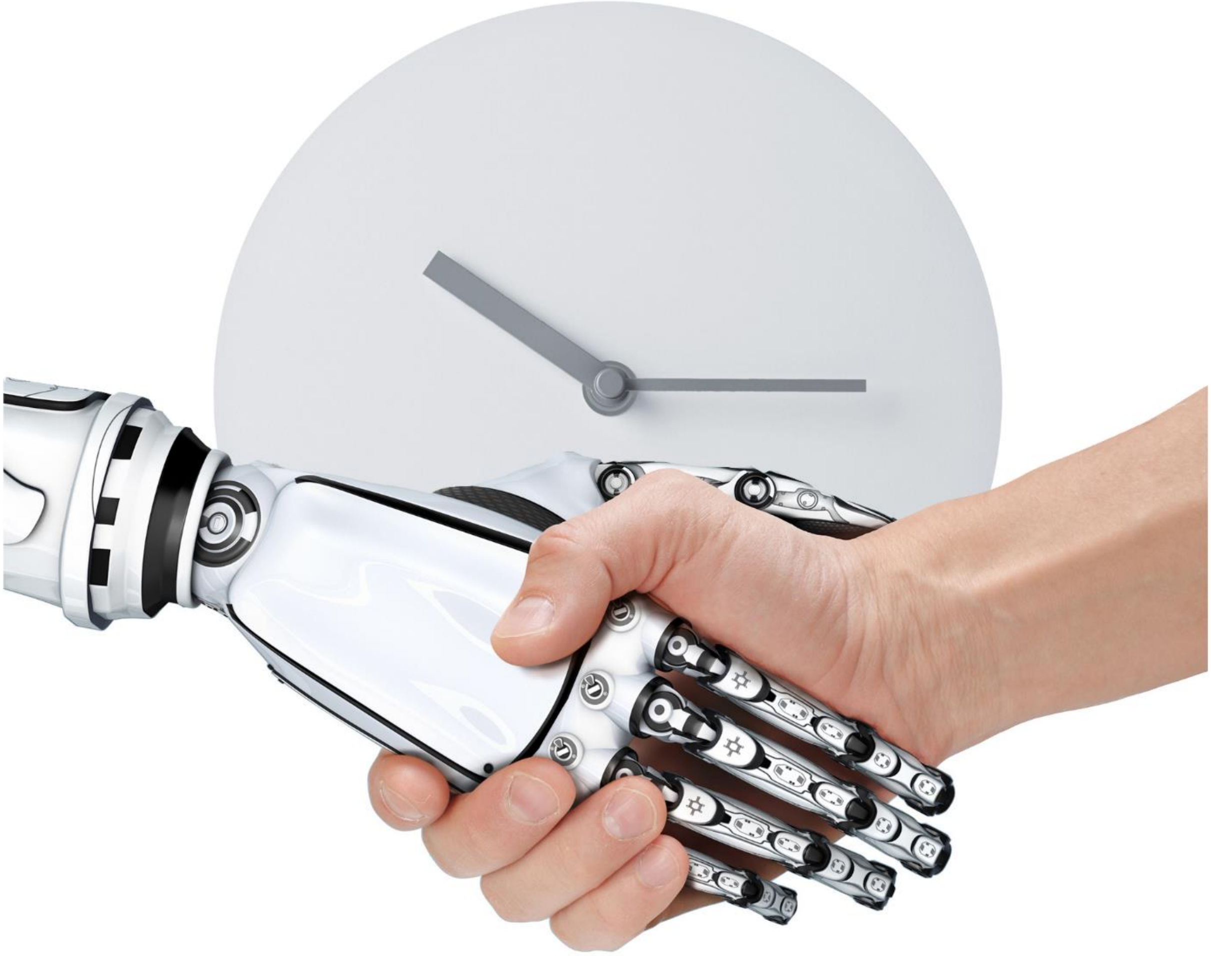
Improving operational performance through the adoption timing of technological and organizational innovations



W. Ostermann
s 4085361
Moordkuil 3
6511 VR, Nijmegen
06 - 24 38 62 20
w.ostermann@student.ru.nl

Dr. P. M.M. Vaessen
Dr. R.A.W. Kok

University:	Radboud University
Student:	Wout Ostermann
Student no.:	4085361
Study:	Innovation & Entrepreneurship
Supervisor:	dr. P.M.M Vaessen
Co-reader:	dr. R.A.W. Kok
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Abstract

This master thesis focuses on the timing of the adoption of technological and organizational innovations and its influence on operational performance. Combining both types of innovations has been proven beneficial for manufacturing firms. However, literature on how firms should time the adoption of technological and organizational innovations is scarce. Most manufacturing firms are technologically deterministic and change its organizational social systems after introducing technologies. The learning costs that arise from this inefficient strategy could have been prevented and synergistic effects could be achieved when both forms are adopted in tandem and synchronized. This research attempts to look into this relationship and compares the sequential technological deterministic approach with the synchronous approach in their effect on operational performance. Operational performance is being measured with three relevant indicators: lead time, scrap rate and energy consumption. Using one-way ANOVA analyses on a survey sample of 149 firms operating in the Dutch manufacturing sector, empirical results reveal several findings. First, most firms indeed adopt technological innovations first when combining technological innovations and organizational innovations. However, no empirical evidence was found for the expectation that firms would be better off with a synchronous adoption approach. In addition, a post hoc analysis reveals that energy consumption decreased for firms that adopted organizational innovations prior to technological innovations. This suggests that managers of Dutch manufacturing firms should learn before doing and prepare its organization prior to the adoption of technology in order to reduce energy related production costs.

Contents

Chapter 1: Introduction and problem definition

1.1 General introduction

History has taught that the biggest improvements have always been supported by the adoption and the development of complementary innovations (Rosenberg, 1979). Innovations are hardly ever adopted in isolation and since the emergence of technologies such as information and communication technologies (ICTs), scholarly have been interested in the interdependencies between technological and organizational innovations (Battisti et al., 2014). The empirical evidence depicts that firms undertake non-technological innovations when introducing technological innovations to reduce costs and outperform firms that only introduced one of the two (Schmidt & Rammer, 2007). However, studies that analyzed innovations found that managers of manufacturing companies are inclined to emphasize on technological innovations (Del Brío & Junquera, 2003). What often happens in practice is that firms first introduce technological changes, then out of necessity proceed to make organizational adaptations (Damanpour & Evan, 1984). This particular sequential order of introducing process innovations prior to organizational innovations might be due to the perceptions among managers, as well as researchers, that technological innovations will be more effective than organizational innovations in helping the organization to improve operational performance. They perceive technological innovations to be more important, more urgent, more tangible and more common than organizational innovations (Lin & Chen, 2007).

Lay et al. (2000) argue that simply adopting technological innovations is not sufficient in gaining competitiveness. These innovations benefit more from their adoption if accompanied by non-technological innovations. For example, a new robot may have been installed in a plant and a new policy applied to appraise employee performance without coordination between the two actions, whereas they could have been made to be mutually reinforcing. A time lag arises due to a rather reactive approach of sequentially adopting technological innovations prior to organizational innovations, which is referred to as ‘organizational lag’ (Evan, 1966). The social system is ignored on first hand in this approach and this may result in lower operational performance, because a company has built up learning costs. The opposite sequential approach, where a firm first adopts organizational innovations before adopting technological innovations, is an alternative. This is referred to as 'learning-before-doing' (Pisano, 1996). However, not much is known about the autonomous effects of this approach on firm performance within the innovation literature. A firm might also prevent to build up these learning costs by reducing the time lag between the adoption of technological and organizational innovations. An innovation strategy that presumes a minimal time lag is referred to as synchronous innovation within the innovation literature (Ettlie, 1988). Ettlie (1988) defines synchronous innovation as "*the planned, simultaneous adoption of congruent technological and administrative innovations. These two types of innovations work together to create a synergistic effect on performance*" (p. 2). These synergistic effects offer benefits in terms of efficiency improvement as well for a strong competitive position in the market. Supported by the resource-based view (RBV), a firm that follows a synchronous approach acquire more valuable, inimitable, and non-substitutable resources compared to firms that follow the sequential approach. Therefore, synchronous innovation helps manufacturing managers to cope with increasing competition. Nevertheless, the synchronous approach demands a more pro-active attitude from managers.

1.2 Scientific relevance

The organizational lag concept introduced by Evan (1966), was tested through samples of public organizations (Damanpour et al., 1984, Damanpour, 1989). It was proved in these studies that the degree of organizational lag is inversely related to organizational performance. Therefore, Damanpour & Aravind (2012) state that the organizational lag model might also be applied in comparative innovation studies among various other types of organizations. To date, the concept of organizational lag between technological and administrative innovations and its effect on operational performance has been unexplored within the manufacturing industry. Furthermore, the adoption and generation of innovation in firms is an ongoing process. Therefore, the true impact of innovation on operational performance requires longitudinal research on the introduction of both technological and organizational innovations (Damanpour & Aravind, 2012). While extensive literature focuses on the adoption of technological and organizational innovations in isolation, empirical evidence on the complementarity between both forms is quite scarce (Battisti et al., 2010). Resulting in limited knowledge about this approach. Scholarly acknowledge the synergistic gains of combining technological with organizational innovations, but the timing of the sequence of adoption is often neglected. Lack of research in innovation literature is due to poor data availability. According to OECD (2009), survey items on the effects of technological innovation, for instance greater efficiency, cost reductions and flexibility, are needed in order to gain more knowledge about the effect of innovation on the economy. In this master thesis insights are drowned from the EMS-questionnaire 2012, involving innovation related data from manufacturing companies in the Netherlands. The year of adoption as an included variable opens up possibilities to overcome the limitations of earlier studies. By assessing the influence of adoption timing of technological and organizational innovations on operational performance, this research aims to compare the effectiveness of the sequential and synchronous approach.

1.3 Research question and sub questions

Do firms combine technological innovations and organizational innovations by adopting technological innovations first, organizational innovations first or by adopting both synchronously and if any, which way is to prefer in order to improve operational performance?

1. Do firms combine technological innovations and organizational innovations by adopting technological innovation first, organizational innovations first or by adopting both synchronously?

2. To what extent does the effect on operational performance differ between the 'technological innovations first' and the synchronous approach?

1.4 Research goal

This study aims to contribute by 1) providing a better understanding of sequential and synchronous innovation and 2) examining the difference in effect of both approaches on operational performance. A broader goal of this master thesis is to assess the competitiveness of a firm in following one of these approaches by using the RBV theory. For managers of these manufacturing companies it is useful to have more knowledge about how to combine technological and organizational innovations. Analyzing these two approaches of innovation adoption and their implication on operational performance would help managers with regard to investment decisions.

1.5 Outline of research

To answer the questions above, I will analyze the European Manufacturing Survey (EMS) 2012 gathered by Ligthart et al. (2013). In the second chapter I will define the concept innovation and its two types: organizational and technological innovation. It is important to provide these definitions in order to obtain sufficient knowledge about the ways of adopting organizational and technological innovation. Furthermore, the dependent variable will be explained in more detail. In chapter two I will also elaborate on the two approaches and its implication on operational performance. Four hypotheses will be formulated to test in our analysis. The third chapter contains the methodology part, in which I explain the measurement method and the data set that is used. In the fourth chapter I will report the results of this research. In the fifth chapter I will connect the theory to the results, which forms the discussion part. I will also asses the quality of my research, reflect the method and do recommendations for further research. In the sixth and last chapter I will conclude my research by answering the research question and sub questions.

Chapter 2: Theoretical framework

This chapter will discuss the theoretical framework concerning the research. To conceptualize the relation between innovation and operational performance, the theory of the RBV is used. In order to understand the construct innovation and its two forms, I will provide a clear definition based on existing literature in the second section. After defining these constructs, the ordering adoption of innovation will be discussed: the sequential and the synchronous approach of technological innovations and organizational innovations. The goal of the theory is to find support for both of these ways in the existing innovation literature. The first hypothesis will be formed by predicting what firms do in practice. The second hypothesis will be formed by assessing the impact of the sequential and the synchronous approach on operational performance. Finally a conceptual model will be presented, based upon the derived hypotheses.

2.1 Resource-based view

In this master thesis, the resource-based view (RBV) functions as a theoretical lens to study the relationship between resources (e.g. technological process innovations and organizational process innovations) and operational performance. The main idea of the RBV is that a firm needs heterogeneous resources, which are valuable, inimitable, and non-substitutable to achieve a more sustainable performance than its competitors (Barney, 1991). Furthermore, the RBV recognizes the importance of intangible assets of a firm. According to the RBV, organizational and technological innovation can be seen as distinctive capabilities developed with accumulated resources. These capabilities in turn contribute to competitive advantage.

The RBV theory has been used in a number of studies in the context of manufacturing. For instance, Zahra & Das (1993) have proposed a framework that studies how technologies and administrative changes deployed as organizational resources improve competitive performance. In this master thesis the resources and capabilities are considered in the following combinations: 1) technologies and physical assets form the technological innovations and 2) organizational capabilities, which include culture, commitment and capabilities for integration form the organizational innovations. In the light of RBV, the sequential and synchronous adoption is expected to have a different effect on operational performance. This is because combining these resources in a different way increases the complexity of resources, which makes it harder to imitate by competitors. If the synchronous approach produces a higher synergy than the sequential approach, it would evidently deliver a higher performance.

2.2 Defining innovation

2.2.1 Introduction

Innovation in a broad sense is about "*adopting or implementing a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations"* (OECD, 2005, p. 32). Adoption and implementation are used as synonyms within this study and refer to the point in time that firms introduce and apply innovations within their plant. The minimum requirement for an innovation is that it significantly improves the organization or is new to the organization. Most scholars think of the concept of innovation as a difficult and complex process, because an innovation is often the result of many interrelated innovations of smaller nature (Fageberg, 2006). The stages of innovation adoption entails initiation, decision to adopt and implementation. Innovations can be created and adopted in the same organization, but they can also be created by one organization, supplied to the market, and bought and adopted by another organization (Dampanpour & Wischevsky, 2006).

Different typologies of innovation are used by scholars in the last few decades. A popular typology of innovation, has been the technical-administrative typology (Evan, 1966). This distinction relates to a general distinction between technologies and the social structure. However, more recently scholar propose a taxonomy that distinguishes between two types of process innovations: technological (technical) innovations and organizational (administrative) innovations (Edquist et al., 2001). Both forms will be part of this study and will be described more in detail below. An illustration of the different dimensions of innovation and the relevant variables in this master thesis are shown in table 1.

	Technological	*Non-technological*
Process Innovations	Technological (technical) innovation	Organizational (administrative) innovation
Product Innovations	Product innovation	Product-service innovation

Table 1: Process innovations and its distinction between technological and non-technological

2.2.2 Technological innovations

A process innovation is the adoption of a new or significantly improved production or delivery method (Damanpour & Aravind, 2012). This includes a significant change in software, equipment, techniques or a combination of these changes and may be derived from the use of new knowledge. This type of innovations is intended to increase quality, decrease the costs of production or to produce or deliver new or significantly improved products. Examples of technological innovations are the adoption of computer-aided design systems or the application of new automation equipment in a production line (OECD, 2005).

2.2.3 Organizational innovations

In a general sense, the term 'organizational innovation' refers to the creation or adoption of an idea or behavior new to the organization (Damanpour et al., 1989). The distinguishing aspects of an organizational innovation compared to technological innovations is the adoption of an organizational routine or procedure for the conduct of work (workplace organization or external relations) that has not been used before in the firm and results from strategic decisions taken by the management. Examples of organizational innovations are the first introduction of management systems for production or supply operations, such as lean production or quality-management systems.

2.3 Complementarities between technological and organizational innovations

Recent literature on innovation underlines the role of combining technological and organizational innovations to improve business performance instead of investing in one of them (Ligthart et al. 2013). Leoni et al. (2001) even state that the separate components do not lead to remarkable results. The sociotechnical theory explicitly addresses the need to align a technology with the organization. According to this approach organizational design is concerned with balancing the technological and social system of an organization (Trist, 1981). The balancing is done so primarily at the level of task and individual job design. This requires a holistic approach and design and some theorists take the technological and social sides of the organization as a single system (De Sitter et al.; 1997). Damanpour & Evan (1984) also suggest in their research that the technological processes and social system need to be in balance in order to function effectively as an organization. By combining these two forms of innovation successfully, innovative performance improves. They argue that a balanced rate of adopting both technological and organizational innovations is more effective in improving a firm's level of performance than either technological or technological innovations alone.

Firms that introduce both technological and non-technological innovations, outperform firms that introduced only one process innovation or one technological innovation (Schmidt & Rammer, 2006). Even though many authors suggest that a combination of technological and organizational innovations on long term is most effective, it remains unclear if managers have an advantage when these forms of innovation are adopted at the same time. Most firms first adopt technologies and adapt its organization to these technologies over time. Some theorists advocate a different view where technologies and adaptations in the social system are adopted synchronously. In the next chapter there will be elaborated on these two approaches. This study doesn't impose to find a certain combination of innovations as desirable that would be applicable in all organizations. Rather, driven by operational advantage considerations, it tries to find an effective way of combining complementary technological and organizational innovations. Which combination of innovations are complementary and would be optimal for a firm, is not part of this study. As internal and external conditions change, so does the desired combination of innovations. Therefore, which combination of technological and organizational innovations complement, is firm specific.

Yet, integration of both forms of innovation seems to be important for all types of firms and this large scale longitudinal study tries to examine this effect.

2.4 Ordering technological and organizational innovations

This chapter discusses how companies combine technological and organizational innovations. Companies tend to combine the adoption sequentially, where technological innovations are first (Khanna et al., 2007; Tushman & Anderson, 1986; Arrow, 1962). However, it is also possible to adopt organizational innovations first (Pisano, 1996). In this study an alternative approach is proposed: synchronously adopting technological and organizational innovations. This chapter elaborates on the three approaches more in depth by drawings insights from the innovation literature. These insights are used to predict what most companies do in practice, which is translated into a first hypothesis.

2.4.1 'Technological innovations first'

Many studies suggest that the technological development is the primary driver of all other developments (Coriat, 2005; Lin & Chen, 2007). An illustrative example is the introduction of tablets in our everyday lives. Apple was the first company that introduced a tablet with its iPad in 2010. In Los Angeles schools began handing out iPads in the fall of 2013 and started upgrading their educational systems (Lapowsky, 2015). This example and the consequences will be further elaborated on in the next section. For now we depart from the view that managers of manufacturing organizations tend to focus on technological innovations when adopting an innovation. This is referred to as 'technological determinism' in the management literature. This theory presumes that an organization's technology drives the development of its social structure or its administrative activities (Frigant & Talbot, 2005).

An important reason for firms to emphasize on adopting technological innovations is the perception of it being more important, more urgent, more tangible and more common than organizational innovations (Lin & Chen, 2007). Lin & Chen (2007) attempted to combine the innovation practices within SMEs (small- and medium-sized enterprises) in Taiwan from integrated and multi-dimensional perspectives. According to Lin & Chen (2007) technological innovations function as a platform for further organizational developments. This implicates that in Taiwanese firms technological innovations precede organizational innovations. Damanpour & Evan (1984) confirm this by stating that technological innovations often are considered easier to implement.

In the organizational learning literature focusing many useful insights can be found with respect to technological innovations preceding organizational innovations. Studies in this field focus on the diffusion of technology within an organization. Arrow (1962) argues that manufacturers using new process technologies are "learning by doing" – their productivity improves for several years after having adopted as they learn to use the technology. Tushman & Anderson (1986) suggest innovative technologies can either be competence-destroying or competence-enhancing for firms. Thus, implementing a new complex technological innovation requires modification in organizational practices and procedures. However, existing innovation literature points out that this modification of organizational practices and procedure often takes place after a technological innovation has been implemented (Damanpour & Evan, 1984). This suggests a rather reactive approach of aligning technologies with the organization. The findings derived from the concept of organizational learning confirm the primacy of technological innovations over organizational innovations.

2.4.2 'Organizational innovations first'

Another option might be a sequential approach where organizational innovations precede technological innovations. Not much has been written about this opposite sequential approach. Most researchers focus on the idea that organizational innovations trigger the overall innovativeness of a firm and this may cause firms to more easily adopt technological innovations (Lam, 2004). In line with this, besides the organizational lag concept, Damanpour & Evan (1984) find that the more administrative innovations were adopted in a given period, the more technical innovations were likely to be adopted in the following period. The mentioned authors study the sequence as organizational innovations being an antecedent of technological innovations and not so much as a strategy itself. In other words, technological innovations are still viewed as the driving forces of process innovations.

Pisano (1996) is one of the few authors that actually studies the pro-active stance of preparing the organization for the adoption of a new technology, which is referred to as 'learning-before-doing'. Pisano (1996) finds that the use of this approach is dependent on the degree of market dynamism of a firm. Therefore, this approach did not prove to have an autonomous effect on performance. The reasoning behind this, is that firms operating in a low dynamic market have enough knowledge to model and plan future production experience. Therefore, these firms are able to learn before doing. In contrast, firms in a high dynamic market have thin knowledge and need the learning process after the adoption. Therefore, these firms are *not* able to learn before doing. Variables that measure market dynamics are not included in the EMS 2012. Due to this complexity, the direction of its influence on operational performance cannot be determined. For this reason, the 'organizational innovations first' approach will be taken along exploratory in this study. The focus lies on comparing the difference in effect of the 'technological first' and the synchronous approach on operational performance.

2.4.3 Synchronous approach

As described in the previous paragraph managers often focus on adopting technological innovations. Henderson & Clark (1990) argue that when a new technology changes the architectural knowledge of the firm, established firms struggle to reconfigure their capabilities. There is a lack of attention for organizational innovations among managers and a time lag arises between the adoption of technological innovations and organizational innovations. By combining technological and organizational innovations simultaneously, this time lag will be minimized or eliminated. Even though a synchronous adoption seems the ideal way of innovation, little is known about how to actually innovate this way.

Ettlie (1988) did extensive research on the simultaneous, overlapping adoption of technological and administrative innovations, which is referred to as 'synchronous innovation'. He found significant evidence that this approach does work and that it represents one dominant method for turning adversity into prosperity. Drawing on an in-depth study of thirty-nine plants and on the experiences of industry leaders, Ettlie (1988) shows how effective use of the latest technologies requires important changes in administrative practices and policies. Synchronous literally means "coincident in time". However, the use of the term does not imply random or chance coincidence of events. Synchronous innovation is the planned, simultaneous adoption of congruent technological and administrative innovations. The main principle of the synchronous approach is that the degree of radicalness in administrative and technological innovations needs to be matched. The cases expected to be the most effective in synchronous innovation, are those that either are low on technological change and low on administrative change, medium change on both components or high change on both components. Companies that emphasize one type of innovation to the exclusion of the other seem to be less effective. The case of excess technological innovations is illustrated in the sequential approach. This strategy obviously assumes that the appropriate level of innovation in both components was correctly assessed at the outset. Thus, the more radical the technology, the more radical the organizational innovation required in the administrative core.

How technological innovations are adopted synchronously with organizational innovations, can be explained with the concept '*social learning*' introduced by Williams et al. (2005) in their book '*social learning in technological innovation*'. Williams et al. (2005) show in their study that social learning is crucial to how generic ICT capabilities are adopted and used in particular settings. The social learning perspective also highlights the importance of practical local activity and knowledge, both in developing new technologies and in developing usages of technologies. This is referred to as 'learning by doing', which was also important in the sequential adoption described in the previous paragraph (Arrow, 1962). However, the concept of social learning extends this view by adding the processes of 'learning by interacting'. To usefully adopt a technology in other contexts, such knowledge cannot be simply transported, it must also be translated combined with other knowledge and transformed. The process of 'learning by interacting' is a required practice for synchronously adopting technological innovations and organizational innovations. The criticism of this concept is that the adoption of technological innovations is not separate from organizational innovations. There rather is an iteration between supply and use and that uptake involves an active appropriation.

The required learning processes, implicates the need for a tight coupling between the technical and organizational core of an organization (Daft, 1978). To ensure successful adoption of technological innovations, the social system should change accordingly. On the other hand, to ensure the adoption of technological innovations, the administrative part of the organization should be open to new ideas and practices (Damanpour et al., 1989). Battisti et al. (2010) suggest that an internal environment that enhances and facilitates the synchronous adoption of technological and organizational innovations, is the flattening of hierarchical structures and training activities. Decentralization is necessary to allow information flows to become more effective and intense. Training activities highlights the importance of work experience, educational attainment and formalized knowledge. The elements of decentralization and worker involvement, together with the introduction of technological innovations, require many supporting processes. The art of pro-actively smoothen the adoption of technological innovations by creating these supporting processes, is the challenge for firms that use a synchronized adoption.

The innovation literature offers three different approaches of adopting technological and organizational innovations for manufacturing organizations. Due to the technological deterministic nature of most manufacturing firms, managers tend to emphasize on innovating technologies. Managers perceive technological innovations to be more urgent and tangible (Lin & Chen, 2007). Organizational innovations often follow later after having accumulated technical knowledge. Damanpour & Evan (1984) suggest this sequence in their study. They tested the organizational lag model, which explains that a discrepancy exists between the rates of adoption of technical and administrative innovations, in a sample of 85 public organizations. Administrative innovations can change an organization’s climate, interdepartmental relations, HR policies, communication etc. These innovations often follow later. Therefore the first hypothesis is as follows:

Hypothesis 1: Most firms will combine technological innovations and organizational innovations by adopting technological innovations first.

2.5 Operational performance as a responding variable

Venkatraman & Ramanujam (1986) did research on how the measurement methods of business performance have been developing in strategy research. They classified business performance into financial measures and indicators of operational performance. The emphasis on operational performance indicators makes us look beyond the “black box” stance that seems to describe the limited use of just financial indicators.

As stated in the previous section, Damanpour & Evan (1984) have indicated that some organizations deal with challenges in the market by successfully integrating technological and administrative innovations into their processes. The improved innovative performance resulting from these combinative effects relates positively to profitability and organizational growth. While this study focuses on the improvement of the internal processes, the interest lies in organizational growth by attaining a number of production improvement goals. By studying the success factors of operational performance, an accurate measurement of the combinative effects of technological and organizational innovation can be given that eventually might lead to financial performance. Important elements of operational performance are the speed of production, product quality and the production costs (Gunday et al., 2011), which will also be part of this study.

2.6 The 'technology first' and synchronous approach affecting operational performance

In the previous section the responding variable of this study is discussed: operational performance. The literature shows us three relevant variable to measure operational performance: speed of production, product quality and production costs (Gunday et al., 2011). This section elaborates in more detail how operational performance is influenced by the adoption timing of technological and organizational innovations. The relationship will be further specified in the three relevant operational performance indicators at the end of this section when formulating the hypotheses.

The 'technology first' approach affecting operational performance

The sequential approach with its emphasis on technology shows a more direct relation to operational performance. Process technologies are introduced to improve production processes and to lower the use of materials or energy consumption (Negny et al. 2012). This is referred to as the 'productivity rationale' (Ettlie, 1988). Another reason is quality enhancement, which refers to the long-range perspective on modernization and suggest a more thorough understanding of the relationship among cost, quality and reduction in inventory (Ettlie, 1988). When uncertainty exists about the dynamic paths of either the costs of or the benefits from the adoption of the two forms of innovation, managers choose for a 'technological innovations first' approach. Given this uncertainty, managers incline to wait before adopting a complementary innovation instead of adopting both innovations at the same time. When choosing this rather safe option, potential failure costs caused by a synchronous adoption are prevented.

In the previous section it is suggested that most organization learn by doing when a technology is adopted. Over time a company modifies its organization to the technology, but this builds up learning costs. This results in a lower operational performance while adopting the technology was to improve the operational performance in the first place. The literature on the development of new manufacturing process technologies contains enough examples of how technology transfer problems have let to development cost overruns, excessive product costs, delayed product introductions and quality problems (Pisano, 1996). An illustrative example was given in the previous section, where a school in Los Angeles began handing out iPads to their students (Lapowsky, 2015). The educational system started to revolutionize its teaching methods by introducing digital learning. However, this 1.3 billion dollars project initiated by the US government turned out to fail. Teachers had to work with a new system without any preparation. The author concludes: don't choose hardware first (Lapowsky, 2015). This is an appropriate illustration of a case were a new technology was introduced with the idea that this would evidently increase productivity and growth. Economists call this the productivity paradox, a concept introduced by Solow (1987). Solow (1987) wondered why the increase in IT technology during the 1980s failed to revive the productivity slowdown per hour.

In line with the reasoning derived from the iPad example above, Boer & During (2001) compared and contrasted findings from three empirical studies involving product innovation, process innovation and organizational innovation. The sample size and the company size of the three studies vary from small to large respectively. All studies involved longitudinal case studies based on interviews and observations. Evidence was found for the relevance of organizational adaptability when adopting technological innovations. Organizational adaptations may be required in the operational, maintenance or operations management processes, in order to be able to achieve the most effective use of the new technology (Boer & During, 2001). The majority of the companies discovered only after the adoption of a technological innovation, that they sometimes had to make radical organizational adaptations. It took some companies another year in order not only to prove technical success, but also prove the business success.

Synchronous approach and operational performance

Adopting organizational innovations aside from technological innovations seems a necessary practice for manufacturing companies. Ignoring organizational innovations inhibits the success of technologies in manufacturing companies in the long run. Therefore, firms can coordinate future innovation plans by considering the two types of innovations in tandem to arrive at a combination that will yield optimal levels of performance (Han, Kim & Srivastava, 1998). The success of the synchronous approach is not affected by when a manager decides to plan a simultaneous innovation. It only requires that the two types of innovation are adopted concurrently.

The more hostile the environment, the more important it is to reduce the time lag between technological and administrative innovation (Ettlie, 1988, p. 3). In other words, to maintain a strong competitive position, a firm needs to reduce the time lag when combining technological and organizational innovations. The days when a manufacturing firm had the luxury of changing one thing at a time are gone, competition grows too stiff to allow this. Anticipating for organizational adaptations together with the adoption of technological innovations would prevent building up the learning costs like in the sequential approach. The synchronous approach appears to be positively associated with a wide range of measures of performance. This includes productivity, and the quality-of-work-life indicators, as well as more global financial measures such as unanticipated expenses. This is an important finding, because it shows that the synchronous approach affects measures that are often not related, but independent of one another.

Some authors are documenting the shift to innovative manufacturing systems among companies, this is referred to as 'lean production' (Florida, 1996). These rather advanced manufacturing systems are distinct from other innovations, while it consists of a blend of technological and organizational changes inside a plant. A study by Ichniowski et al. (1997) have found significant performance gains due to the synchronous adoption of a bundle of innovative technological and work organizational practices in the steel finishing industry. They administered a survey to a sample of 450 manufacturing firms. In addition, they drew from a survey of 1.500 Japanese-affiliated manufacturing establishments. By using cluster analysis they explored the adoption of bundles of related manufacturing practices by firms in the survey. The largest part of the sample exhibits high rates of adoption of both technological and organizational innovations, while these firms consider improving operational performance highly relevant to corporate performance.

Success is not inevitable when following the synchronous approach. Three firms in the study of Ettlie (1988) have backed off from their administrative program efforts during technology deployment, and at least one has fallen short of its expected modernization goal.

Unfortunately, Ettlie (1988) does not devote much effort in describing how and why these firms were failing to synchronize the adoption of technological and organizational innovations. He exclusively shows evidence for the successful cases. The unsuccessful cases often suggest a mismatch in the degree of radicalness between technological and organizational innovations. The more innovative the technology of a new processing system, the more seriously a firm should consider simultaneous innovation in the administrative component and vice versa. However, it is hard to assess for a manager to classify an innovation into a degree of radicalness in order to know which technological or organizational innovation will correspond adequately. Ettlie (1988) uses the total costs of an innovation as an indicator to measure the degree of radicalness. This seems a rather limited indicator, while degree of radicalness of innovation is characterized in much broader terms such as the degree of dramatic change that transforms existing markets or industries (Ettlie et al., 1984). The impact on markets or industries is hard to predict on forehand, which makes planning a synchronous approach a challenging and risky practice. This is confirmed by Battisti et al. (2014), stating that firms may have diseconomies of scope caused by simultaneous adoption of complementary innovations due to managers that have difficulties in dealing with simultaneous changes in several spheres of the plant's activity.

In sum, having provided challenges for both approaches it is expected that a synchronous adoption of technological and organizational innovations eventually will be more effective in improving operational performance. The 'technology first' approach is preferred by most managers, because it shows a more tangible, immediate financial result. Though, the learning costs of adjusting the organization may lower the operational performance. Therefore, among other authors, Ettlie (1988), opts for a synchronous approach, because this creates a valuable competitive position and reduces learning costs. The requirements of a firm to synchronously adopt innovations have to be taken into consideration as well. An organization needs to possess the capabilities to plan a synchronous adoption of technological and organizational innovations. Furthermore, managers need to know the degree of radicalness of technological and organizational innovations that have to be combined synchronously.

In order to make operational performance more concrete, three separate operational performance indicators are selected from the EMS 2012: lead time, scrap rate and energy consumption. How every indicator is expected to be influenced by the adoption timing of technological and organizational innovations will be explained briefly. It is expected that the synchronous approach will be most effective in reducing the value of those indicators, which will improve operational performance.

Hypothesis 2 is focused on lead time. Lead time refers to the days or hours a plant needs from the placement of order till a finished product. Long lead times indicate wasted time and wasted time is undesirable (Tersine & Hummingbird, 1995). When innovating synchronously, new technologies are adopted simultaneously with new work practices that are involved with the production process. In other words, employees start working in a different way when they also start operating new technologies. The potential synergistic effects that flow from this simultaneous adoption, might reduce learning costs and time that is wasted. The lead time could be improved more than when the new organizational innovations are adopted many years after the adoption of the new technology. Therefore, hypothesis 2 are as follows:

Hypothesis 2: In a comparison of groups of manufacturing firms, those that synchronously adopt technological innovations and organizational innovations will more effectively reduce lead time than will those that adopt technological innovations prior to organizational innovations.

The second indicator is scrap rate. These costs are quality costs associated with defects that are discovered before the end product has been delivered to the customer (Omachonu et al., 2004). The same reasoning counts for this indicator. The potential synergy effects and lower learning costs of the synchronous approach more effectively reduce scrap rate than when new work practices are adopted many years later. Therefore, hypothesis 3 is as follows:

Hypothesis 3: In a comparison of groups of manufacturing firms, those that synchronously adopt technological innovations and organizational innovations will more effectively reduce scrap rate than will those that adopt technological innovations prior to organizational innovations.

The third and last indicator is energy consumption. The energy costs resulting from energy consumption are a part of the production costs. Energy saving technologies and environmental management systems obviously aim to reduce energy consumption within a plant. Other technological and organizational innovations that aim to improve production processes in a different way, are not adopted to specifically improve on environmental performance. However, these other innovations often have an unintended result of reducing the energy consumption as well. For example, lean practices aim to improve the quality of processes by detecting and removing errors (Florida, 1996). When these lean practices are implemented simultaneously with a new technology, both innovations might benefit from synergistic effects and the overall energy consumption might be reduced more effectively. Therefore, it is expected that a synchronous adoption of technological and organizational innovation also is beneficial when reducing energy consumption. This is translated in hypothesis 4. The energy consumption indicator is set up as a flow variable in the EMS 2012, which offers us to measure an increase or decrease in a given period. A flow variable is more accurate in measuring performance than fixed variables, because it is less influenced by other factors such as the size of a firm.

Hypothesis 4: In a comparison of groups of manufacturing firms, those that synchronously adopt technological innovations and organizational innovations will more effectively reduce energy consumption than will those that adopt technological innovations prior to organizational innovations.

2.7 Conceptual framework

Figure 1 depicts graphically the effects of adoption timing of technological and organizational innovations on the performance variables discussed in section 2.5. Box 1 deals with the hypothesized superior performance effects of simultaneously introducing technological and organizational innovation (abbreviated in the following as TI and OI respectively) compared to introducing TI prior to OI. It is suggested that a company that implements TI and OI simultaneously has shorter lead times, lower scrap rates and less energy consumption compared to a company giving priority to TI.

In Box II of Figure 1 we consider the case of a firm that gives priority to OI over TI in that OI precedes TI. Since the innovation literature fails to clearly discuss this case, we will compare the performance effects of a company in which OI precedes TI with a factory where the reverse is the case and TI occurs prior to OI. Equally we will compare the performance effects of the OI first case with a company that generally tends to implement TI and OI simultaneously.

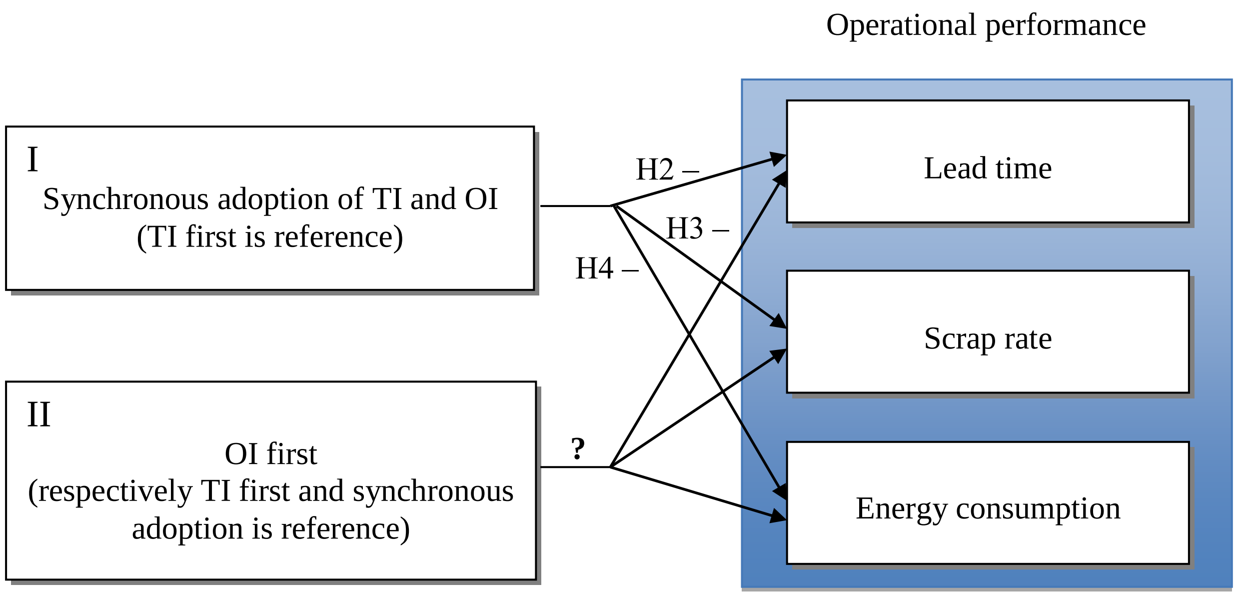

Figure 1: Preliminary model

Chapter 3: Methodology

In this chapter the methodology will be discussed. In order to test the hypotheses and conceptual model, data has to be collected and analyses are needed. Before this process starts, decisions have to be made what data will be collected and which analyses will be done. First the sample of this study and the information about the data collection will be elaborated. Furthermore, the research unit of analysis will be explained. After having done this, the variables of the conceptual model will be operationalized. Eventually the research strategy gives a better view of which analyses will be done. Lastly, some statements are given about the expected quality of this research.

3.1 Sample and data collection

The data in this study are drawn from the European Manufacturing Survey (EMS) 2012, referring to the period 2010-2012. The European Manufacturing Survey (EMS) is a study conducted every three years and organized by research institutes and universities from and across Europe. The German Fraunhofer Institute for Systems and Innovation Research (ISI) coordinates the study. In this study eighteen countries participated. The survey aims to gain more insight in the efforts of industrial firms to modernize their production and processes. It focuses on the adoption of new manufacturing technologies, the use of innovative organizational and managerial concepts as well as on various performance indicators such as productivity, quality or flexibility of companies (Ligthart et al., 2013). Radboud University is one of the European research institutes that participates in this study and accounts for the data in The Netherlands.

3.2 Research unit of analysis

The unit of analysis is the major entity that is being analyzed in a study (Field, 2013). This can be on individual, group or organizational level. The research unit of analysis of this study is similar to the study of the EMS 2012: industrial firms in The Netherlands with more than ten employees.

3.3 Measurement of variables

In this section I will further elaborate on the items that measure technological innovations and organizational innovations. The EMS 2012 consists of 19 indicators that measure technological innovation and 22 indicators that measure organizational innovation. These indicators are displayed in table 2 and table 3. Based on these indicators the time lag and its implication on operational performance will be measured. In addition, three control variables are added based on existing literature. The operationalization of the variables is shown in table 2.

Technological Process Innovations
1. Industrial robots in manufacture and assembly
2. Warehouse management systems (WMS)
3. Technologies for a safe human-machine interaction
4. Intuitive, multi-modal program methods
5. Techniques for processing alloys
6. Techniques for processing composite materials
7. Production technologies for micro mechanic components
8. Nano technological production processes
9. Enterprise resource planning (ERP)
10. Virtual reality and/or simulation of designing production process
11. Virtual reality and/or simulation of designing products
12. Product life cycle management (PLM)
13. Idea management systems
14. Dry processing / minimum lubrication
15. Control systems that shut down machines
16. Winning back waste heat
17. Power-heat-coupling
18. Technologies to generate green energy
19. Technologies to generate heat with green energy technologies

Table 2: EMS Indicators Technological Process Innovation

Organizational innovations
1. Value Stream Mapping
2. Functional classification of production units
3. Demand-driven production (Kanban)
4. Methods to optimize changeover time
5. Total production maintenance (TPM)
6. Quality management based on INK-model

7. Workplace design based on 5s method
8. Standardized and detailed work instructions
9. Task enrichment
10. Continuous improvement (Kaizen)
11. Autonomous task groups in manufacture and assembly
12. Visual management
13. Quality management audit: ISO 9000
14. Six Sigma method
15. Environmental audit: ISO 14031
16. Energy-audit: ISO 50001:2011
17. Total Cost of Ownership (TCO)
18. Formal meetings to generate ideas
19. Measures to retain old employees or their knowledge
20. Time reserved for experimenting
21. Talent development programs
22. Skill training to enhance creativity and innovation

Table 3: EMS indicators Organizational Innovation

Explanatory variable: Adoption timing of TI & OI

In order to measure the three ordering approaches of TI & OI, one explanatory variable is formulated: adoption timing of TI & OI. The year of adoption is used to create this variable, which ranges from 1960 till 2012. First the average year of adopted technological innovations and the average year of adopted organizational innovations on firm level will be calculated. These values will be subtracted from one another. This way the time lag between technological innovations and organizational will be calculated. A recoding of this variable needs to be executed in order to test our hypotheses. The variable time lag will be categorized into the TI first, OI first and the synchronous approach. An outcome of 0 indicates a sequential adoption where technological innovations precede organizational innovations, an outcome of 1 indicates a synchronous adoption and an outcome of 2 indicates a sequential adoption where organizational innovations precede technological innovations. As made clear in the previous chapter, the other sequential approach where organizational innovations precede technological innovations, is taken along for exploratory reasons. This way the effect on operational performance will be tested for all three approaches, but the focus is on comparing the 'technology first' approach and the synchronous approach. The responding calculation will be discussed in Chapter 4.

Dependent variable: Operational performance

The dependent variable operational performance will be measured by three indicators: lead time of the products produced, scrap rate and energy consumption development in percentages. The lead time is measured in days. The scrap rate is measured by the percentage of failed products. The development of energy consumption is based on 2009 - 2012. This can be either a decrease or an increase. Lead time is measured on a continuous scale. Scrap rate and energy consumption is measured on an interval scale.

Control variables

The effects of the explanatory variables are controlled for by specific effects of plant size and manufacturing subsectors. Plant size is included as a control variable, because Cheng et al. (2014) found that firm size significantly influences organizational innovation and business performance. To measure plant size, the number of employees is used. Manufacturing subsectors is included as a control variable to explore the differences between the sectors. Lastly, the number of adopted TI and the number of adopted OI are included as control variables while this is expected to influence the calculation of the variable adoption timing TI & OI. The involved calculations will be explained in more detail in the next chapter.

Type of variable	**Variable name**	**Indicator/group**	**Minimum**	**Maximum**	**Measurement level**
Dependent	Operational performance	Lead time	0	Infinite	Continuous
		Scrap rate	0	Infinite	Interval
		Energy consumption development in percentages	-100	100	Interval
Explanatory	Adoption timing of TI & OI		0	2	Ordinal
Control	Number of adopted TI		0	19	Interval
Control	Number of adopted OI		0	22	Interval
Control	Sector		0	7	Nominal
Control	Size		0	2	Ordinal

Table 4: Operationalization of variables

3.4 Research strategy

The analysis will consist of two parts. The first part is the descriptive analysis. Within this part the variables will be viewed and analyzed in more detail by displaying graphs and tables. The variables will also be compared using graphical comparisons.

The second part of the analysis is a statistical analysis. A correlation analysis will be used to check general correlations between the variables. One-way ANOVA will be done to explore the set of hypotheses more in depth. The statistical program SPSS 18.0 will be used to analyze the data.

3.5 Quality of research

In order to make sure that the data is valid, the assumptions of one-way ANOVA will be tested: normal distribution. no significant outliers and homogeneity of variances. The internal validity of the EMS data is expected to be high, because the database records the time when specific innovations were introduced in the plants. Generally, the introduction of the innovations preceded the period of measurement of the outcomes. This reduces the possibility of reverse causation between innovation and performance, and ensures the direction of the associations found. Thus, the EMS 2012 is the detailed and comprehensive measurement of modernization processes and this is accompanying high internal validity of the data (Ligthart et al., 2013).

The fully structured design of the questionnaire made sure that no biases could occur. Furthermore, the items in the EMS are focused on aspects of the manufacturing firm and hardly prone to subjectivity. In order to increase the reliability of the data, there is verified on beforehand that the questionnaire was sent to the right person, which was most able to complete the questionnaire properly. Therefore, the measurement method is expected to be highly reliable.

Chapter 4 Analyses and results

This chapter consists of five parts. Section 4.1 describes how the data is gathered and how many firms participated in the EMS 2012. Section 4.2 shows a univariate analyses of the independent and three dependent variables. Also, this part attempts to give an illustrative view of the adoption of technological and organizational innovations among the firms. The most important variable *adoption timing of TI & OI* is constructed of years of adoption of both technological as well as organizational innovations. This variable contains the two opposite sequential approaches and the synchronous approach. Furthermore, the dependent variable *operational performance* will be part of discussion. This will be done by showing tables with statistics and graphs. Some calculations regarding variables will also be done and discussed. Section 4.3 consists of analyses with more in depth statistical details. This part will check if the independent variable, dependent variables and control variables correlate with one another. Section 4.4 builds upon the correlation analyses by doing a one-way ANOVA test. The difference in effect of the three adoption timings of TI and OI upon the dependent variables will be tested. The main focus lies on comparing the effect of the sequential approach, where technological innovations precede organizational innovations, with the synchronous approach. After that, the focus lies on the sequential analyses, where organizational innovations precede technological innovations. As indicated in section 2.7 this is an exploratory analyses, since there are no hypotheses formed on the performance of companies that tend to give priority to organizational innovations. These tests will be supported with statistical tables. In section 4.5 the outcomes of the univariate, bivariate and the one-way ANOVA analyses will be described in the light of the hypotheses extracted from the literature review in Chapter 2.

4.1 Response

The data was gathered by students studying at the Radboud University in 2013 and 2014. The Dutch bank Rabobank provided a list with addresses of 7499 industrial firms in The Netherlands, which was the sampling frame. Every student was handed a list of 100 firms and contacted these firms by phone to ask a manager if he or she would like to participate in this study. When the CEO, R&D manager or production manager accepted their request and confirmed to be willing to participate, the firm was sent a hard copy file of the questionnaire.

From the 7499 firms in the list, 3433 firms (46%) were contacted. 901 firms (12%) were willing to participate and 148 firms (2 percent) eventually filled in and returned the questionnaire. Thus, with an amount of 3433 firms contacted and a response of 149 firms, the response rate is 4,3 percent.

4.2 Univariate analysis

Technological innovations

In figure 2 the number of adopted technological innovations is presented within a chart bar. 28% of the firms didn't adopt any technological innovation, which will be considered missing values when calculating the time lag. To have a complete view on the degree of technological innovation among all firms, these cases are shown in this univariate analysis. One case didn't fill in any technological innovation, which is considered a system missing value. The names of the technological innovations involved can be found in the previous chapter. The figure shows that a downward slope exists in the number of adopted technological innovations and the percentage of firms. The range of this variable reaches from 0 to 9 innovations with an average number of adopted technological innovations of 2,3. The median is 2,3 and the standard deviation is 2,5. In the previous section can be seen that there are 19 technological innovation items in total. A detailed account of the statistics can be found in appendix 1.1.

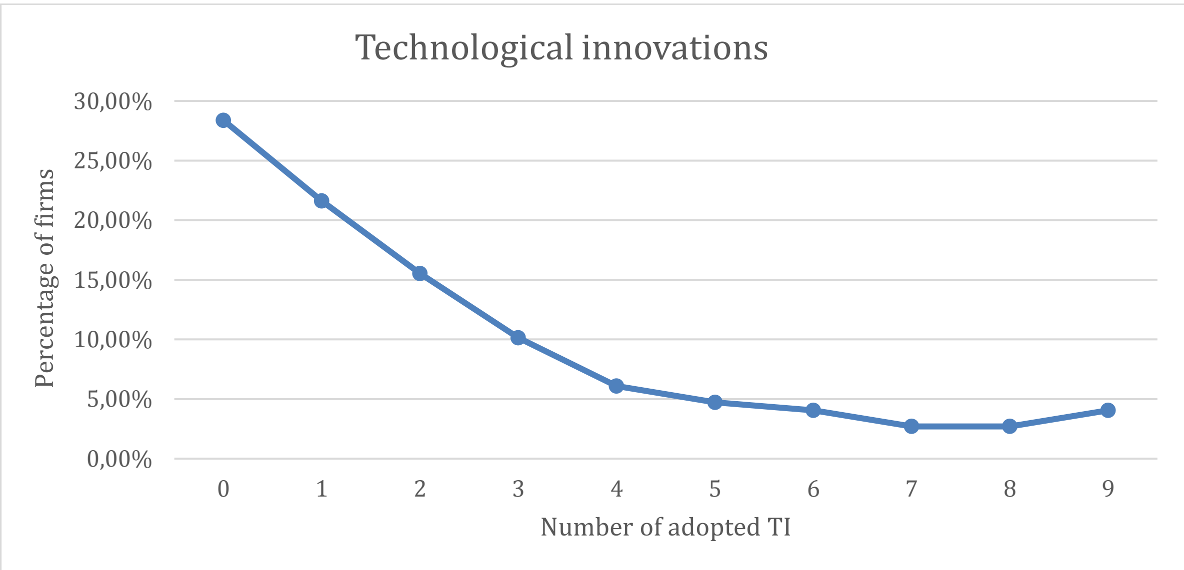

Figure 2: Number of adopted technological innovations among firms

Organizational innovations

In figure 3 the number of adopted organizational innovations is presented within a chart bar. Roughly 5% of the cases didn't apply any organizational innovations and will be considered missing values. The names of the organizational innovations involved can be found in the previous chapter. When looking at figure 3, one can see that the division of the number organizational innovations among firms is much more irregular than the division of the number of technological innovations. The range of this variable is higher than the range of technological innovations and reaches from 0 to 21 innovations with an average number of adopted organizational innovations of 8,2. The median is 8 and the standard deviation is 5,56. It can be stated that the firms in the EMS 2012 adopted more organizational innovations than technological innovations. This suggests that the adoption of a single technological innovation asks for multiple organizational adjustments. A detailed account of the statistics can be found in appendix 1.1.

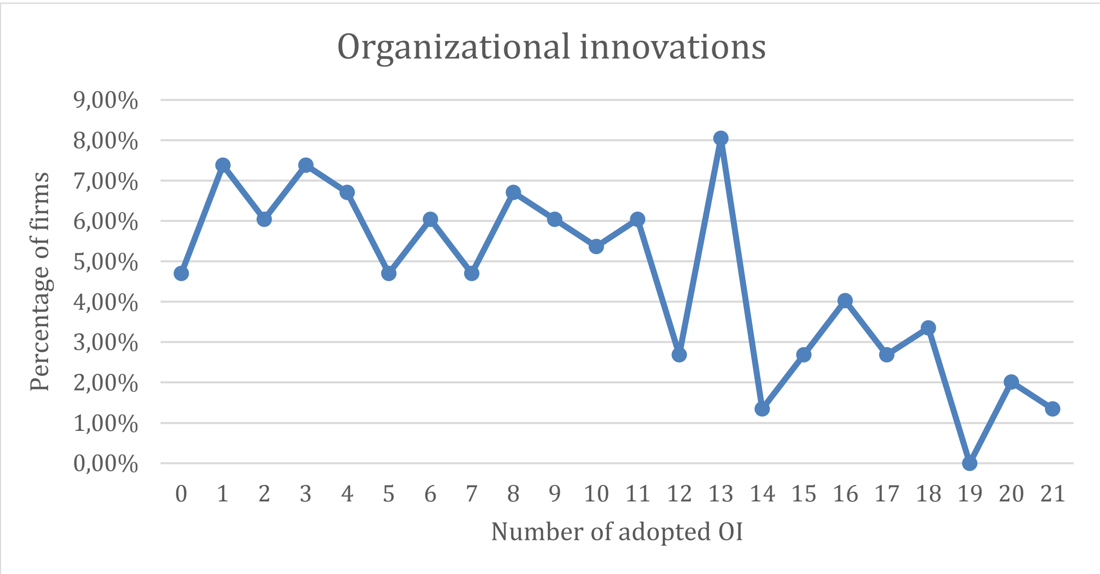

Figure 3: Number of adopted organizational innovations among firms

Combining technological and organizational innovations

Figure 4 shows the percentage of firms that did not adopt either technological or organizational innovations, did adopt either technological or organizational innovations or adopted both technological innovations and organizational innovations. Roughly 70% of the firms applied both technological and organizational innovations. This implies that 70% of the firms combined technological and organizational innovations. This group of firms will eventually be part of the analyses when assessing the influence of time lag on operational performance. A noteworthy finding is that the firms in the sample did not emphasize on adopting technological innovations, but on organizational innovations.

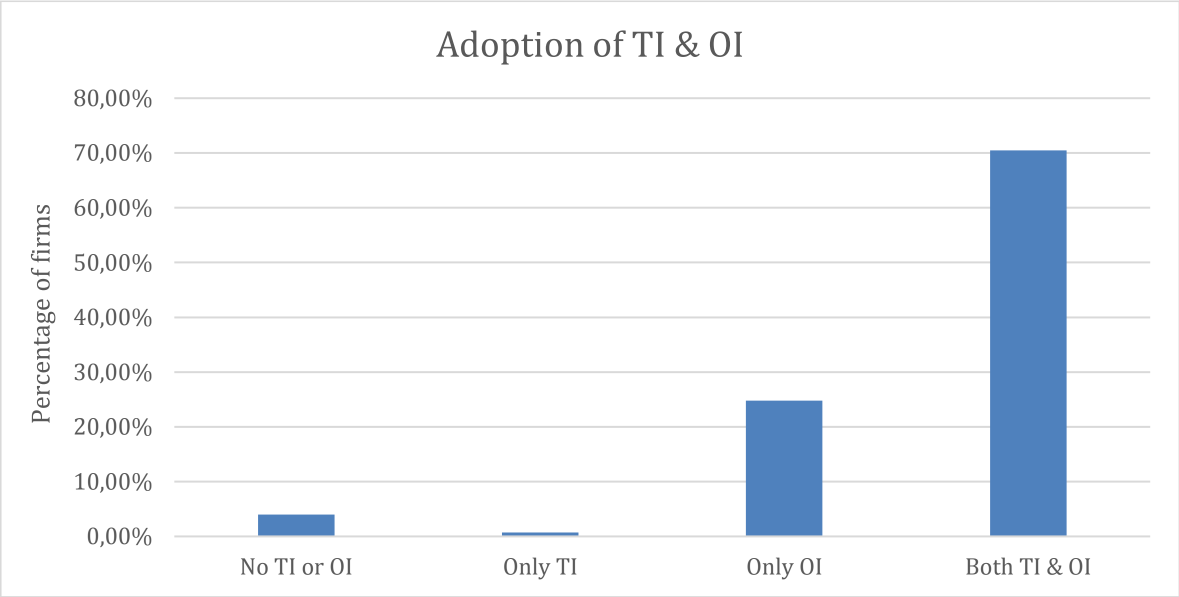

Figure 4: Adoption of TI & OI among firms

Explanatory variable: Adoption timing of TI & OI

As discussed, the explanatory variable within this study is the adoption timing of technological and organizational innovations. Therefore, it actually consists out of two variables instead of one. Recoding has to be made in order to deal with this. The average year of adoption is calculated per company for all the technological innovations as well as the organizational innovations. By subtracting them from each other a single value will be the outcome. This way a rough average of the estimated time lag between technological innovations and organizational innovations in a firm is calculated. Figure 4 graphically shows the division of time lag among the firms in ascending order. The total number of firms (N=100) is smaller than the actual sample size (N=149), because time lag could not be calculated for firms that did not adopt any technological innovation. The range of this variable reaches from -27,33 to 22 years with an average time lag of -1,83 years. The median is -1,24 and the standard deviation is 7,56. As expected in chapter two and confirmed by the sample in the EMS 2012, most firms follow the TI first approach. This means that on average technological innovations are adopted 1,83 years earlier than organizational innovations. This is shown in appendix 1.5.

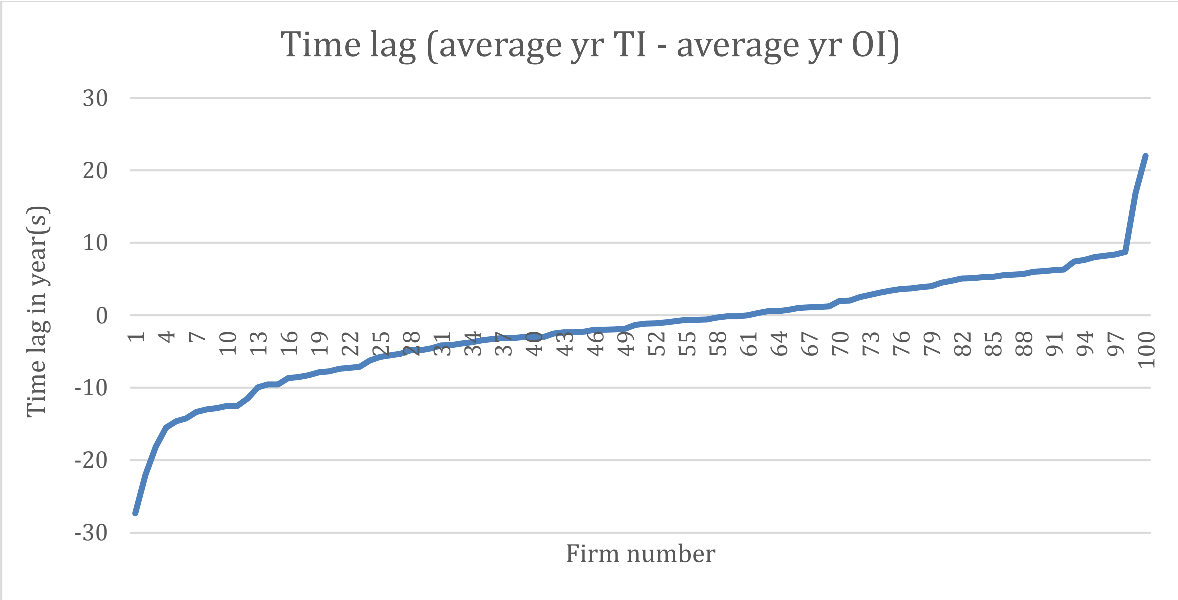

Figure 5: Calculated time lag among firms in ascending order

In order to construct the variable adoption timing of TI & OI, one more recoding has to be done. By grouping the values with a time lag between -1 year and +1 year, the synchronous approach is measured. Thus, the firms with a maximum time lag of one year are considered innovating synchronously. In other words, when the average adoption year of technological innovations is within one year of the average adoption year of organizational innovations (and the other way around), it is considered synchronous adoption. This results in three possible outcomes: outcome 0 indicates that technological innovations precede organizational innovations (all values lower than -1 year), outcome 1 indicates that technological innovations and organizational innovations are adopted synchronously (all values between –1 year and +1 year), outcome 2 indicates that organizational innovations precede technological innovations (all values higher than +1 year). Figure 5 graphically represents the distribution of the variable 'Adoption timing TI & OI'. It shows that 14% of the firms adopted technological and organizational innovations synchronously, while 52% of the firms adopted technological innovations prior to organizational innovations.

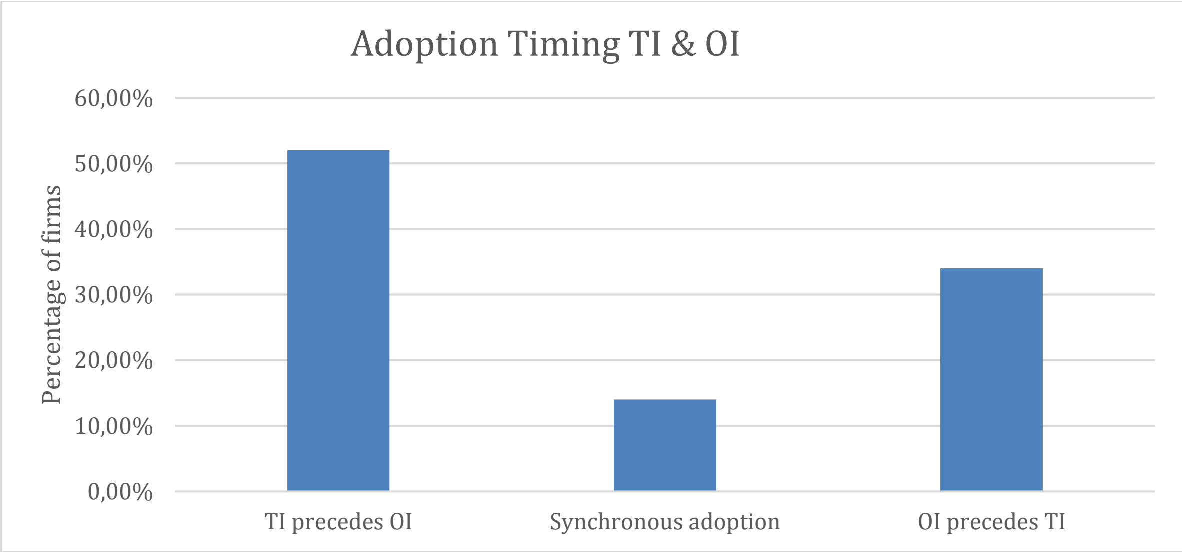

Figure 6: Adoption timing of TI & OI among firms

Dependent variable: Lead time

The first dependent variable that will be part of analysis is lead time. Figure 7 shows a histogram of the division of lead time in days among the firms. The lead time is categorized in groups of 20 days in order to plot a comprehensible histogram. In the bivariate and one-way ANOVA analyses, lead time will still be used as a continuous variable. Appendix 1.3 shows the statistics of the continuous variable. The range of this variable reaches from 1 day to 730 days with an average of 39,43 days. The median is 15 and the standard deviation is 83,66 days. As can be seen in figure 7, nearly 60% of the firms reported a lead time between 0 and 19 days.

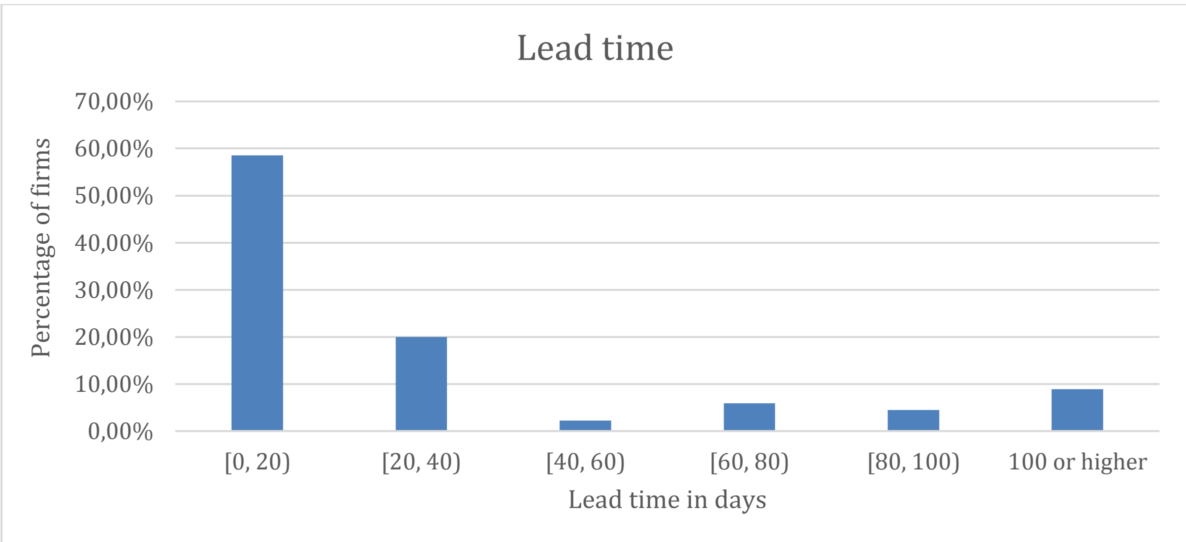

Figure 7: Lead time in days among firms

Dependent variable: Scrap rate

The second dependent variable that will be part of the analysis is the scrap rate measured by the percentage of failed products. Figure 8 shows a histogram of the division of scrap rate among the firms. The scrap rate is categorized into groups of one percent in order to plot a comprehensible histogram. In the bivariate and one-way ANOVA analyses, scrap rate will still be used as a continuous variable. Appendix 1.3 shows the statistics of the continuous variable. The range of this variable reaches from 0 to 50 percent with an average of 3,37 percent. The median is 1,9 and the standard deviation is 6,42 percent. Most firms fail 5 percent or less of their produced products.

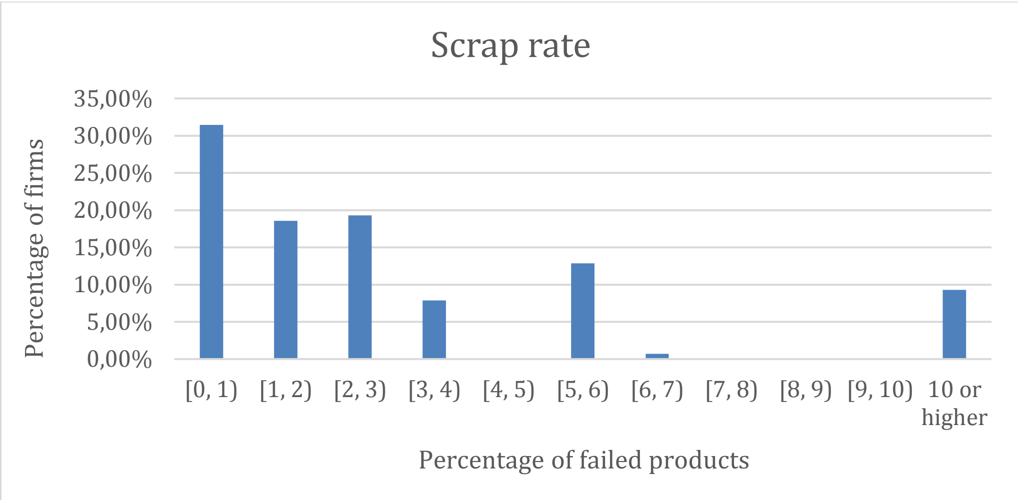

Figure 8: Scrap rate among firms

Dependent variable: Energy consumption development

The third dependent variable that will be part of analysis is energy consumption. Figure 9 shows the division of energy consumption among the firms. The energy consumption is categorized into groups of ten percent in order to plot a comprehensible histogram. In the bivariate and one-way ANOVA analyses, energy consumption will still be used as a continuous variable. Appendix 1.3 shows the statistics of the continuous variable. The range of this variable reaches from -30 to 50 percent with an average of 1,65 percent. The median is 0 and the standard deviation is 11,07 percent (see table 5). As can be seen in figure 8, nearly 50% of the firms reported not an increase nor a decrease in energy consumption.

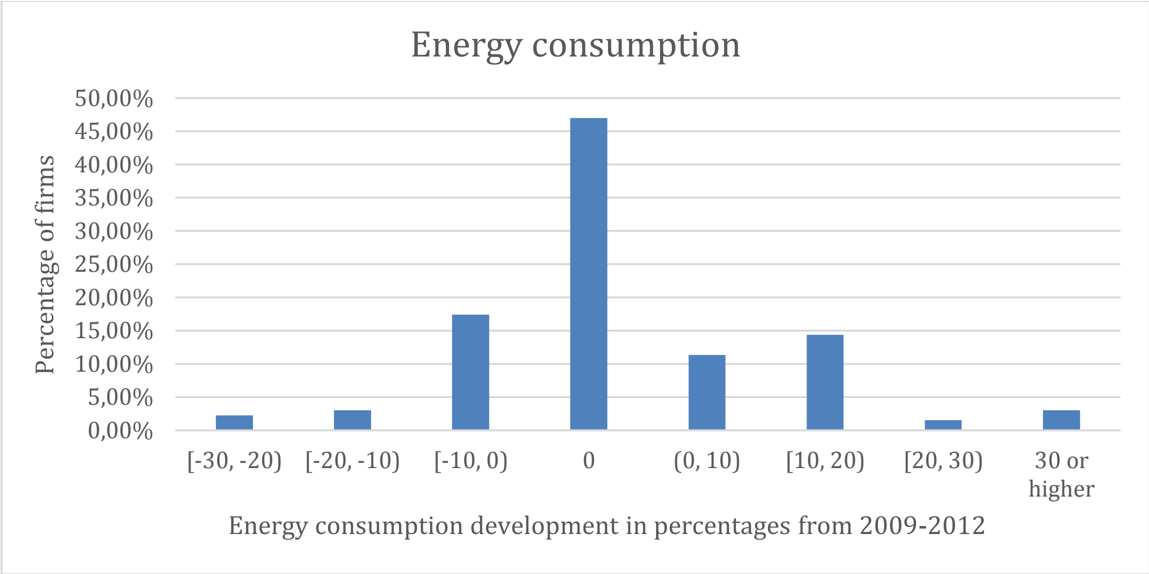

Figure 8: Energy consumption among firms

4.3 Bivariate analysis

In the previous section the variables of this study are analyzed independently and separate from each other. This section aims to find correlations between the dependent, independent and control variables. Table 6 present the descriptive statistics and correlation coefficients between the variables. As can be seen in table 6, the correlation between the independent variable *adoption timing TI & OI* and dependent variable *energy consumption* is significant (-0.28, $p < 0.001$). This implicates that a timed adoption of technological and organizational innovations significantly reduces energy consumption. The one-way ANOVA analysis that will be executed in the next paragraph aims to investigate the differences between the three approaches. There is no significant relation found between *adoption timing TI & OI* and *lead time*. Neither between *adoption timing TI & OI* and *scrap rate*. Furthermore, the control variable correlates significantly with the dependent variables *lead time* (0.19, $p < 0.05$) and *scrap rate* (0.18, $p < 0.05$). This finding shows that when firms grow bigger, it needs more time to finish a product. Also, a firm produces more failed products while it grows bigger. The control variables *number of TI*, *number of OI* and *industry sector* do not correlate significantly with any dependent or independent variable. Therefore, these control variables will not be part of analysis when testing group differences. This shows that the higher number of adopted organizational innovations compared to the number of adopted technological innovations among the firms do not affect the results of the one-way ANOVA analysis that will be performed in the next paragraph.

Variables	N	Mean	s.d.	1.	2.	3.	4.	5.	6.	7.
Dependent variables										
1. Lead time	135	39.43	83.66	1.00						
2. Scrap rate	140	3.37	6.42	0.06	1.00					
3. Energy consumption	134	1.60	10.71	0.08	-0.05	1.00				
Independent variable										
4. Adoption timing TI & OI: - 0 = TI precede OI - 1 = synchronous adoption - 2 = OI precede TI	100			0.02	-0.09	-0.28**	1.00			
Control variables										
5. Number of TI	148	2.32	2.51	0.09	0.11	-0.15	-0.13	1.00		
6. Number of OI	149	8.24	5.56	0.17	0.12	-0.17	0.01	0.52**	1.00	
7. Firm size	149			0.19*	0.18*	-0.12	-0.02	0.46**	0.48**	1.00
8. Industry sector	148			0.16	0.07	0	-0.01	0.01	0.04	0.05

Table 5: descriptive statistics and Spearman correlation coefficients

*Notes: Two tailed significance: *p<0.05, **p<0.001. Values are rounded to two decimal places. Standard deviation abbreviated as s.d.. The mean and s.d. are not shown for variables with a nominal or ordinal measurement level*

4.4 One-way ANOVA

4.5.1 Sample size

The sample size is the most important element for significance testing and generalizability of the results (Field, 2013). The complete case approach yields a sample size of N = 88 for the variable *natural log lead time*, N = 90 for the variable *scrap rate* and N = 86 for the *energy consumption* variable. The sample sizes are smaller than the initial sample size of N = 149, because many firms haven’t adopted any technological innovation. These firms are excluded from the analysis, because the time lag cannot be calculated for these firms. Furthermore, 14 firms haven’t filled in any value on *lead time*, 9 on *scrap rate* and 13 firms on energy consumption. Lastly, some outliers are removed that will be discussed in the next paragraph and appendix 3.2. The sample size affects the generalizability of the obtained results by the ratio of observations to independent variables (Field, 2013). Adding up all technological and organizational innovations as independent variable items shows that sample sizes are insufficient and do not exceed Field’s (2013) minimum ratio of 5:1. When doing an one-way ANOVA test, it is important to have equal group sizes in order to have accurate results. As can be seen in section 4.3, the group of firms that innovate synchronously is smaller than the other two groups. This will have implications on the normality assumption, that is discussed in the next paragraph.

4.5.2 Testing for normality

The next step is to check the first assumption that has to be met before employing the one-way ANOVA analysis (Field, 2013). Preliminary analyses showed violations of these assumptions. A natural logarithm transformation was applied to the dependent variables *lead time* to improve upon normality. The non-normality of the dependent variables *scrap rate* and *energy consumption* cannot be solved with a natural logarithm transformation. Therefore the one-way ANOVA test is run regardless, because this test is fairly “robust” to deviations from normality (Field, 2013). The “robust” aspect is with respect to a Type 1 error and not the power (Type II error) of the test (Field, 2013). However, it is important to point out that the group sizes are not equal and that the F-statistic has to be interpreted with caution. A detailed account is showed in appendix 3.1. The results of testing the other two assumptions can be found in appendix 3.2 and 3.3. These will be discussed in the next paragraph.

4.5.3 Results of one-way ANOVA

The current paragraph will proceed with a one-way ANOVA analysis. The three adoption timing approaches of TI & OI will be analyzed in their effect on *lead time*, *scrap rate* and *energy consumption*. The adoption timing approaches of TI & OI are categorized as: 0) technological innovations precede organizational innovations, 1) synchronized adoption of technological innovations and organizational innovations and 2) organizational innovations precede technological innovations. This one-way ANOVA analysis will be executed using SPSS. The full output, a brief discussion and results of the one-way ANOVA analysis can be found in appendix 4. Table 6 below shows the means and standard deviations of the different groups of the dependent variable on the three dependent variables.

A one-way ANOVA was conducted to determine if the effect on *lead time* was different for groups of adoption timing of TI & OI. As discussed above, data was transformed to improve normality and, as assessed by Shapiro-Wilk test ($p < .05$). This causes results hard to interpret. Furthermore, five outliers were detected and removed using box plots. There was homogeneity of variances, as assessed by Levene's test for equality of variances ($p = .404$). Thus, the assumption of homogeneity of variances of the one-way ANOVA test is met. From Hypothesis 2 we expect a company that synchronously adopts TI an OI to have shorter lead times than a company that first implements TI and afterward OI. However this appears not to be valid. Lead time of the synchronous innovators is even longer than the lead time of the TI-first-innovators (Table 6). However, the difference is not statistically significant; $F(2,85) = 0.415$, $p = .661$.

Another one-way ANOVA was conducted to determine if the effect on *scrap rate* was different for groups of adoption timing of TI & OI. As discussed above, the non-normality of the data, as assessed by Shapiro-Wilk test ($p < .05$), did not improve after transforming the variable. Furthermore, three outliers were detected and removed using box plots. There was homogeneity of variances, as assessed by Levene's test for equality of variances ($p = .466$). Thus, the assumption of homogeneity of variances of the one-way ANOVA test is met. From Hypothesis 3 we expect a company that synchronously adopts TI an OI to have lower scrap rates than a company that first implements TI and afterward OI. Although from Table 6 scrap rates of synchronous innovators actually appear to be somewhat lower than both scrap rates of TI-first-innovators and OI first innovators, the difference between the different adoption timing TI & OI groups is not statistically significant, $F(2,87) = 1.631$, p = .202. The same was expected for this variable as for lead time.

The third one-way ANOVA was conducted to determine if the effect on energy consumption was different for groups of adoption timing of TI & OI. As discussed in the previous paragraph, data was not normally distributed, as assessed by Shapiro-Wilk test ($p < .05$). Furthermore, two outliers were detected and removed using box plots. The assumption of homogeneity of variances was violated, as assessed by Levene's test for equality of variances (p = .000). While the assumption of homogeneity of variances has been violated, the Welch test will be tested (Field, 2013). Table 6 reveals that energy consumption is statistically significantly different for the different groups of adoption timing of TI & OI, Welch's $F(2, 25.768) = 7.238$, p = .003. Though according to the expectation formulated in chapter 2 we expected significant group differences in growth of *energy consumption*, the direction of the differences is not as expected. Table 6 reveals that energy consumption has increased strongest in synchronous innovators (9,33%), less strong in TI first innovators (2,17%) and has actually decreased in OI first innovators (-3,84%). The control variable firm size did not correlate significantly with the development of energy consumption, as can be seen in the previous section. This indicates that firms with a high number of employees do not necessarily have an increase or decrease in energy consumption from 2009-2012. The same counts for firms with a low number of employees. Therefore, the covariate firm size will not be included in this analyses.

In order to compare all possible combinations of group differences when the assumption of homogeneity of variances is violated, the Games-Howell post hoc test is a good test. Games-Howell post hoc analysis revealed that the mean increase in energy consumption of the synchronous adoption group compared with the group of OI preceding TI (13.2, 95% CI [0.4, 25.9], p = 0.042) was statistically significant. The same counts for the increase in energy consumption of the group of TI preceding OI compared with the group of OI preceding TI (6.01, 95% CI [1.7, 10.4], p = 0.004). However, the actual aim of the study was to analyze the differences between the group of synchronous adoption and the group of TI preceding OI. The differences between these groups showed a mean increase of 7.2, 95 % CI [-5.4, 19.7)], which was not statistically significant (p = 0.3160). An important finding is that synchronous adoptions had the highest mean (M = 9.33), indicating that this is the least energy saving approach, as can be seen in table 6. On the contrary, the OI preceding TI group had the lowest mean (M = -3.84), indicating that this is the most energy saving approach. This finding will be discussed more thoroughly in the next section. When comparing the mean of the synchronous adoption group and the OI precedes TI group, one can see that the difference is remarkably high: nearly 12%. The difference between the TI precede OI group and the OI precede TI group is roughly 6%.

	Natural log lead time			Scrap rate			Energy consumption		
Adoption timing of TI & OI group	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
TI precede OI	49	1.20	0.54	43	2.65	2.59	42	2.17	6.57
Synchronous adoption	12	1.34	0.43	14	1.36	1.76	12	9.33	2.17
OI precede TI	27	1.26	0.49	33	2.24	2.17	32	-3.84	8.44

Table 6: Means and standard deviations of the groups of the independent variable on the dependent variables

4.5 Hypotheses testing

The results found in the analyses from the previous section will be used to test the hypotheses set at the beginning of this research. First, the hypothesis concerning what most firms do in practice, will be discussed. The first hypothesis was based on the argument that most firms are technological deterministic of nature. Managers of these firms presume that technological innovations are more important, more urgent, more tangible and more common than organizational innovations. For this reason, managers first innovate the technologies of the firm and adjust their work practices later on. This development is called the TI first approach.

After discussing the first hypothesis, the other three hypotheses will be discussed. These hypotheses test the effect of the adoption timing of TI & OI on the three variables: lead time, scrap rate and energy consumption. These variables are selected from the EMS 2012 in order to measure operational performance. It is expected that on all three variable, the reducing effect of adoption timing TI & OI is caused by the synchronous approach. Reasons for this are the synergistic effects and less inefficiencies that result from a simultaneous adoption of both technological and organizational innovations. The results of the bivariate and one-way ANOVA will be combined in order to preliminary accept or reject the hypotheses.

Hypothesis 1: Most firms will combine the adoption of technological innovations and organizational innovations sequentially, where technological innovations precede organizational innovations.

Hypothesis one is supported by the graphical analyses as well as the one-way ANOVA analyses. By looking at the graph in figure 3, one can see that most firms combine technological innovations and organizational innovations. After further specifying how firms combine these two forms of innovations, the graph in figure 6 shows that most firms adopt technological innovations prior to organizational innovations (52%). Furthermore, after subtracting the average adoption year of TI by the average adoption year of OI, the average time lag is -1,8 year. These findings confirm the expectations based on the management literature in chapter 2. According to Frigant & Talbot (2005) this is due to the technological deterministic nature of most firms. Managers perceive technological innovations more urgent, more important, more common and more tangible (Lin & Chen, 2007). Therefore managers are inclined to first adopt technological innovations. The second most used approach is adopting organizational innovations prior to technological innovations (34%). Even though little is known about the OI first approach, the percentage of firms that follow this approach is higher than the percentage of firms that follow the synchronous approach. The least used approach was a synchronized adoption of technological innovations and organizational innovations (14%).

Hypothesis 2: In a comparison of groups of manufacturing firms, those that synchronously adopt technological innovations and organizational innovations will more effectively reduce lead time than will those that implement technological innovations prior to organizational innovations.

Hypothesis 2 focuses on the effect of the *adoption timing approaches of TI & OI* on the responding dependent variable *lead time.* The bivariate analysis shows a minor positive effect of *adoption timing of TI & OI* on *lead time*. Furthermore, the average lead time was the highest for the synchronous adoption group and the lowest for the TI precede OI group. This is contrary to the expectation, while a negative effect was expected, where the average lead time would be highest for the TI precede OI group and the lowest for the synchronous adoption group. However, both the effect and the group differences of *adoption timing of TI & OI* on *lead time* were non-significant. One can say that the result do not support the assumption that the synchronous approach or the TI first approach influences the time that a firm needs to produce a product. Thus, hypothesis 2 is not supported by the bivariate analyses nor by the one-way ANOVA analysis. Based upon the results found, it is not possible to state difference in effect of the TI first approach and the synchronous approach on lead time.

Hypothesis 3: In a comparison of groups of manufacturing firms, those that synchronously adopt technological innovations and organizational innovations will more effectively reduce scrap rate than will those that implement technological innovations prior to organizational innovations.

Hypothesis 3 looks into the effect of the adoption timing approaches of TI & OI on the responding dependent variable *scrap rate.* The bivariate analysis shows a minor negative effect of *adoption timing of TI & OI* on *scrap rate,* which is according to the expectations. Appendix 4 shows the results of the one-way ANOVA and in particular the means plot.

When looking at this plot, it can be stated that firms with a synchronous approach had the lowest percentage of failed products on average. However, the bivariate analyses showed a non-significant relationship and the one-way ANOVA showed that the group differences where non-significant as well. These results do not support the assumption that the synchronous approach or the TI first approach influences the percentage of failed products. Based upon the results found, it is not possible to state differences in effect of the TI first approach and the synchronous approach on scrap rate. Therefore, hypothesis 3 has to be rejected.

Hypothesis 4: In a comparison of groups of manufacturing firms, those that synchronously adopt technological innovations and organizational innovations will more effectively reduce energy consumption than will those that implement technological innovations prior to organizational innovations.

The bivariate and one-way ANOVA analysis show a significant result for the effect of *adoption timing of TI & OI* on *energy consumption*. However, due to the problem of non-normality, it is worth mentioning that one should be careful in generalizing these results. When analyzing the differences between the three approaches more thoroughly in the post hoc tests of the one-way ANOVA analyses, one can see that the group differences between the group of synchronous adoption and the group of TI preceding OI are non-significant. Furthermore, synchronous adoption proves to be the least energy saving approach, thus causing the highest energy costs. Therefore, hypothesis 4 has to be rejected. The most important finding in the post hoc test is the significant group differences between the group of OI preceding TI and the synchronous adoption group. Even more so, the group of OI preceding TI was the only approach that actually showed an average decrease of energy consumption, while the other approaches showed an average increase. This result implicates that a sequential approach where organizational innovations precede technological innovations is most effective in reducing energy consumption. Once again, the non-normality of the variable energy consumption has to be taken into account.

Chapter 5: Conclusions and discussion

5.1 Summary

This chapter provides the bridge between the gathered literature and the empirical results. After having introduced the subject of combing technological innovations and organizational innovations in chapter 1, the problem statement was given. How do firms combine these two forms of innovation and which combination is to prefer from an operational performance point of view? This was the main focus of this study. An elaboration of the TI first, OI first and synchronous approach has been done in chapter 2 based on the innovation literature. After having compared the content of the three approaches, it was expected that firms in practice follow the TI first approach, but should follow the synchronous approach in order to improve operational performance. Firms in practice are technological deterministic of nature and because managers perceive technological innovations more common, more urgent, more tangible and more important, they first adopt technological innovations (Lin & Chen, 2007). However, Ettlie (1988) has proposed a different approach where TI & OI are adopted synchronously. This approach would offer synergistic benefits and would reduce the inefficiencies of adjusting the organization after having adopted technological innovations. Chapter 3 provides a methodological elaboration of how the adoption timing of TI & OI and operational performance will be measured. Chapter 4 describes the results and analyses based on the 149 firms that participated in the EMS 2012. The data is analyzed by performing an univariate descriptive analysis, a bivariate analysis and a one-way ANOVA analysis. The results of these analyses are used as empirical evidence to test the four formulated hypotheses from chapter 2. Support was found for hypothesis 1, indicating that most firms combine the adoption of technological and organizational innovations sequentially by adopting technological innovations first. The other four hypotheses, that tested the differences in effect between the TI first and the synchronous approach on the three indicators of operational performance, had to be rejected. Nevertheless, the hypotheses testing presented interesting findings. Chapter 5 attempts to solve the problem statement formulated at the start of this research, by answering the research questions. The answers on the research questions will be based on the findings derived from the discussed hypotheses. As well the conceptual model has to be evaluated. Finally, suggestions will be given for further research as well as some limitations regarding this study.

5.2 Adoption timing approaches and the improvement of operational performance

The aim of this research was to provide insight in the adoption timing of technological and organizational innovations and its improving effect on operational performance. A general research question was formulated to do research on this:

Research question: *Do firms combine technological innovations and organizational innovations by adopting technological innovations first, organizational innovations first or by adopting both synchronously and if any, which way is to prefer in order to improve operational performance?*

After the hypotheses have been tested, this part of the research focuses on looking back at the main research question and to formulate a substantial answer. By combining the results of the graphical univariate analyses, the correlation analyses and the one-way ANOVA analyses, the following answer can be given. Firms combine the adoption of technological and organizational by adopting technological innovations first. Contrary to the expectation, the synchronous adoption approach did not prove to be effective in improving operational performance. The OI first approach seems to be most effective in reducing energy consumption and, therefore in improving the energy related operational performance. This was a remarkable finding, while this opposite form of the sequential approach was taken along for exploratory reasons. By answering the two sub questions, this finding will be elaborated more in detail.

Sub question 1: *Do firms combine technological innovations and organizational innovations by adopting technological innovation first, organizational innovations first or by adopting both synchronously?*

The first sub question focuses on what pattern firms follow in practice. The two approaches are measured by subtracting the mean year of adoption of technological innovations by the mean year of adoption of organizational innovations. After making three groups for the variable adoption timing of TI & OI, the synchronous approach and the two opposite sequential approaches, graphical analyses were done in order to answer this sub question. As the literature suggests, firms can combine the adoption of technological innovations and organizational innovations sequentially or synchronously. The sequential approach where technological innovations precede organizational innovations seems to be used by most firms. This is confirmed by the results of our graphical and one-way ANOVA analyses. Another noteworthy finding was that most firms adopted a small number of technological innovations compared to a high number of organizational innovations. This suggests that single technological innovations ask for multiple organizational adjustments.

Sub question 2: *To what extent does the effect on operational performance differ between the TI first approach and the synchronous approach?*

The second sub question of this research tries to explore the actual difference in effect on operational performance between the sequential and synchronous approach. Combinative effects of technological and organizational innovations showed positive effects on profitability and organizational growth. To measure organizational growth, operational performance was chosen as a responding variable. In order to answer the second sub question, three hypotheses have been formulated and analyzed. The operational performance of firms was analyzed by measuring lead time in days (lead time), percentage of failed products (scrap rate) and energy consumption development between 2009 and 2012 (energy consumption). These indicators are selected, because they measure important elements of operational performance: the speed of production, product quality and the production costs (Gunday et al., 2011). Results showed that there is no significant correlation between adoption timing of TI & OI and lead time neither between adoption timing of TI & OI and scrap rate. However, the effect on energy consumption proved to be significant. In order to answer the question above, a one-way ANOVA test was executed. This analyses showed that the significant negative relationship between adoption timing of TI & OI and energy consumption was not caused by firms using the synchronous adoption approach neither the TI first approach. Thus, there is no significant difference between the TI first approach and the synchronous approach.

5.3 Theoretical reflection

The findings from the literature in chapter 2 that study the TI first approach are confirmed by the data from the EMS 2012. Most firms choose to adopt a technological innovation first and do not want to rush another investment in the social system of an organization (Coriat, 2005).

Firms in practice are technological deterministic of nature and because managers perceive technological innovations more common, more urgent, more tangible and more important, they first adopt technological innovations (Lin & Chen, 2007). These firms wait and see how the initial innovation turns out to affect the organization. Arrow (1962) mentions in his article that these firms are learning by doing, indicating that their productivity improves for several years as they learn to use the technology. According to the RBV this sequential strategy makes a firm vulnerable in its market, because this innovation strategy is easily imitated by other firms. In other words, adopting a technology that is available to competitors while at the same time waiting to adjust the organization does not offer added value, because most firms follow this strategy. Furthermore, a firm that follows the TI first approach builds up learning costs when modifying its organization to the technology, such as excessive product cots, delayed product introductions and quality problems (Pisano, 1996).

Having pointed out why a TI first approach would be unfavorable, Ettlie (1988) proposes a more efficient alternative: synchronous adoption of TI & OI. Synchronous innovation is the planned, simultaneous adoption of congruent technological and administrative innovations. This proposition is based on an in-depth study of thirty-nine plants and on the experiences of industry leaders. Ettlie's (1988) most important motive to follow the synchronous approach is to cope with the growing competition of the organization. Furthermore, effective use of the latest technologies requires important changes in administrative practices and policies. The synergistic effects of simultaneously adopting technological and organizational innovations might offer an added value that is twofold: firms have an innovation strategy that is harder to imitate and it might improve operational performance by reducing inefficiencies. However, the results of this study implicate that a synchronous adoption of TI & OI does not offer a significant advantage compared to the TI first approach. Even though Ettlie (1988) states that the synchronous approach offers many cost-reductive and efficiency improving benefits, he also states that it is a risky practice. It is hard for a manager to classify a set of innovations into a degree of radicalness in order to know which technological or organizational innovation will correspond adequately. Furthermore, making these changes simultaneously can be infeasible due to, for example, difficulties in synchronizing all changes and basic coordination problems (Brynjolfsson and Milgro, 2013). Managers need to deal with simultaneous changes in several spheres of the plant's activity and this may cause diseconomies of scope. Another explanation for the insignificant results of the synchronous adoption could be the organizational structure of the companies. Most manufacturing organizations have a centralized structure where work is standardized. Battisti et al. (2010) suggest that a flat hierarchical structure is necessary to enhance and facilitate a synchronous adoption of TI & OI. A decentralized structure is necessary to allow information flows to become more effective among employees. A last suggestion for the lack of success of the synchronous approach might be that firms do not immediately stop using the old technology/practice when adopting a new one. Often this is process of familiarization and both new and old way are used in the production process. Therefore, it takes longer before the effects on operational performance are visible.

The results of the analyses were not all insignificant. It was the opposite sequential approach, where organizational innovations precede technological innovations, that accounts for a significant decrease in energy consumption. This finding implicates that firms that adopt OI first are most successful in reducing the energy related production costs. An explanation might be that firms first need to accumulate knowledge and familiarize employees with this before adopting a technology in order to be successful. In other words, firms learn *before* doing instead of learning *by* doing. This is an interesting finding, because it is the contrary to what most firms do. As stated in chapter 2, the use of this adoption strategy is dependent on market dynamics. Pisano (1994) studied the adoption strategies of new manufacturing processes in high dynamic and low dynamic markets. He found that there is not one best approach (learning-by-doing or learning-before-doing), but that it is dependent on the kind of knowledge environment a firm operates in. A thorough knowledge of the effect of specific innovations and their interdependencies increases the successfulness of a learning-before-doing approach. Learning-by-doing is more suited for firms that lack the knowledge base to predict and simulate effects on forehand. This suggests that the knowledge about the effect of energy reducing technologies and policies on the energy consumption is available to most firms. Therefore, learning-before-doing is a strategy that is well suited for reducing energy consumption. However, while the EMS 2012 does not measure market dynamics and the nature of a firm's knowledge base, this suggestion cannot be tested.

5.4 Limitations and suggestions for further research

As every research conducted, limitations need to be explained and discussed, in order to make suggestions for further research. Looking back at the writing process, a first limitation regarding research conducted must be pointed out. The synchronous approach did not prove to be beneficial in terms of operational performance. As Ettlie (1988) states, the main principle of the synchronous approach is that the degree of radicalness of TI & OI needs to be matched. The EMS 2012 involves a variable that could be of use in measuring the radicalness of an innovations: the extent of an innovation. This variable measures the impact the adoption of an innovation has on the organization itself. The effect of synchronous adoption on operational performance could be present only for a combination of innovations that have a high impact. Further research could distinguish between innovations with a low, medium and high impact when measuring the time lag between TI & OI.

A second limitation refers to the sample size of this survey. The number of technological innovations adopted by firms is a lot smaller than the number of organizational innovations adopted by firms. This has implications for the calculated mean of year of adoption and consequently the independent variable adoption timing of TI & OI. In particular, many firms that didn't adopt any technological innovation are not part of the analyses and this reduces the sample size. A low sample size reduces the generalizability of the results from this study (Field, 2013). The control variables *number of TI* and *number of OI* were included to tackle this problem. Unfortunately these control variables did not significantly correlate with the dependent variable, neither the independent variables. A suggestion for further research would be to include more technologies than organizational innovations in the survey, while most technologies are quite specific.

A third limitation is the dependent variable operational performance. Innovation literature suggests that productivity, flexibility and other efficiency measures are also related to both types of innovation (Ligthart et al., 2013). These findings show that there are plenty of indicators that could be analyzed using the three timing approaches. This research was limited to three dependent variables due to maintaining a manageable scope of subjects. Another limitation is that only one variable involves a flow measurement: energy consumption. This variables measures an increase or a decrease from 2009-2012, while the other two variables measure one value at one point in time: 2012. The flow variable is more accurate in measuring performance than the other variables that are fixed variables, because it is less influenced by other factors such as the size of a firm. Therefore, further research could use the conceptual framework and perform tests on different and/or more indicators with dependent variables that involve a flow measurement.

A fourth limitation is the focus on the synchronous approach in this study. The main advantage of synchronous innovation is aiming for a strong competitive position by combining technological resources with organizational capabilities at the same point in time. However, this study points out that this approach does not cause a stronger improvement of operational performance. The OI first approach was taken along exploratory in the analyses, because it did not prove to have an autonomous effect on performance (Pisano, 1966). This approach does appear to be beneficial in terms of energy cost reductions in this study. Even though this statement should be interpreted with caution due to non-normality issues, it does emphasize the relevance of adopting organizational innovations first. Further research should examine the OI first approach more thoroughly and assess its impact on operational performance.

5.5 Research implications

This study contributes in three ways to the innovation literature that studies a combination of technological and organizational innovations. First, the analyses focus on relating specific adoption timing approaches (i.e. the TI first approach and synchronous approach) to specific operational performance outcomes (i.e. lead time, scrap rate and energy consumption), instead of focusing on the performance of combining these innovations in general. Including the timing aspect shows us that most firms indeed first adopt technological innovations and later adopt organizational innovations. This confirms the finding from the literature that most firms are technologically deterministic. Second, the TI first approach did not prove to be effective in improving operational performance. This finding suggests that the organizational lag concept is also apparent in the manufacturing industry and unfavorable in terms of operational performance. Third, the synchronous approach does not prove to be beneficial in order to improve operational performance. The literature suggests that this approach reduces learning costs and creates synergies between both forms of innovation. A firm would also improve its competitive position. However, this study suggests that this is not an appropriate alternative to the TI first approach in terms of operational performance.

5.6 Managerial implications

This study helps managers of Dutch manufacturing firms comprehend how the adoption timing of technological and organizational innovations affects operational performance. No empirical evidence exists for the contribution of the sequential approach, where technological innovations precede organizational innovations, to an improvement of operational performance. This is a valuable implication, while most firms seem to follow this approach. Synchronous adoption of technological and organizational innovations does not seem to be a better alternative. However, if a firm wants to reduce its energy consumption, adopting organizational innovations prior to technological innovations seems to be most promising.

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Appendix 1: Univariate analysis

1.1 Statistics technological and organizational innovations

Statistics

		SUM_TI	SUM_OI
N	Valid	148	149
	Missing	1	0
Mean		2,3243	8,2416
Median		1,5000	8,0000
Std. Deviation		2,51855	5,56005
Minimum		,00	,00
Maximum		9,00	21,00
Sum		344,00	1228,00

1.2 Statistics Time lag and Adoption timing TI & OI

Statistics

		TIME_LAG	ADOPTION_TIMING_TI_OI
N	Valid	100	100
	Missing	49	49
Mean		-1,8281	,8200
Median		-1,2417	,0000
Std. Deviation		7,55746	,91431
Minimum		-27,33	,00
Maximum		22,00	2,00
Sum		-182,81	82,00

1.3 Statistics of all three dependent variables

Statistics

		Lead time in days	Percentage of failed products	Energy consumption development in percentages from 2009-2012
N	Valid	135	140	134
	Missing	14	9	15
Mean		39,430	3,373574	1,6023
Median		15,000	1,900000	,0000
Std. Deviation		83,6609	6,4208015	10,70969
Minimum		1,0	,0000	-30,00
Maximum		730,0	50,0000	50,00
Sum		5323,0	472,3003	211,50

Appendix 2: Correlation analyses

Descriptive Statistics

	Mean	Std. Deviation	N
Lead time in days	39,430	83,6609	135
Percentage of failed products	3,373574	6,4208015	140
Energy consumption development in percentages from 2007-2009	1,6023	10,70969	134
ADOPTION_TIMING_TI_OI	1,2000	,66667	100
SUM_TI	2,3243	2,51855	148
SUM_OI	8,2416	5,56005	149
Firm size	2,4698	1,24963	149
Industry sector	3,9662	2,10737	148

Correlations

	Lead time in days	Percentage of failed products	Energy consumption development in percentages from 2009-2012	ADOPTION_TIMING_TI_OI	SUM_TI	SUM_OI	Firm size	Industry sector

Spearman's rho	Lead time in days	Correlation Coefficient	1,000	,059	,080	,021	,087	,168	,191*	,160
		Sig. (2-tailed)	.	,513	,385	,843	,320	,051	,027	,065
		N	135	127	119	93	134	135	135	134
	Percentage of failed products	Correlation Coefficient	,059	1,000	-,053	-,092	,106	,118	,177*	-,072
		Sig. (2-tailed)	,513	.	,552	,382	,216	,165	,037	,396
		N	127	140	127	93	139	140	140	139
	Energy consumption development in percentages from 2009-2012	Correlation Coefficient	,080	-,053	1,000	-,280**	-,151	-,167	-,121	,000
		Sig. (2-tailed)	,385	,552	.	,009	,084	,055	,166	,996
		N	119	127	132	86	132	132	132	131
	ADOPTION_TIMING_TI_OI	Correlation Coefficient	,021	-,092	-,280**	1,000	-,134	,011	-,002	-,013
		Sig. (2-tailed)	,843	,382	,009	.	,185	,916	,983	,894
		N	93	93	86	100	100	100	100	100
	SUM_TI	Correlation Coefficient	,087	,106	-,151	-,134	1,000	,516**	,455**	,011
		Sig. (2-tailed)	,320	,216	,084	,185	.	,000	,000	,893
		N	134	139	132	100	148	148	148	147
	SUM_OI	Correlation Coefficient	,168	,118	-,167	,011	,516**	1,000	,477**	,037
		Sig. (2-tailed)	,051	,165	,055	,916	,000	.	,000	,651
		N	135	140	132	100	148	149	149	148

	Firm size	Correlation Coefficient	,191*	,177*	-,121	-,002	,455**	,477**	1,000	,047
		Sig. (2-tailed)	,027	,037	,166	,983	,000	,000	.	,573
		N	135	140	132	100	148	149	149	148
	Industry sector	Correlation Coefficient	,160	-,072	,000	-,013	,011	,037	,047	1,000
		Sig. (2-tailed)	,065	,396	,996	,894	,893	,651	,573	.
		N	134	139	131	100	147	148	148	148

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Appendix 3: Assumptions for one-way ANOVA

At the individual variable level, three assumptions have to be met: normal distribution of observations, no significant outliers, and homogeneity of variances (Field, 2013). The following sections will show the tests of these assumptions in detail for the original and imputed datasets.

3.1 Assumption 1: Normality

The dependent variable should be approximately normally distributed for each group of the independent variable. That will be tested with the Shapiro-Wilk test of normality. This is a numerical method and is recommended when the sample size is small like in this study <100 (Field, 2013).

Dependent variable: lead time

As can be seen in Table 2, the variable lead time is not normally distributed, as assessed by Shapiro-Wilk's test ($p < .05$). To solve this normality issue, a natural log transformation of this variable is computed. After having done this, the natural log lead time is normally distributed, as assessed by Shapiro-Wilk's test ($p > .05$)

Tests of Normality

	ADOPTION_TIMING_TI_OI	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Lead time in days	TI precede OI	,333	50	,000	,408	50	,000
	synchronous adoption	,327	13	,000	,766	13	,003
	OI precede TI	,313	30	,000	,498	30	,000

a. Lilliefors Significance Correction

Table 1: Test of normality for lead time

Tests of Normality

	ADOPTION_TIMING_TI_OI	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
TrLEAD_TIME	TI precede OI	,116	50	,088	,968	50	,200
	synchronous adoption	,176	13	,200*	,914	13	,206
	OI precede TI	,154	30	,067	,969	30	,519

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 2: Test of normality for natural log lead time

Dependent variable: scrap rate

As can be seen in Table 3, the variable scrap rate is not normally distributed, as assessed by Shapiro-Wilk's test ($p < .05$). To solve this normality issue, a natural log transformation of this variable is computed. While some firms reported a failure percentage rate of 0, all values are increased by 1 in order to include these cases. After having done this, the natural log lead time is still not normally distributed for the groups TI precedes OI and synchronous adoption, as assessed by Shapiro-Wilk's test ($p < .05$). For this reason, the initial variable scrap rate will be used in the one-way ANOVA analysis.

Tests of Normality

	ADOPTION_TIMING_TI_OI	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Percentage of failed products	TI precede OI	,298	45	,000	,506	45	,000
	synchronous adoption	,251	14	,017	,762	14	,002
	OI precede TI	,214	34	,000	,736	34	,000

a. Lilliefors Significance Correction

Table 3: Test of normality for scrap rate

Tests of Normality

	ADOPTION_TIMING_TI_OI	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
TrIFC	TI precede OI	,136	45	,036	,932	45	,011
	synchronous adoption	,161	14	,200*	,872	14	,045
	OI precede TI	,128	34	,169	,947	34	,102

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 4: Test of normality for natural log scrap rate

Dependent variable: energy consumption

As can be seen in table 4, *energy consumption* is not normally distributed, as assessed by Shapiro-Wilk's test ($p < .05$). This is due to the fact that 62 firms reported not an increase nor a decrease of energy consumption. This causes a high kurtosis and this cannot be solved with a natural log transformation. Therefore, the tests are run regardless the non-normality.

Tests of Normality

	ADOPTION_TIMING_TI_OI	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Energy consumption development in percentages from 2009-2012	TI precede OI	,264	43	,000	,907	43	,002
	synchronous adoption	,304	12	,003	,789	12	,007
	OI precede TI	,209	32	,001	,908	32	,010

a. Lilliefors Significance Correction

Table 4: Test of normality for energy consumption

Independent variable: time lag

The independent variable adoption timing of TI & OI consists of three outcomes. While the value centre around three categories, it is hard to assess the normality. In order to solve this problem, the variable *time lag* will be checked for normality. Table 5 shows the results and it can be concluded that the variable time lag is normally distributed.

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
TIME_LAG	,069	98	,200*	,982	98	,188

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

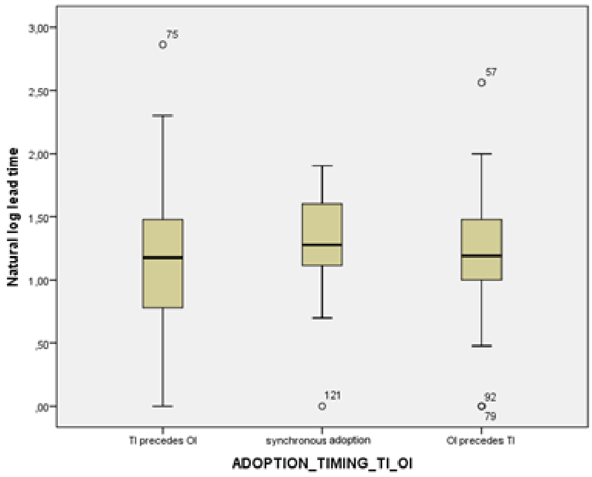
Table 5: Test of normality for time lag

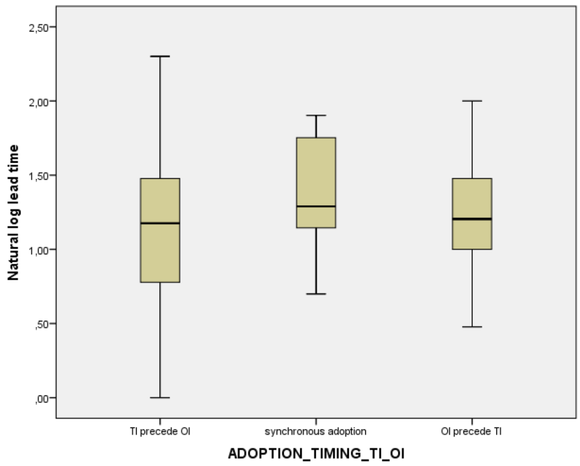
3.2 Assumption 2: Outliers

There should be no significant outliers in the groups of the independent variable in terms of the dependent variable (Field, 2013). If scores are unusual in any group of the independent variable, these scores are called outliers. To determine if the data has outliers, box plots are generated. Any data points that are more than 1.5 box-lengths from the edge of their box are classified as outliers, these are marked as circular dots. Any data point that is illustrated with an asterisk, are more than 3 box-lengths away from the edge of their box.

Dependent variable: Natural log lead time

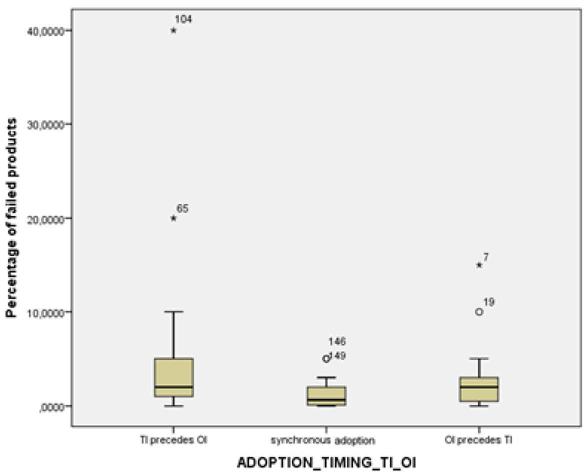
As can be seen in the figures below, five outliers (case 57, 75, 79, 92 and 121) are detected. These cases are removed. After removing these values, the boxplots do not show any more outliers. The left figure shows the boxplot before removal of the outliers and the right figure shows the boxplot after removal of the outliers.

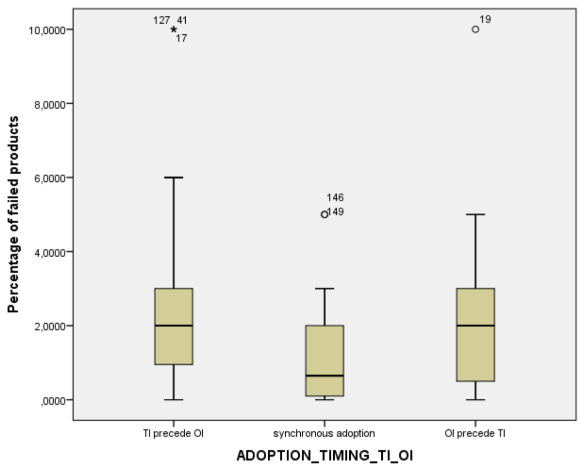




Dependent variable: Scrap rate

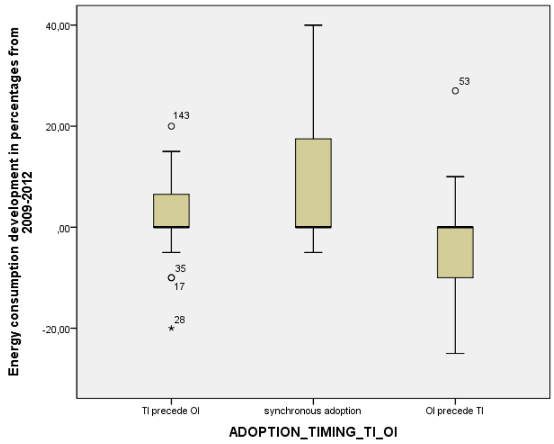
As can be seen in the figures below, there are quite some outliers apparent. Three outliers are marked with an asterisk (case 7, 65 and 104) and are above 10% failure rate. Only these values are removed in order to retain a sufficient sample size. After removing these values, the boxplots still shows some outliers. The left figure shows the boxplot before removal of the outliers and the right figure shows the boxplot after removal of the outliers.

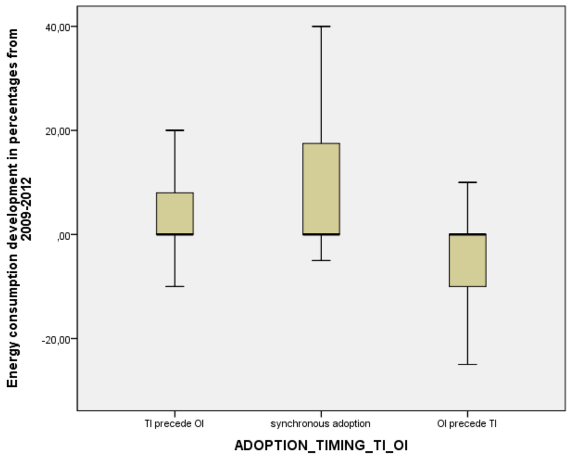




Dependent variable: Energy consumption

The left figure below shows several outliers. After removing the two biggest outliers (case 53 and 28), the box plots do not show any more outliers. The left figure shows the boxplot before removal and the right figure shows the boxplot after removal of the outliers.





3.3 Assumption 3: Homogeneity of variance

The one-way ANOVA assumes that the population variances of the dependent variable are equal for all groups of the independent variable (Field, 2013). The assumption of homogeneity of variance is tested using Levene's test of equality of variances. The result of this test is found in the Test of homogeneity of variances table, as highlighted for all three dependent variables below. There was homogeneity of variances for the dependent variables natural log lead time (p = .404) and scrap rate (p = .466) , as assessed by Levene's test for equality of variances. Furthermore, there is homogeneity of variances for the control variable firm size (p = .164). However, the assumption of homogeneity of variances was violated for the dependent variable energy consumption, as assessed by Levene's test for equality of variances (p = .000). Table 6 presents the results of the Levene's test for equality of variances.

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Natural log lead time	,917	2	85	,404
Percentage of failed products	,771	2	87	,466
Energy consumption development in percentages from 2009-2012	9,026	2	83	,000
Firm size	1,841	2	97	,164

Table 6: Levene's test of equality of variances for dependent variables and control variable

Appendix 4: One-way ANOVA results

Descriptives

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Natural log lead time	TI precede OI	49	1,2039	,53983	,07712	1,0489	1,3590	,00	2,30
	synchronous adoption	12	1,3446	,41097	,11864	1,0835	1,6057	,70	1,90
	OI precede TI	27	1,2557	,42893	,08255	1,0860	1,4253	,48	2,00
	Total	88	1,2390	,48932	,05216	1,1353	1,3427	,00	2,30
Percentage of failed products	TI precede OI	43	2,651163	2,5878261	,3946398	1,854747	3,447578	,0000	10,0000
	synchronous adoption	14	1,364286	1,7640021	,4714494	,345781	2,382790	,0000	5,0000
	OI precede TI	33	2,236373	2,1670474	,3772345	1,467971	3,004774	,0000	10,0000
	Total	90	2,298892	2,3456594	,2472542	1,807603	2,790181	,0000	10,0000
Energy consumption development in percentages from 2009-2012	TI precede OI	42	2,1667	6,57385	1,01437	,1181	4,2152	-10,00	20,00
	synchronous adoption	12	9,3333	15,95068	4,60457	-,8012	19,4679	-5,00	40,00
	OI precede TI	32	-3,8438	8,43996	1,49199	-6,8867	-,8008	-25,00	10,00
	Total	86	,9302	9,95258	1,07321	-1,2036	3,0641	-25,00	40,00

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Natural log lead time	,917	2	85	,404
Percentage of failed products	,771	2	87	,466
Energy consumption development in percentages from 2009-2012	9,026	2	83	,000

Robust Tests of Equality of Means

		Statistic[a]	df1	df2	Sig.
Natural log lead time	Welch	,489	2	32,549	,618
Percentage of failed products	Welch	2,184	2	41,293	,125
Energy consumption development in percentages from 2009-2012	Welch	7,238	2	25,768	,003

a. Asymptotically F distributed.

Multiple Comparisons

Dependent Variable		(I) ADOPTION_TIMING_TI_OI	(J) ADOPTION_TIMING_TI_OI	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Natural log lead time	Tukey HSD	TI precede OI	synchronous adoption	-,14067	,15868	,650	-,5192	,2378
			OI precede TI	-,05173	,11808	,900	-,3334	,2299
		synchronous adoption	TI precede OI	,14067	,15868	,650	-,2378	,5192
			OI precede TI	,08895	,17092	,862	-,3188	,4967
		OI precede TI	TI precede OI	,05173	,11808	,900	-,2299	,3334
			synchronous adoption	-,08895	,17092	,862	-,4967	,3188
	Games-Howell	TI precede OI	synchronous adoption	-,14067	,14150	,588	-,4969	,2155
			OI precede TI	-,05173	,11297	,891	-,3227	,2193
		synchronous adoption	TI precede OI	,14067	,14150	,588	-,2155	,4969
			OI precede TI	,08895	,14453	,813	-,2741	,4520
		OI precede TI	TI precede OI	,05173	,11297	,891	-,2193	,3227
			synchronous adoption	-,08895	,14453	,813	-,4520	,2741
Percentage of failed products	Tukey HSD	TI precede OI	synchronous adoption	1,2868771	,7167176	,177	-,422121	2,995876
			OI precede TI	,4147901	,5390443	,723	-,870550	1,700130
		synchronous adoption	TI precede OI	-1,2868771	,7167176	,177	-2,995876	,422121
			OI precede TI	-,8720870	,7429111	,472	-2,643543	,899369
		OI precede TI	TI precede OI	-,4147901	,5390443	,723	-1,700130	,870550
			synchronous adoption	,8720870	,7429111	,472	-,899369	2,643543
	Games-Howell	TI precede OI	synchronous adoption	1,2868771	,6148212	,107	-,222542	2,796296
			OI precede TI	,4147901	,5459363	,729	-,891182	1,720762
		synchronous adoption	TI precede OI	-1,2868771	,6148212	,107	-2,796296	,222542

			OI precede TI	-,8720870	,6037967	,332	-2,360654	,616480
		OI precede TI	TI precede OI	-,4147901	,5459363	,729	-1,720762	,891182
			synchronous adoption	,8720870	,6037967	,332	-,616480	2,360654
Energy consumption development in percentages from 2009-2012	Tukey HSD	TI precede OI	synchronous adoption	-7,16667*	2,95812	,046	-14,2262	-,1072
			OI precede TI	6,01042*	2,12056	,016	,9497	11,0711
		synchronous adoption	TI precede OI	7,16667*	2,95812	,046	,1072	14,2262
			OI precede TI	13,17708*	3,05911	,000	5,8766	20,4776
		OI precede TI	TI precede OI	-6,01042*	2,12056	,016	-11,0711	-,9497
			synchronous adoption	-13,17708*	3,05911	,000	-20,4776	-5,8766
	Games-Howell	TI precede OI	synchronous adoption	-7,16667	4,71497	,316	-19,7335	5,4002
			OI precede TI	6,01042*	1,80415	,004	1,6690	10,3518
		synchronous adoption	TI precede OI	7,16667	4,71497	,316	-5,4002	19,7335
			OI precede TI	13,17708*	4,84025	,042	,4413	25,9129
		OI precede TI	TI precede OI	-6,01042*	1,80415	,004	-10,3518	-1,6690
			synchronous adoption	-13,17708*	4,84025	,042	-25,9129	-,4413

*. The mean difference is significant at the 0.05 level.

Natural log lead time

			Subset for alpha = 0.05
	ADOPTION_TIMING_TI_OI	N	1
Tukey HSD[a,b]	TI precede OI	49	1,2039
	OI precede TI	27	1,2557
	synchronous adoption	12	1,3446
	Sig.		,622

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 21,310.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Percentage of failed products

			Subset for alpha = 0.05
	ADOPTION_TIMING_TI_OI	N	1
Tukey HSD[a,b]	synchronous adoption	14	1,364286
	OI precede TI	33	2,236373
	TI precede OI	43	2,651163
	Sig.		,141

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 24,002.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

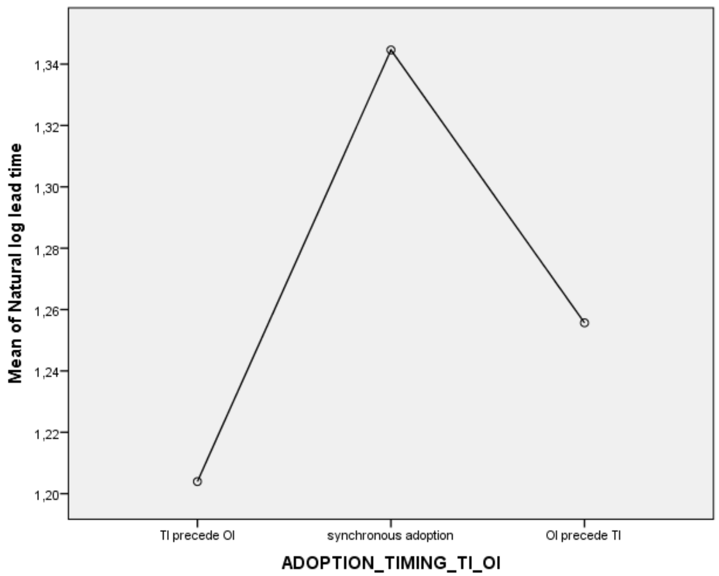
Energy consumption development in percentages from 2007-2009

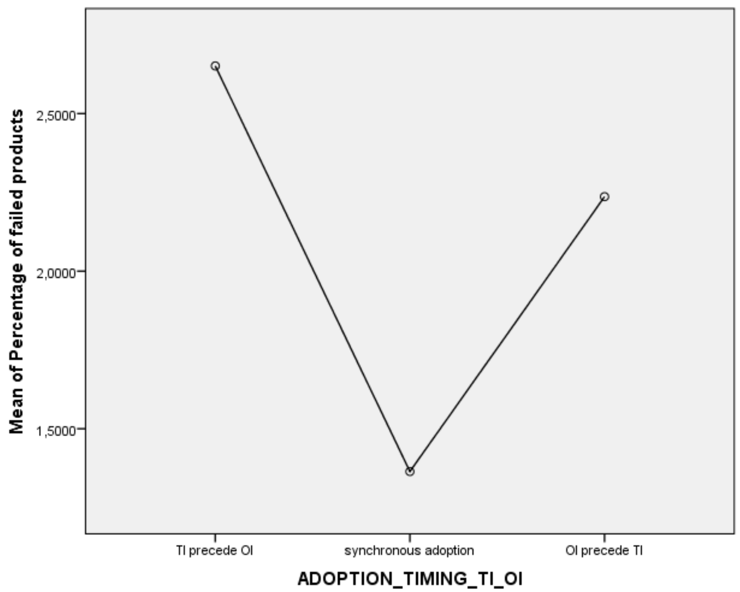
	ADOPTION_TIMING_TI_OI	N	Subset for alpha = 0.05	
			1	2
Tukey HSD[a,b]	OI precede TI	32	-3,8438	
	TI precede OI	42	2,1667	
	synchronous adoption	12		9,3333
	Sig.		,079	1,000

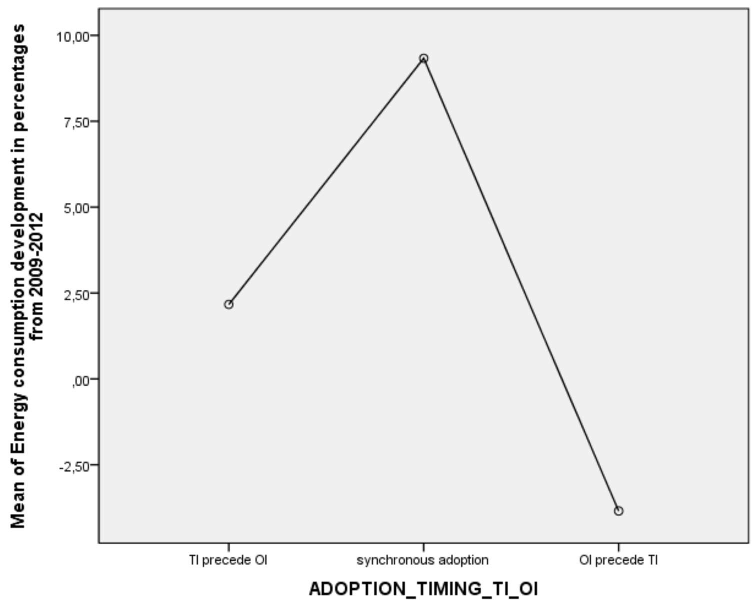
Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 21,677.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.


1,34
1,32
1,30
1,28
1,26
1,24
1,22
1,20
Mean of Natural log lead time
TI precede OI
synchronous adoption
OI precede TI
ADOPTION_TIMING_TI_OI


Mean of Percentage of failed products
2,5000
2,0000
1,5000
TI precede OI
synchronous adoption
OI precede TI
ADOPTION_TIMING_TI_OI


Mean of Energy consumption development in percentages from 2009-2012
10,00
7,50
5,00
2,50
,00
-2,50
TI precede OI
synchronous adoption
OI precede TI
ADOPTION_TIMING_TI_OI

Appendix 5: Items used from European Manufacturing Survey 2012

3 **Welke van de volgende technologieën worden momenteel in uw bedrijfsvestiging toegepast?**

Toepassing gepland voor 2015	Nee	Technologieën toegepast in uw bedrijfsvestiging	Ja	Voor het eerst gebruikt (Jaar)[1]	upgrade sinds 2009 Ja	upgrade sinds 2009 Nee	Omvang van het toegepaste potentieel (g=gering; m=midden; h=hoog)[2]
		Robots en automatisering					
☐	☐	Industriële robots (voor hanteren van gereedschap en werkstukken) in fabricage en assemblage	☐	19/20	☐	☐	g m h
☐	☐	Gebruik van geautomatiseerde warehouse managementsystemen (WMS) voor interne logistiek en orderverzamelen	☐	19/20	☐	☐	g m h
☐	☐	Technologieën voor veilige mens-machine interactie (bijv. coöperatieve robots, open werkstations e.d.)	☐	19/20	☐	☐	g m h
☐	☐	Intuitieve, multi-modale programmeringsmethoden (bijv. spraakherkenning, herkenning van gebaren, bewezen trajecten)	☐	19/20	☐	☐	g m h
		Bewerkings- en productietechnologieën					
☐	☐	Technieken voor verwerking van legeringen (aluminium-, magnesium-, titaniumlegeringen, enz.)	☐	19/20	☐	☐	g m h
☐	☐	Technieken voor verwerking van composietmaterialen (bijv. carbonvezel, glasvezel)	☐	19/20	☐	☐	g m h
☐	☐	Productietechnologieën voor micromechanische componenten (micromachinale bewerking, lithografie e.d.)	☐	19/20	☐	☐	g m h
☐	☐	Nanotechnologische productieprocessen (bijv. oppervlaktebewerking)	☐	19/20	☐	☐	g m h
		Digitale fabriek / IT netwerken					
☐	☐	Digitale uitwisseling van productieplannings-gegevens met supply chain managementsystemen van toeleveranciers/klanten (ERP)	☐	19/20	☐	☐	g m h
☐	☐	Virtual reality en/of simulatie bij (her)inrichting van het productieproces (bijv. production flows, single process steps)	☐	19/20	☐	☐	g m h
☐	☐	Virtual reality en/of simulatie bij productontwerp/ ontwikkeling (bijv. digital prototyping, EEM)	☐	19/20	☐	☐	g m h
☐	☐	Product Lifecycle Management (PLM)	☐	19/20	☐	☐	g m h
☐	☐	IT sytemen voor opslag en management van ideeën (idea management systems)	☐	19/20	☐	☐	g m h
		Energie en grondstoffenbesparing					
☐	☐	Droge bewerking/minimum smering	☐	19/20	☐	☐	g m h
☐	☐	Controlesystemen die machines stilleggen bij onderbenutting	☐	19/20	☐	☐	g m h
☐	☐	Terugwinning van kinetische en procesenergie (terugwinnen afvalwarmte)	☐	19/20	☐	☐	g m h
☐	☐	Warmtekrachtkoppeling (Bi-/Trigeneratie)	☐	19/20	☐	☐	g m h
		Technologieën voor het opwekken van duurzame energie					
☐	☐	Technologieën voor het opwekken van zonne- of windenergie, waterkracht, biomassa of geothermische energie	☐	19/20	☐	☐	g m h
☐	☐	Technologieën voor warmte-opwekking door middel van zonne-energie, biomassa of geothermische energie	☐	19/20	☐	☐	g m h

Toelichting:

1 Het jaar waarin deze technologie voor het eerst werd toegepast in uw bedrijfsvestiging (maak een schatting indien u onzeker bent over het exacte jaar)

2 Daadwerkelijke toepassing ten opzichte van maximaal zinvolle toepassingsmogelijkheden: omvang van het gebruikte potentieel is "gering" bij eerste aanzetten, "midden" bij gedeeltelijke toepassing en "hoog" bij omvangrijke toepassing

8.1 **Welke van de volgende organisatieconcepten en werkwijzen worden momenteel in uw bedrijfsvestiging toegepast?**

Toepassing gepland voor 2015	Nee	Organisatieconcepten	Ja	Voor het eerst toegepast[1]	Omvang van het toegepaste potentieel (g=gering; m=midden; h=hoog)[2]
		Organisatie van de productie			
☐	☐	In kaart brengen van logistieke knelpunten in de totale productieketen (Value Stream Mapping)	☐	19/20	g m h
☐	☐	Klant- of productgeoriënteerde inrichting van productie-eenheden (i.t.t. functionele indeling)	☐	19/20	g m h
☐	☐	Vraaggestuurde productie (afschaffen van tussenvoorraden, Kanban)	☐	19/20	g m h
☐	☐	Methoden voor het optimaliseren van omsteltijden (bijv. Single Minute Exchange of Die)	☐	19/20	g m h
☐	☐	Methoden voor vergroting machinebeschikbaarheid door onderhoud, training en veiligheid (TPM=Total Production Maintenance)	☐	19/20	g m h
☐	☐	Kwaliteitsmanagement op basis van het INK-model (bijv. EFQM, Zero Defects)	☐	19/20	g m h
		Organisatie van het werk			
☐	☐	Werkplekinrichting volgens 5s methode (aanblik werkplek en hygiëne)	☐	19/20	g m h
☐	☐	Gestandaardiseerde en gedetailleerde werkinstructies	☐	19/20	g m h
☐	☐	Taakverrijking (integratie van planning, uitvoering of controle)	☐	19/20	g m h
☐	☐	Continue verbeteren (Kaizen, kwaliteitscirkels e.d.)	☐	19/20	g m h
☐	☐	Autonome taakgroepen in fabricage en assemblage	☐	19/20	g m h
		Standaarden en audits			
☐	☐	Visueel management (grafische weergave werkprocessen)	☐	19/20	g m h
☐	☐	Kwaliteitsmanagement op basis van ISO 9000	☐	19/20	g m h
☐	☐	Six Sigma methode	☐	19/20	g m h
☐	☐	Milieucertificering volgens ISO 14031	☐	19/20	g m h
☐	☐	Energie-audit volgens ISO 50001:2011	☐	19/20	g m h
☐	☐	Total Cost of Ownership (TCO: planning van investeringen en activiteiten op basis van de totale, de gehele levenscyclus dekkende kosten)	☐	19/20	g m h
		Human resource management			
☐	☐	Formele bijeenkomsten van medewerkers voor het genereren van ideeën	☐	19/20	g m h
☐	☐	Maatregelen voor het behoud van oudere werknemers of hun kennis voor uw bedrijfsvestiging (bijv. trainingsprogramma's, beloningsvormen e.d.)	☐	19/20	g m h
☐	☐	Tijd gereserveerd voor experimenteren (hetzij alleen of in groepen)	☐	19/20	g m h
☐	☐	Talentontwikkelingsprogramma's (bijv. promotie jong talent naar seniorposities, speciale trainingsprogramma's e.d.)	☐	19/20	g m h
☐	☐	Training van vaardigheden voor vergroting creativiteit en innovatie (bijv. technieken voor probleemoplossing, idee-ontwikkeling of brainstorming)	☐	19/20	g m h

Toelichting:

1 Het jaar waarin dit organisatieconcept voor het eerst werd toegepast in uw bedrijfsvestiging (maak een schatting indien u onzeker bent over het exacte jaar)

2 Daadwerkelijke toepassing ten opzichte van maximaal zinvolle toepassingsmogelijkheden: omvang van het gebruikte potentieel is "gering" bij eerste aanzetten, "midden" bij gedeeltelijke toepassing en "hoog" bij omvangrijke toepassing

19 **Welke van de volgende kenmerken is het meest van toepassing op uw hoofdproduct(groep) in 2011?**

Wat is de gemiddelde productietijd van uw hoofdproduct(groep)?
(doorlooptijd vanaf moment dat opdracht binnenkomt bij productie tot gereed product) ca. ___ werk-dagen of ___ uren

Hoeveel procent van uw productie moet na kwaliteitscontrole nabewerking ondergaan of geheel worden afgekeurd? ca. ___ . ___ %

21 **Tussen 2009 en 2011, hoe heeft het jaarlijkse energieverbruik (kWh)in uw bedrijfsvestiging zich ontwikkeld?**

	gedaald	gelijk gebleven	gestegen
Energieverbruik sinds 2009	☐	☐	☐

Energieverbruik is.... gedaald met ca. ___ % gestegen met ca. ___ %