,156	,888	1,126
	Chemical	-,198	,166	-,108	-1,192	,235	,607	1,647
	Machinery	,215	,157	,114	1,367	,173	,717	1,395
	Electronic	,176	,229	,059	,769	,443	,855	1,170
	Digi_Production index of digitalization process innovations used	-,059	,027	-,205	-2,171	,031	,561	1,782
	ProcessOrganization index of innovative practices in process organization used	-,023	,026	-,079	-,865	,388	,609	1,643
3	(Constant)	,797	,244		3,262	,001		
	lnSize number of employees 2017 (log)	,078	,056	,113	1,386	,168	,744	1,344
	Food	-,518	,227	-,186	-2,278	,024	,744	1,343
	Textile	-,061	,166	-,031	-,369	,713	,715	1,399
	Construction	,414	,271	,114	1,528	,128	,886	1,129
	Chemical	-,163	,166	-,090	-,986	,326	,599	1,668
	Machinery	,239	,157	,127	1,520	,130	,712	1,405
	Electronic	,213	,229	,071	,931	,353	,848	1,179
	Digi_Production index of digitalization process innovations used	-,018	,035	-,061	-,500	,618	,329	3,042
	ProcessOrganization index of innovative practices in process organization used	-,024	,026	-,081	-,902	,369	,608	1,644
	i_cDiPoXOrPr	,016	,009	,188	1,821	,070	,463	2,161

a. Dependent Variable: lnQualityComplaints

3.22: Model summary: product lead time

Model Summary[d]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	,479[a]	,229	,199	1,32161	,229	7,572	7	178	<,001	
2	,492[b]	,242	,203	1,31819	,013	1,462	2	176	,235	
3	,492[c]	,242	,199	1,32183	,000	,033	1	175	,857	2,138

a. Predictors: (Constant), Electronic, lnSize number of employees 2017 (log), Construction, Textile, Food, Machinery, Chemical

b. Predictors: (Constant), Electronic, lnSize number of employees 2017 (log), Construction, Textile, Food, Machinery, Chemical, ProcessOrganization index of innovative practices in process organization used, Digi_Production index of digitalization process innovations used

c. Predictors: (Constant), Electronic, lnSize number of employees 2017 (log), Construction, Textile, Food, Machinery, Chemical, ProcessOrganization index of innovative practices in process organization used, Digi_Production index of digitalization process innovations used, i_cDiPoXOrPr

d. Dependent Variable: lnProdLeadTime

3.23 Model summary: not on time

Model Summary[d]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	,288[a]	,083	,047	1,06274	,083	2,299	7	178	,029	
2	,295[b]	,087	,040	1,06636	,004	,396	2	176	,674	
3	,301[c]	,090	,038	1,06742	,003	,652	1	175	,421	2,147

a. Predictors: (Constant), Electronic, lnSize number of employees 2017 (log), Construction, Textile, Food, Machinery, Chemical

b. Predictors: (Constant), Electronic, lnSize number of employees 2017 (log), Construction, Textile, Food, Machinery, Chemical, ProcessOrganization index of innovative practices in process organization used, Digi_Production index of digitalization process innovations used

c. Predictors: (Constant), Electronic, lnSize number of employees 2017 (log), Construction, Textile, Food, Machinery, Chemical, ProcessOrganization index of innovative practices in process organization used, Digi_Production index of digitalization process innovations used, i_cDiPoXOrPr

d. Dependent Variable: lnNotOnTime

3.24: Model summary: scrap rate

Model Summary[d]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	,330[a]	,109	,074	,83676	,109	3,111	7	178	,004	
2	,376[b]	,142	,098	,82592	,033	3,353	2	176	,037	
3	,382[c]	,146	,097	,82609	,005	,926	1	175	,337	2,106

a. Predictors: (Constant), Electronic, lnSize number of employees 2017 (log), Construction, Textile, Food, Machinery, Chemical

b. Predictors: (Constant), Electronic, lnSize number of employees 2017 (log), Construction, Textile, Food, Machinery, Chemical, ProcessOrganization index of innovative practices in process organization used, Digi_Production index of digitalization process innovations used

c. Predictors: (Constant), Electronic, lnSize number of employees 2017 (log), Construction, Textile, Food, Machinery, Chemical, ProcessOrganization index of innovative practices in process organization used, Digi_Production index of digitalization process innovations used, i_cDiPoXOrPr

d. Dependent Variable: lnScrapRate

3.25: Model summary: quality complaints

Model Summary[d]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	,259[a]	,067	,030	,72595	,067	1,827	7	178	,085	
2	,342[b]	,117	,072	,71032	,050	4,958	2	176	,008	
3	,365[c]	,133	,084	,70569	,016	3,317	1	175	,070	1,960

a. Predictors: (Constant), Electronic, lnSize number of employees 2017 (log), Construction, Textile, Food, Machinery, Chemical

b. Predictors: (Constant), Electronic, lnSize number of employees 2017 (log), Construction, Textile, Food, Machinery, Chemical, ProcessOrganization index of innovative practices in process organization used, Digi_Production index of digitalization process innovations used

c. Predictors: (Constant), Electronic, lnSize number of employees 2017 (log), Construction, Textile, Food, Machinery, Chemical, ProcessOrganization index of innovative practices in process organization used, Digi_Production index of digitalization process innovations used, i_cDiPoXOrPr

d. Dependent Variable: lnQualityComplaints

Appendix 4: interview scheme

Goal of my Master's Thesis:

I am investigating whether companies experience benefits when they implement work process innovations and technological process innovations jointly and integrated, rather than separately.

Interview Script:

This is a semi-structured interview, which means I have formulated a number of main questions that I will then follow up on during the interview.

Introduction (5 min)

1. Who are you and what is your role within the company?
2. Can you briefly describe your company (think of core activities, sector, main products)?
3. How are you involved in innovation within the production process?

Main Topic 1: Technological Process Innovation (15 min)

Introduction: Technological process innovation is defined as new technological elements introduced into the production process (e.g., new machines, ERP systems, 3D printer technology).

1. What significant technological innovations and improvements have been implemented in production in your company recently?
    - Examples
2. What primarily prompted these changes? (Relate to the previous question)
    - What was the impact of these innovations (better efficiency)?
3. How are these technological innovations implemented in production (implementation)?
    - What related organizational changes did you make to successfully implement them?
    - What obstacles did you encounter during implementation?

Main Topic 2: Work Process Innovation (15 min)

Introduction: Work process innovation involves implementing new organizational and management methods. It focuses on improving how tasks are performed, communication between team members, and streamlining decision-making processes (think of KANBAN, Lean principles, Total Quality Management, structural changes, standardized work instructions).

1. What significant innovations and improvements have been implemented in work processes recently?
    - Examples
2. What primarily prompted these innovations? (Relate to the innovations mentioned in the previous question)
    - What is the impact of these innovations?
3. How are these innovations implemented in the work organization (implementation)?
    - Have you implemented related technological process innovations to facilitate this implementation?
    - What obstacles did you encounter?

Main Topic 3: Synergy Between Technological Innovation and Work Process Innovation (15 min)

Introduction: Synergy between technological process innovation and work process innovation refers to the situation where the joint implementation of improvements in both technological processes and work processes reinforces each other, leading to more significant benefits than when applied separately (e.g., implementing new process robots simultaneously with new decision-making procedures or adapting work processes to new advanced machines).

1. To what extent do you align innovations/changes in technological production systems and work processes with each other?
    - Examples
2. What primarily prompts the joint implementation of these work process innovations and technological process innovations? (Relate to the previous question)
    - Examples
    - What is the impact of this joint implementation?
3. What activities do you undertake to implement work process innovations and technological process innovations in an integrated manner?
    - Implementation activities undertaken
    - Obstacles