Radboud Universiteit

# Optimizing Product Innovation beyond R&D?

The relationship between R&D and Product Innovation is analyzed with Industry 4.0 techniques Smart Working and Smart Manufacturing as moderators

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**Date:** 17-6-2024

**Version:** 1

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## Chapter 1 – Problem context and research question

Innovation and new product development are critical aspects for many businesses, without these innovations, they are simply at risk of survival. A McKinsey survey also highlighted the importance of innovation, where 84% of CEOs believe innovation is critical for growth. Still, only 6% are satisfied with their innovation process, and 80% of the business models are at risk if they remain untouched by innovative renewal (McKinsey, n.d.). One form of innovation is Product Innovation (Goffin et al., 2000), which is about introducing new products or services to the market (Bergek et al., 2008). New products created due to Product Innovation could be seen as the result of, and is driven by, Research and Development (R&D) (Coombs & Bierly, 2006). R&D is the organizational process of new knowledge generation and doing things differently and better (Cinquini et al., 2013; Barge-Gil & López, 2014). In addition, we observe Industry 4.0, which has been introduced as the Fourth Industrial Revolution. It ensures more efficient manufacturing processes through the use of automation, the Internet of Things (IoT), Artificial Intelligence (AI), and Data Analytics but it can also support the process of Product Innovation (Frank et al., 2019).

This research aims to identify to what extent Industry 4.0 techniques Smart Manufacturing and Smart Working influence the relationship between R&D and Product Innovation. Smart Manufacturing strengthens manufacturing processes while Smart Working contributes to how technology helps employees work more efficient and flexible. Both techniques could influence the relationship R&D has with Product Innovation. Within this chapter, we will introduce the study with a brief discussion of the concepts and then introduce the research question which will be covered followed by the aim objective of which we also discuss the importance and significance, after which the overall structure and limitations of this research will be described.

Nowadays companies need to stand out among their competitors to survive in the competitive landscape (Marzi et al., 2017; Kim et al., 2015). Therefore, companies strive to develop new products capable of delivering distinct values at a more affordable price (Marzi et al., 2017). Product Innovation is the driver of this process and determines the Product Innovation Performance of a company (Kim et al., 2015). Kim et al. (2015) conclude in previous research that dynamic industries influence Product Innovation more than non-dynamic industries. Frank et al. (2019) indicate that there is more Product Innovation in large firms than in small firms. Probably, because large firms have more resources to use for Product Innovation. However, Leonard–Barton (1992) examined Product Innovation in combination with the core capabilities of a company. He shows a paradox that the role of resources can have both positive and negative impacts depending on how the resources are anchored and applied in the company. Industry 4.0, including Smart Manufacturing and Smart Working, could also shift how resources are deployed within a company.

Smart Manufacturing represents the integration of conventional manufacturing with Industry 4.0 base technologies that result in higher efficiency, flexibility, and quality of the various production activities through data processing and automation (Frank et al.,2019; Kusiak, 2017). Smart Manufacturing allows companies to work more efficiently and use resources more sustainably. It also relies on shared technologies that enhance through direct and indirect collaborations with other companies, resulting in similar manufacturing processes across the industry. Creativity is necessary to remain distinctive (Kusiak, 2017).

Smart Working is in contrast to other Industry 4.0 techniques about the integration of advanced technologies and intelligent systems in the work practices of employees. Smart Working drives the integration and collaboration between employees and technological innovations, to fully benefit from the possibilities that Industry 4.0 technologies offer. Applications such as AI, robotics, and wearable devices contribute to this (De Assis Dornelles et al., 2022). Smart Working enables deploying employees more efficiently and is particularly effective for companies aiming for flexibility in the production process. This aligns well with the employees who, in contrast to traditional techniques, can handle different shapes well and are flexible. Smart Working applications can be used in the assembly, training, and quality control phase, but also in the Product Innovation processes (De Assis Dornelles et al., 2022).

Where Product Innovation is so important in the current landscape, and more and more companies are opting for Industry 4.0 techniques, it is important that companies know to what extent these techniques can give them a competitive advantage, if they are also necessary to innovate. The signals differ regarding contributions to Product Innovation; Smart Manufacturing can make business processes more generic, whereby the uniqueness and competitive advantage decrease, encouraging companies to be creative to differentiate (Kusiak, 2017). Smart Working encourages employees' flexibility, stimulating their learning and inquisitiveness (De Assis Dornelles et al., 2022). Still, at the same time, it appears to depend on how these resources are implemented within the company (Leonard–Barton, 1992).

Given the ambiguity and different possible explanations and applicability of Industry 4.0 on Product Innovation within the manufacturing industry, this research will aim to identify and analyze the influence that Smart Working and Smart Manufacturing have on the relationship of R&D on Product Innovation within the manufacturing industry. The central research question is: *'Do Smart Manufacturing and Smart Working have a moderating effect on the relation between R&D on Product Innovation within manufacturing firms, and how are these relationships organized by the (SME) manufacturers?'*

To answer this question, this study will outline research objectives to identify the influences of Smart Manufacturing and Smart Working on the relationship between R&D and Product Innovation. The existing literature on the Industry 4.0, R&D, and Product Innovation concepts suggests conflicting signals and has not been explicitly investigated in this combination, creating a gap this research aims to fill. This gap provides an opportunity to provide scientific added value. The results of this research can also offer practical insights to the manufacturing industry, supporting their decision-making regarding the adoption of Industry 4.0 techniques and their contribution to the R&D and Product Innovation process.

This research will focus on and be limited to the Dutch manufacturing industry. It will investigate how Industry 4.0 techniques, Smart Manufacturing, and Smart Working, influence the relation R&D has on Product Innovation. It will remain limited to these two out of the four front-end techniques of Industry 4.0. This focuses on understanding how external smart process factors can influence the effectiveness of R&D in stimulating Product Innovation. First, a literature review of R&D, Product Innovation, Smart Manufacturing, and Smart Working will be provided, followed by the methodology used to address the research questions. Subsequently, the results obtained from the implementation of this method will be presented. Finally, a conclusion and discussion will be provided, along with recommendations for future research.

# Chapter 2 – Theoretical Framework

This section will provide an overview of the R&D and Product Innovation literature and Industry 4.0 techniques: Smart Manufacturing and Smart Working. Existing literature has already elaborated on the individual concepts. The contributing combination of R&D with Product Innovation, and Industry 4.0 with Smart Manufacturing and Smart Working, can also be sought between all these concepts. By treating the different concepts separately, a picture will emerge where overlaps, or logical links, and other connections arise. This will lead to the hypothesis being tested in this study.

## 2.1 R&D and Product Innovation

R&D and Product Innovation are two closely related concepts. However, each has its own characteristics, they are also interlinked and related to each other. In this section, the concepts will discussed as well as the relationship between them.

R&D involves companies' systematic and creative efforts to expand their knowledge base. This encompasses various fields, including technology, social sciences, and cultural understanding. R&D can consist of research and experiments, and is mainly focused on discovering new applications, processes, or methods to use in or expand their core business (Heij et al., 2019). R&D includes efforts to find new products and improve existing processes (Miles, 2007). R&D activities consist of searching for new information through analysis, but also by experimenting and even developing prototypes. In the final stages of R&D, it already appears and overlaps with Product Innovation (Miles, 2007). Pisano (1994) also argues that even a low level of R&D could already lead to Product and Process Innovation. The traditional R&D landscape is undergoing a shift. Companies collaborate more in their R&D process, which is also known as Open Innovation. Enkel et al. (2009) discuss this phenomenon and highlight the benefits of reducing the amount of time in which innovations are acquired and the greater extent to which innovations are absorbed. But it also covers the risks of losing control, high costs, finding the right partners, relying on the same innovations, and becoming more generic.

Before the concept of Product Innovation is discussed, it is useful to first discuss the concept of innovation. West and Anderson (1996) define innovation as the attempt to gain benefits from change. It could be seen as changing a product or process and benefiting from this change afterward. Other definitions are more general and focus on the ‘new’ aspect. The definition of Nohria and Gulati (1997) and Zaltman et al. (1973), for instance, suggest that any aspect of a business can be seen as an innovation when it is new or renewed. The concept of innovation can then be seen as an umbrella concept for the following four types of innovation: New- products, services, manufacturing processes, and business processes (Goffin et al., 2000).

Product Innovation, the concept this research focuses on, arises when companies release new products or services. They could do this to differentiate or develop a new revenue stream. Product Innovation can take place by optimizing manufacturing, or the product delivery process; for instance to smoothen the process consumers do business with a firm (Goffin et al., 2000). Dougherty (1992) considers Product Innovation as the crucial aspect of corporate renewal, and Bowen et al. (1994) as the driving force behind renewal. Product Innovations can be radical as well as incremental. Incremental Product Innovations consist of improvements or modifications to existing products. These changes are not revolutionary but an upgrade of the initial product. These kinds of innovations could be product upgrades, cost reductions, or repositioning of existing products (Holahan et al., 2013). Radical Product Innovations are new-to-the-world products or groundbreaking ideas identifiable with more distinction from existing products. Radical Product Innovations could be but are not limited to, new product lines, innovations not present in the market, or next-generation advances (Holahan et al., 2013).

Product Innovation is also considered within the relationship with the Research Based View. Leonard–Barton (1992) elaborates on this in his paper in which he examines the nature of the core capabilities of a firm in combination with product development. Core competencies can have both a positive and negative impacts on innovation. Employee skills and technical systems form a basis for successful innovation if properly coordinated. However, an insufficiently renewed environment can cause rigidity and inertia within the organization that is counterproductive to Product Innovations (Leonart-Barton, 1992).

R&D and Product Innovation have a certain overlap but it is not the same. The knowledge gained through R&D is the input of Product Innovation (Danneels, 2002). The relationship between R&D and  Product Innovation has been analyzed, it is concluded that the increase in knowledge through R&D has a positive influence on Product Innovation (Forsman, 2009; Wu & Shanley, 2009; Zahra & Chaples, 1993; Zahra et al., 2000). Heij et al. (2019) also analyzed the relationship and concludes that an increase in R&D and thus more knowledge acquired positively contributes to Product Innovation. However, too much R&D makes this knowledge difficult to interpret and therefore contributes less. All in all, they conclude that a balanced focus on R&D is essential for maximizing Product Innovation. A positive relationship between the main relationship of R&D and Product Innovation is expected (H1).

H1: *'R&D has a positive influence on Product Innovation.'*

### 2.2 Industry 4.0

Industry 4.0 can change the entire product manufacturing process, making it more efficient and competitive. The front-end techniques are Smart Manufacturing, Smart Products, Smart Supply Chain, and Smart Working. Smart in this context implies the intelligence of these front-end techniques, facilitated by the base technologies: Internet of Things, Cloud Services, Big Data, and Analytics (Frank et al., 2019). Within this research, we will focus on the front-end technologies: Smart Manufacturing and Smart Working.

#### 2.2.1 Smart Manufacturing

In today's manufacturing industry, Information and Communication Technology (ICT) can be implemented to the fullest extent possible. Applying sensors measuring all outputs and movements, collecting it as big data, and using analytics to keep track of the complete process and even adjusting it to make it smart (Wang et al., 2021). Before Smart Manufacturing, the manufacturing industry was already experimenting with this technique. Around 1995 there was an industrial research program (IMS) with major companies from all over the world collaborating and working on new ways of manufacturing (Kusiak, 2017). America had its program (NGMS) but with the same intention; making manufacturing intelligent (Groumpos, 1995; Kusiak, 2017). When the concept of the Internet of Things was found and implemented in manufacturing the concept of Smart Manufacturing was born. As a result, Smart Manufacturing focuses on the combination of the physical assets within manufacturing, the real machinery, and the cyber-physical systems (Kusiak, 2017).

The definitions of Smart Manufacturing are closely linked, they are all about using one or more of the Industry 4.0 base techniques to contribute to the manufacturing process. NIST (2022) defines Smart Manufacturing as follows: "a fully integrated, collaborative manufacturing systems that respond in real-time to meet changing demands and conditions in the factory, in the supply network, and customer needs" (NIST, 2022) which fits our research aim, and resembles a concise formulation of the concept.

Kusiak (2017) describes six foundation elements on which Smart Manufacturing is built. These pillars as he calls them are not exhaustive nor stationary partly because of the dynamic of the technique.

1. Manufacturing technology and processes: this is about the emergence of the manufacturing technologies itself. The manufacturing process becomes more enhanced with newly advanced and automated machinery.
2. Materials: Smart Manufacturing does not impose requirements on the materials used, but can however enrich the lifespan. By paying special attention to reuse. It can also contribute to finding new materials to use.
3. Data: the normal manufacturing process is enriched with data. Sensors, wireless technology, and data analysis make it possible to better coordinate properties, processes, deliveries, and needs.
4. Predictive engineering: this enables anticipatory rather than reactive entrepreneurship. Think of predicting the behavior of a supply chain or integrating and aligning productivity, product quality, energy, and transportation. It will change the manufacturing industry by seeking a separate approach for sensitive and less sensitive products and factors.
5. Sustainability: Kusiak (2017) calls sustainability a paramount component. Again, to waste as little materials, production processes, energy, and contaminants as possible, and to deal with them as effectively and efficiently as possible. He also indicates that the boundary between production and service will disappear. Reusing products is not currently a traditional production activity, but it could become so.
6. Resource sharing and networking: The techniques that are used will not all be owned by the companies. Companies will depend on service providers on whom their competitors also depend. Although sharing the creativity space will be a challenge and will be the aspect where companies can make their difference.

Kusiak (2017) concludes that Smart Manufacturing involves autonomy, evolution, simulation, and optimization. The extent and speed at which companies transform depends on resources: data and tools available. 'smartness' will depend on the extent to which companies can benefit from these technologies.

As discussed by Chesbrough (2003), Open Innovation principles could indicate that shared innovations have a counter-effective influence on firms. They are lowering their competitive unique advantage. And that these firms are in a difficult position between sharing and using others' innovations and keeping their advantage. This dynamic can lead to disruption of the process of unique knowledge development from R&D, as sharing innovations can result in a loss of exclusivity and differentiation for individual companies. Although Smart Manufacturing technologies optimize production processes and enhance efficiency, they are based on standardization techniques and make the manufacturing firms more generic (Kusiak, 2017). The combination of these Open Innovations and Smart Manufacturing trends could undermine the relationship between R&D and Product Innovation, as firms may struggle to maintain a competitive edge through differentiated product offerings which could harm the relationship between R&D and Product Innovation. However, if the right partners are chosen, such as universities, they can boost the unique knowledge creation within the companies. Collaboration with external research institutes can lead to breakthrough discoveries and innovative solutions (Kamuriwo et al., 2017) that might otherwise not have been found by the internal R&D teams.

In addition, also the second pillar about materials, described by Kusiak (2017), can have a positive influence on R&D and Product Innovation. By focusing on exploring new materials and improving existing ones, R&D teams can develop innovative products that meet the ever-changing demands of the market which can be implemented thanks to Smart Manufacturing. For example, these materials can be used to create more sustainable products with improved performance or a lower environmental impact.

The third pillar highlights the data collection tools within Smart Manufacturing (Kusiak, 2017) that could provide a valuable source of insight for R&D teams. By collecting and analyzing data from various sources, such as production processes, customer interactions, and market trends, the R&D department can identify trends, identify potential bottlenecks, and discover new opportunities for Product Innovation. These data-driven insight can make R&D efforts more efficient and increase the likelihood of successful product launches.

H2: *'Smart Manufacturing strengthens the relationship R&D has on Product Innovation.'*

### 2.2.2 Smart Working

Smart Working involves the evolution within the dimensions of work culture and technology. It highlights a shift in employees' approach to work, prioritizing flexibility, collaboration, and innovation (Bednár & Welch, 2019). In comparison with the other three frontend technologies, Smart Working focuses on the combination of employees within the system instead of only the application of the technology without humans involved (Frank et al., 2019). Smart Working is especially important when companies focus on flexibility in their manufacturing processes, as employees are the most flexible and adaptive resources in the process (Marcon et al., 2021). Bednár and Welch (2019) discuss several definitions of Smart Working, like the evolution of approaches to work and the decision-making process, as well as the communications, and collaboration alternations. They also cite the work of McEwan *'Smart working practices are agile, dynamic, and emergent. They are the outcomes of designing organizational systems that facilitate customer-focused, value-creating relationships that are good for business and good for people'* (McEwan, 2013, as cited in Bednár & Welch, 2019).

Different technologies contribute to Smart Working. Technologies in general do not determine Smart Working; they only support and assist the concept of Smart Working. Smart Working consists of more than just the use of technologies such as AI and IoT in the work process. It's about changing, renewing, and modernizing the work processes; it's about promoting flexibility and collaboration and encouraging innovation and creativity among employees (Bednár & Welch, 2019). De Assis Dornelles, et al. (2022) highlights 15 technologies that can contribute to Smart Working: *Augmented reality (AR), Collaborative robots (CR), Virtual reality (VR), Wearable devices (WD), Environment and machine sensors (SENS), Automation (AUT), Voice-enabled assistant (VEA), Digital Twin (DT), Smart decision support systems (SDSS), Automated Guided Vehicle (AGV), Computer Vision (CV), Industrial social networks (ISN), Exoskeletons (EXO), Visual Analytics (VA), and Artificial intelligence (AI)*. All these tools streamline employee work efficiently. This could be making it less physically intensive or making it easier to make decisions.

The Smart Working concept in the manufacturing industry consists of ways of working that stimulate employees in their daily work and make the manufacturing process more efficient and flexible. At the same time, it allows the employees to develop creativity and improve their skills, which will not only improve the employee's work process but could also contribute to Product Innovation. Because of the insights that these employees can come up with. De Assis Dornelles, et al. (2022) also highlight several counterarguments for Smart Working; effective implementation can be challenging, expectations overestimated, and the adaptation between employees can vary. These could undermine the overall contribution of Smart Working.

Given the resource-based view perspective discussed by Leonard–Barton (1992) about the extent to which resources within a company contribute to the success of Product Innovation. It is indicated that this influence depends, among other things, on how the resources have been implemented within the company and whether inertia may have occurred. Given the new but also promising literature on the Industry 4.0 resource Smart Working, and encouraging employees to learn and develop, inertia seems unusual. As shown earlier, R&D can lead to new knowledge and insights that are then used in Product Innovation. However, the extent to which this knowledge is translated into innovative products can be influenced by the implementation of Smart Working processes. By enabling employees to develop their creativity and skills, Smart Working can strengthen the effectiveness of R&D and contribute to a greater degree of Product Innovation (H3).

H3: *'Smart Working strengthens the relationship R&D has on Product Innovation.'*

**2.3 Conceptual model**

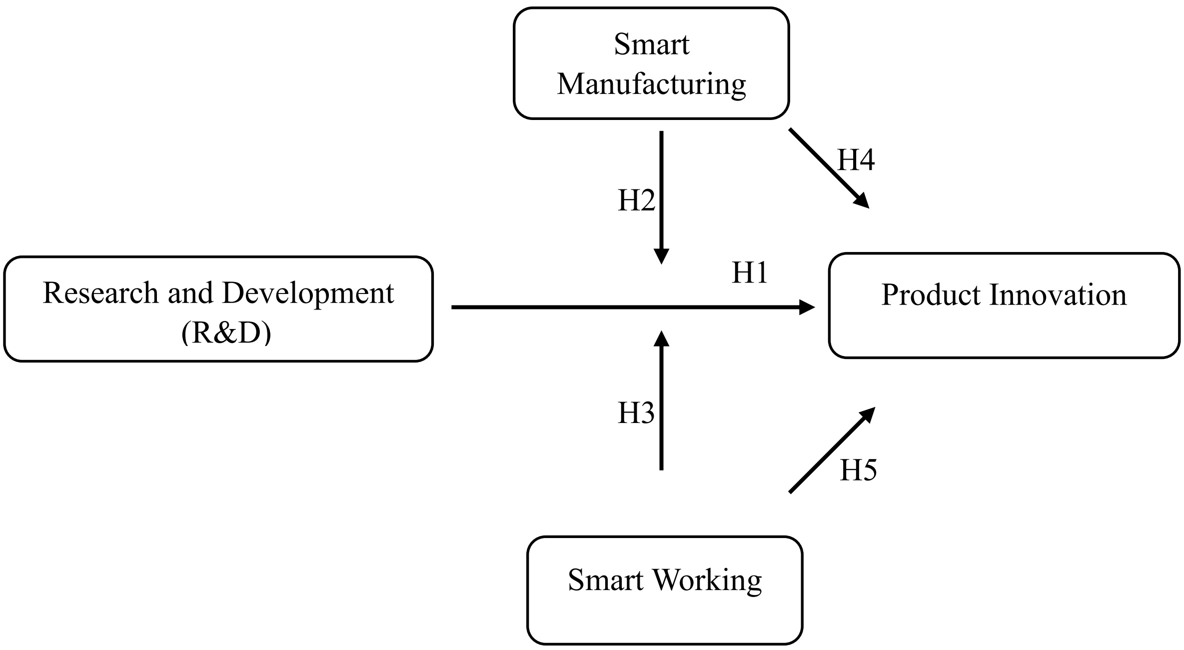
The literature discussed and hypothesis formulated have resulted in the conceptual model presented in Figure 1. The various relationships in this model and the associated hypotheses will be tested similarly to the arrows in this model. The relationship between R&D on Product Innovation will be examined directly (H1). In this relationship, the moderating influence of the concepts of Smart Manufacturing and Smart Working will also be tested (H2 & H3). Moreover, this study will not only investigate the moderating effects of Smart Manufacturing and Smart Working on the relationship between R&D and Product Innovation but also directly analyze the impact of these moderating factors on Product Innovation (H4 & H5).

*H4: 'Smart Manufacturing has a positive relationship with Product Innovation.'*

*H5: 'Smart Working has a positive relationship with Product Innovation.'*

By studying both the indirect and direct influences of Smart Manufacturing and Smart Working, the aim is to gain a more thorough understanding of how these processes influence the innovation capacity of organizations.

**Figure 1.** *Conceptual model*



# Chapter 3 – Methodology

This chapter explains the methodology that will be used to conduct the research. It will be explained which quantitative variables will be used in the analysis and which respondents will be interviewed. Finally, attention will be paid to the validity of the research.

## 3.1 Research Design

This research is conducted using a mixed methods approach. The Convergent Parallel Design method has been selected for this analysis, which consists of quantitative and qualitative data to test the same hypotheses. Within this design, no order is required or results used by one analysis in the other. Both studies are carried out, in theory, simultaneously and interpreted afterward. This method is most suitable for understanding the research question due to the strengths, and non-overlapping weaknesses of quantitative and qualitative methods (e.g. small sample, details, in-depth) (Creswell & Creswell, 2017). The quantitative study with this provides a more generalizable insight into the observed phenomena. In contrast, the qualitative analysis provides more contextual insights and knowledge.

The hypothesized relationships are quantitatively analyzed with data collected in the European Manufacturing Survey (EMS) to test the statistical influence and explanation of the variables and relationships. Qualitative research is conducted through interviews. To find more insight into these relationships. The first part of the research question *"Do smart manufacturing and smart working have a moderating effect on the relationship between R&D on Product Innovation within manufacturing firms…?"* will be mainly analyzed by the quantitative research part. The last part *"… how are these relationships organized by the (SME) manufacturers?"* will mainly be answered using Qualitative analysis. The main reason for choosing a convergent design is the assumption that there is equal value in collecting and analyzing both quantitative and qualitative data to answer the research question the best (Creswell & Creswell, 2017).

Various data sources are used; scientific literature, quantitative data from the EMS, and qualitative insights from the interviews. Due to all these different forms of information and several forms of research methods surrounding the subject being researched, triangulation is taking place. This results in an increase in validity (Creswell & Creswell, 2017; Mathison, 1988). In addition, this mixed methods method will also provide a more overarching picture. For example, the qualitative study will demonstrate whether the influences are significant, while the qualitative part can demonstrate more substantive context about the relationships. This would not have been possible if only one method had been chosen and is therefore an enrichment of this research.

### 3.2 Quantitative Research

The relationship between R&D and Product Innovation will be tested quantitatively. Additionally, the moderating concepts of Smart Manufacturing and Smart Working will be tested for this relationship. As well as the direct effect of these smart techniques on Product Innovations. For the quantitative part, secondary data from the European Manufacturing Survey will be used. This survey is an initiative to map innovations within the European manufacturing industry and to renew these every few years. The most current survey dates from December 2022 (Radboud University, n.d.). The 186 respondents in the survey are being used in the study.

The validity and reliability of the variables will be examined using statistical analyses, such as Cronbach's alpha. Next, the variables Smart Manufacturing and Smart Working will be tested as moderating effects on this relationship. The direct influence of these moderating effects on Product Innovation will also be examined. Once this has been completed, all hypotheses will be analyzed quantitatively.

To assess the hypotheses quantitatively, efforts have been made to align the concepts in this study with corresponding data extracted from the EMS survey. R&D is measured with a variable that represents whether R&D is taking place or not. Product Innovation will be analyzed using an indicator that represents whether Product Innovation is taking place or not. Both R&D and Product innovation are measured using a dichotomous variable.

While the EMS Survey does not explicitly measure the constructs of Smart Manufacturing and Smart Working, several indicators that belong to these smart concepts have been measured and can therefore together indicate the dimensions of Smart Manufacturing and Smart Working. Grouped measures are employed to capture these constructs. These grouped measures are formed by combining indicators, that align with Smart Manufacturing and Smart Working, as discussed in the literature review. This approach ensures that the chosen factors of the EMS survey are consistent with the conceptual framework presented in this research. For Smart Manufacturing, all indicators covered within the Digital Process Technologies Innovation section (section 11 within the EMS questionnaire) are relevant. Concerning Smart Working, the indicators about Organizational Process Innovation (section 8 within the EMS questionnaire) are relevant and therefore used.

The units of measurement and the extent to which these techniques are present within the companies have been measured in various ways. To avoid distinguishing between the various Smart levels, all values of these measurement units will been converted into binary values, denoting presence (1) or absence (0), thereby representing the level in this manner. Since it can be hard to determine a measurement scale for these umbrella concepts, the assumption has been made that the more active techniques shown in indicators, the more this smart technology is present within a company.  A complete overview of the variable to be used is included in Table 1. The full quantitative data analysis will be done using SPSS.

**Table 1.** *Operationalization table based on european_Manufacturing_Survey_2022_NL*

| ID | Question | Dimension |
|---|---|---|
| | **R&D** | |
| 23.2(4) | Welke percentage van de omzet betreft de Onderzoek en Ontwikkelingsactiviteiten (O&O, R&D) in 2021? | Percentage |
| | **Product Innovation** | |
| 16.1a(1) | Wat was het aandeel van deze nieuwe/verbeterde producten in de omzet van 2021? | Percentage |
| | **Smart Manufacturing** | |
| 11.1_1 | Mobiele/ draadloze apparaten voor programmering en bediening van installaties en machines (bijv. tablets) | Yes (1) - No (0) |
| 11.1_2 | Digitale oplossingen voor het direct beschikbaar maken van tekeningen, werkschema's en -instructies op de werkvloer | Yes (1) - No (0) |
| 11.1_3 | Digitale productieplanning en roostering (bijv. ERP- of ASP systeem) | Yes (1) - No (0) |
| 11.1_4 | Systemen voor geautomatiseerd management van interne logistiek en orderverzameling (e.g. RFID, warehouse management system) | Yes (1) - No (0) |
| 11.1_5 | Digitale uitwisseling van productieplanningsgegevens met toeleveranciers en/of klanten (elektronische data uitwisseling (EDI) | Yes (1) - No (0) |
| 11.1_6 | Product Lifecycle Management (PLM) systemen of product- of productieproces datamanagement | Yes (1) - No (0) |
| 11.1_7 | Bijna real-time productiemanagementsystem en (bijv. systemen voor gecentraliseerde besturing en machinemonitoring, MES) | Yes (1) - No (0) |
| 11.1_8 | Additive technologieën en simulatietechnieken 3D printertechnologie voor prototypes, | Yes (1) - No (0) |
| 11.1_9 | 3D printertechnologie voor de vervaardiging van producten, onderdelen, mallen, instrumenten, e.d. | Yes (1) - No (0) |
| 11.1_10 | Software voor simulatie van productontwerp (bijv. productprestaties, betrouwbaarheid van onderdelen) | Yes (1) - No (0) |

| ID | Question | Dimension |
|---|---|---|
| 11.1_11 | Software voor simulatie van productieprocessen (bijv. op niveau van proces, productielijn, fabriek of toeleveringsketen) | Yes (1) - No (0) |
| 11.1_12 | Software voor geavanceerde berekeningen, simulaties en data analyse d.m.v. High Performance/Edge computing | Yes (1) - No (0) |
| | **Smart Working** | |
| 8_1 | Organisatie van de productie Integratie van werkzaamheden (planning, bediening, en controle op niveau van machine operator) | Yes (1) - No (0) |
| 8_2 | Klant- of productgerichte productie in de fabriek (in plaats van functie/proces gerichte productie) | Yes (1) - No (0) |
| 8_3 | Het controleren van de productie volgens het vraagsturing-principe (bijv. KANBAN, intern zero-buffer principe) | Yes (1) - No (0) |
| 8_4 | Methodes voor het optimaliseren van de omstel en/of insteltijd (bijv. SMED | Yes (1) - No (0) |
| 8_5 | Gestandaardiseerde en gedetailleerde werkinstructies, (bijv. Standard Operation Procedures SOP, vooraf vastgesteld tijdschema op basis van Media Oriented Systems Transport MOST) | Yes (1) - No (0) |
| 8_6 | Productiemanagement/ - beheersing Visueel management en monitoren van werkprocessen en werkstatus op schermen in de productie | Yes (1) - No (0) |
| 8-7 | Methoden om de kwaliteit van de productie te waarborgen (bijv. Total Quality Management, certificaten, continue verbetering van productieprocessen) | Yes (1) - No (0) |
| 8_8 | Betrekken van werknemers in ontwikkeling van innovaties (bijv. toegewezen werktijd, geformaliseerde sessies voor idee-ontwikkeling | Yes (1) - No (0) |
| 8_9 | Bonussystemen voor medewerkers voor uitmuntende prestaties in productie en/of innovatie | Yes (1) - No (0) |
| 8_10 | Gecertificeerd milieubeheersingssysteem (zoals EN ISO 14001 of EcoManagement and Audit Scheme (EMAS)) | Yes (1) - No (0) |
| 8_11 | Gecertificeerd energiemanagementsysteem (zoals EN ISO 50001 of recenter) | Yes (1) - No (0) |

For the moderating effect, an interaction variable will be created in which R&D is multiplied by the variables measuring Smart Manufacturing and Smart Working. Before these variables are multiplied, they will be centered to avoid multicollinearity. The most applicable analysis to measure this relationship is a Reliability and Logistic Regression Analysis. This allows both the direct effects and the moderating concepts to be analyzed. This method is particularly suitable due to the dichotomous dependent being analyzed. To optimize reliability, not only the dependent variables are implemented, but control variables are also included to determine whether the sector or size of the firm impacts the relationship.

### 3.3 Qualitative Research

A qualitative research method is added to gain insights into the different relationships. In-depth interviews with 5 manufacturing companies that have Smart Manufacturing and Smart Working aspects within their production process will be interviewed about their experience with the influence of these concepts and the influence they have on the relationship from R&D to Product Innovation. These interviews are held with the people within the organization with experience and expertise in the production process, the use of Industry 4.0 aspects, and R&D/Product Innovation. A semi-structured interview script is drawn up for the qualitative interviews and can be found in Appendix A. The interviews aim to explore more practical information about the relationships. This allows for further elaboration on the influences and outcomes of the various concepts. In addition, insights not indicated in the literature could be found. Overall, the qualitative part will be aimed to determine how the (SME) manufacturers organize these relationships; what they notice about Smart Manufacturing and Smart Working, and how they experience the various relationships and influences on this.

The interviews will be analyzed using a deductive, theory-driven analysis. After the interviews are conducted and transcribed, they will be coded according to the theoretical factors, and relationship aligning with the theoretical framework and hypotheses. This method ensures that the qualitative data is examined through a theoretical lens. This procedure provides a robust process of coding, analyzing, and reporting the qualitative data aligning with the research objectives.

### 3.4 Validity, Reliability and Ethics

Because this study uses a mixed methods approach, triangulation arises. This combination of quantitative and qualitative data contributes to validity by providing a broader perspective on the same phenomenon, thereby increasing the robustness and credibility of the findings. It results in a more complete understanding of the research problem.

The variables derived from the EMS survey may differ or may not provide a complete representation of the concepts within this study. While the indicators for R&D and Product Innovation seem to provide a complete picture, attention has been given to assigning all the right measurements to Smart Manufacturing and Smart Working. There are also unmeasured techniques that do fall under these indicators. This compromises the validity of these measurement constructs, and it is important to take this into account interpreting the results.

Ensuring validity in qualitative research involves interviewing the right interviewees so that they provide experience-based answers. Additionally, the interview script is drawn up based on the theory, and only a general description of the research will be given to respondents in advance to avoid leading questions. With regard to reliability, external data form the EMS survey is used. Companies that did not fit into the manufacturing industry were filtered out before the analysis, resulting in a representative dataset. The number of interviews to be conducted is limited, saturation will not be achieved. The interviewees will also have diverse experiences, which does not encourage reaching saturation. However, it will result in a broad context being outlined.

Research must uphold various ethical considerations to ensure its legitimacy and maintain the integrity of its findings. To achieve this, transparency and accountability are essential, and explicit attention has been given to multiple components. Guidelines described by, but not limited to, APA (n.d.) and Smith (n.d.) were taken into account. How these were dealt with will be discussed in the reflection of the research.

# 4. Research Results

Within the results chapter, the collected and analyzed data will be presented. This will provide an overview of all the information that has been collected, including the relations that have been tested. First, the quantitative results will be presented followed by the qualitative results. The results for both methods are logically built up, describing the concepts followed by the hypotheses. The chapter will end with a graphical, all-encompassing, overarching representation of the results gathered by both methods.

## 4.1. Quantitative Results

The hypotheses have been tested quantitatively using a Reliability and Logistic Regression analysis, resulting in the outcomes presented in this chapter.

### 4.1.1 Descriptive Statistics

This section presents the descriptive statistics of the analyses performed on the EMS Survey. The EMS questionnaire requires that the companies participating have at least 10 employees and fall within one of the categories that belong to the manufacturing industry. The frequency table shows that there are 186 valid answers. The smallest company that participates has 10 employees, and the largest has 3000 with a median of 45. Given the skewness and kurtosis, the size variable has been transformed into the natural logarithm (ln) due to an outlier. This changes the distorted image into a better normal distribution, resulting in a skewness and kurtosis of 1.152 and 6.090 (Appendix B.1). The skewness meets the guideline that it is within +3 and -3. However, the kurtosis deviates from what can still be caused by the outlier but, is less critical in this case (Kline, 2023).

The respondents from the survey are distributed across various manufacturing sectors. Table 2 illustrates the distribution of the respondents across the several sectors. This distribution does not deviate significantly from the average distribution that the assumption is made that it is a representative reflection of the population. They also provide a varying indication of whether they carry out R&D and Product Innovation. As well as the extent to which Smart Manufacturing and Smart Working play a role within these companies. To provide an overarching picture, the variables used, including the index variable for Smart Manufacturing and Smart Working, are listed in Table 2.

As shown in Table 2, 47.3% indicated they carry out R&D activities. A larger group of 48.4% indicated that they had Product Innovation within their company. This value of companies that engage in Product Innovation is quite low. We also see that companies score an average of 3.96 on the index sum variable Smart Manufacturing and 5.12 on Smart Working.

Smart Working thereby appears to be more prevalent than Smart Manufacturing. Industry 4.0 seems to be present to some extent among companies and given the relatively high standard deviation of more than 2.5 on both smart concepts, it also appears that it is quite variable. Some companies use the possibilities of Industry 4.0 more than others, as the descriptive statistics show.

**Table 2.** Quantitative Descriptive Statistics

| Variable | Mean/% | Min | Max | St. dev. |
|---|---|---|---|---|
| Size | 246.89 | 10 | 3000 | 2197.56 |
| Log size | 3.93 | 2.30 | 10.31 | 1.07 |
| Industry | | | | |
| -Metals and Metal products | 26.34% | 0 | 1 | |
| -Food, Beverages and Tobacco | 7.25% | 0 | 1 | |
| -Textiles, Leather, Paper, and Board | 16.12% | 0 | 1 | |
| -Construction, Furniture | 4.30% | 0 | 1 | |
| -Chemicals (energy and non-energy) | 20.43% | 0 | 1 | |
| -Machinery, Equipment Transport | 18.82% | 0 | 1 | |
| -Electrical and Optical equipment | 6.45% | 0 | 1 | |
| R&D | 47.3% | 0 | 1 | |
| Product Innovation | 48.4% | 0 | 1 | |
| Smart Working | 5.12 | 0 | 11 | 2.53 |
| Smart Manufacturing | 3.96 | 0 | 10 | 2.56 |

#### 4.1.2 Measurement models

The degree to which the companies carry out Smart Manufacturing and Smart Working is measured by the index variables consisting of a list of techniques and processes that fit one of these two concepts. The more a company scores on the variables, the higher it is assumed the firm's level of this concept is. For both measurement models, the variables are further reflected in this section.

The index on which Smart Manufacturing is measured has moderate reliability, measured with Cronbach's Alpha, of .652 (Appendix C.4). All variables among this grouped indicator, including the active frequency and this percentage compared to the total number of respondents are shown in Table 3. The Smart Manufacturing variable used shows that Software for production planning and scheduling and providing digital working drawings are the most popular techniques used. Software for the simulation of production processes on the other hand, is used the least. It is remarkable that most of the variables are used by less than a quarter of the respondents. This also shows that Smart Manufacturing is still in its infancy among SME manufacturing companies (Table 3).

**Table 3.** *Smart Manufacturing variables*

| Variable | Percentage |
|---|---|
| ti_MobileDev Technology - Mobile/wireless devices for programming and operation | 37.6% |
| ti_DigSolutions Technology - Digital solutions for providing drawings, work schedules or work instructions directly on the shopfloor | 50.5% |
| ti_ProdPlanning Technology - Software for production planning and scheduling | 63.4% |
| ti_IntLogistics Technology - Systems for automation and management of internal logistics | 29.6% |
| ti_DigExchange Technology - Digital Exchange of product/process data with suppliers / customers | 33.3% |
| ti_PLCsystems Technology - Product-Lifecycle Management-System | 16.1% |
| ti_RealtimeControl Technology - Near real-time production control system | 24.2% |
| ti_manuRobots Technology - Industrial robots for manufacturing processes | 22.6% |
| ti_handRobots Technology - Industrial robots for handling processes | 27.4% |
| ti_3Dprototype Technology - Additive manufacturing 3D for prototyping | 22.0% |
| ti_3Dprint Technology - Additive manufacturing 3D for products components etc | 15.6% |
| ti_softProdDesign Technology - Software for product design simulation | 28.0% |
| ti_softAdvComp Technology - Software for advanced computations, data analysis High-Performance Edge computing | 15.1% |
| ti_softProcess Technology - Software for simulating production processes | 10.8% |

On the Smart Working Index, the reliability has been demonstrated to be moderate with a Cronbach's Alpha of .714 (Appendix C.2). All variables among this grouped indicator, including the active frequency and this percentage compared to the total respondents, are shown in Table 4. It’s indicated that the customer-tailored product approach is the most popular, and the majority of companies endorse this way of working. In addition, procedures that ensure and control quality are widely used. The least-used part of Smart Working is the certifications surrounding energy management (Table 4).

**Table 4.** *Smart Working variables*

| Variable | Percentage |
|---|---|
| oi_IntegrationTasks Organizational concepts - Integration of tasks (8_1) | 68,8% |
| oi_CustomerLines Organizational concepts - Customer- or product-oriented lines (8_2) | 81,2% |
| oi_PullPrinciple Organizational concepts - Production controlling following the Pull principle (8_3) | 34,4% |
| oi_ChangeOver Time Organizational concepts - Fixed process flows to reduce setup time or optimize change-over time (8_4) | 28% |
| oi_WorkInstruction Organizational concepts - Standardized and detailed work instructions (8_5) | 48,9% |
| oi_DisplayBoards Organizational concepts - Display boards in production to illustrate work processes and work status (8_6) | 46,2% |
| oi_QualityMeasures Organizational concepts - Methods of assuring quality in production (8_7) | 73,1% |
| oi_EmployeeInnovation Organizational concepts - Employee involvement in innovation development (8_8) | 60,2% |
| oi_EmployeeBonus Organizational concepts - Employee bonus systems in production (8_9) | 29,6% |
| oi_CertifiedEnvironmentMS Organizational concepts - Certified environmental management system (8_10) | 32,3% |
| oi_CertifiedEnergyMS Organizational concepts - Certified energy management system (8_11) | 9,7% |

### 4.1.3 Model Statistics

Before the hypotheses are tested the model statistics will be described and assumptions will be tested as described in Hair (2018). The full model fit analysis is included in Appendix D. First, the Omnibus Test of Model Coefficients was significant ($p < .001$), indicating that the model including the independent variables fits and predicts the data better than without the independent variables. The model has a -2 Log likelihood value of 212.66, a Cox & Snell $R^2$ of 0.215, and a Nagelkerke $R^2$ of 0.287, which indicates that the dependent variables explain approximately 21,5% to 28,7% whether firms perform Product Innovation or not. The Hosmer and Lemeshow Test presents a significant output, indicating a lack of fit. The classification table showed an overall correct percentage of 76.3%, reflecting the model's accuracy in predicting the outcome. Finally, regarding the assumptions according to Hair (2018): Although, the sample size (n=186) is smaller than the recommended 400, the distribution of the sample is assumed to be sufficient for a reliable analysis. This is partly due to the comparable distribution of business categories according to the actual distribution.  Regarding the independence of observations, the data has been collected in such a way that each observation is independent and really different from the other, for the index variables, there is no overlap in the items used.

**4.1.4 Hypotheses Testing**

All hypotheses were analyzed using Logistic Regression Analysis with dichotomous Product Innovation as the dependent variable. The hypotheses were tested for significance ($p < .005$). The hierarchal regression model was run in three blocks, first with the control variables, then with the direct effects, and finally with the moderating interaction effects. Since there were no big differences between the models the complete model is used to explain influence of the total effect the best. All these tested hypotheses are presented in this chapter.

**The first hypothesis predicts that R&D has a positive influence on Product Innovation.** The logistic regression analysis in Table 5 showed that conducting R&D significantly positively influences Product Innovation ($B = 1.154$, $p < 0.001$). The first hypothesis is accepted. Furthermore, the analysis shows an Odds ratio of 3.170. This indicates that for every increase in R&D, from inactive to active, the probability of Product Innovation increases by a factor of 3.170.

**The second hypothesis predicts that Smart Manufacturing strengthens the relationship that R&D has on Product Innovation.** Also, Table 5 shows the interaction between Smart Manufacturing and R&D had an odds ratio of 0.948 but no significant effect on Product Innovation ($B = -0.053$, $p < 0.729$), indicating that there is no strengthening effect of Smart Manufacturing on the relationship between R&D and Product Innovation. Hypothesis 2 is rejected.

**The third hypothesis predicts that Smart Working strengthens the relationship that R&D has with Product Innovation.** The influence of Smart Working is analyzed within the second hypothesis. The interaction between Smart Working and R&D as shown in, Table 5, indicates no significant effect on Product Innovation ($B = -0.099$, $p < 0.534$) with an 0.906 Odds ratio. It reflects a non-strengthening effect of Smart Working on the relationship between R&D and Product Innovation. Hypothesis 3 is rejected.

**The fourth hypothesis predicts that Smart Manufacturing has a positive relationship with Product Innovation.** Likewise, there was no significant relationship between Smart Manufacturing and Product Innovation ($B = 0.144$, $p < 0.224$) with an odds ratio of 1.155 indicating that Smart Manufacturing has a non-significant influence on Product Innovation (Table 5). Hypothesis 4 is rejected.

**Table 5.** *Logistic Regression Analysis*

| | | B | Sig. | Exp(B) |
|---|---|---|---|---|
| Step 1[a] | Firm Size (log) | ,106 | .554 | 1.112 |
| | Metals and Metal products | | .008 | |
| | Food, Beverages and Tobacco | ,749 | .293 | 2.116 |
| | Textiles, Leather, Paper and Board | ,920 | .086 | 2.510 |
| | Construction, Furniture | -1,091 | .343 | .336 |
| | Chemicals (energy and non-energy) | 1,602 | .003 | 4.965 |
| | Machinery, Equipment Transport | 1,283 | .011 | 3.608 |
| | Electrical and Optical equipment | 2,247 | .005 | 9.462 |
| | Smart Working | ,098 | .404 | 1.103 |
| | Smart Manufacturing | ,144 | .224 | 1.155 |
| | R&D | 1,154 | .001 | 3.170 |
| | Smart Manufacturing * R&D | -,053 | .729 | .948 |
| | Smart Working * R&D | -,099 | .534 | .906 |
| | Constant | -2,967 | .000 | .051 |

**The fifth and final hypothesis predicts that Smart Working has a positive relationship with Product Innovation.** No significant relationship was found between Smart Working and Product Innovation ($B = 0.098$, $p < 0.404$), with an odds ratio of 1.103, indicating that Smart Working has a non-significant influence on Product Innovation (Table 5). Hypothesis 5 is rejected.

As shown in Table 5, the reference variables are also included. The analysis indicates that none of the control variables significantly influence the dependent variable, except the sector Chemicals (energy and non-energy), which differs from the reference sector Metals and Metal products, with an odds ratio of 4.965 ($B = 1.602$, $p < 0.003$).

### 4.2. Qualitative results

Although the quantitative analysis only revealed one significant hypothesis, insights into the different topics and hypotheses will be reflected in this qualitative chapter, which can clarify and provide more context. The interviews with different SME manufacturing firms have brought more depth into the analyzed concepts and relations. Five manufacturing companies were interviewed. The different topics and relationships active within this research have been discussed. The data and statements made by the interviewees have been analyzed, and some relevant quotes are selected and presented in this chapter and translated into English for use in the text. A brief and non-identifiable description of the companies and interviewees is given in Table 6. In addition, the interviews of a fellow researcher have also been analyzed and used to a limited extent. Since this use is minimal and given the emphasis on other concepts, this will not be discussed in detail. [1]

**Table 6.** *Interviewees description*

| Ref. | Company description | Size | Interviewee |
|---|---|---|---|
| I1 | Accumulation system manufacturer (machine construction) | 21-50 | Lead engineering and R&D |
| I2 | Plastics manufacturing | 51-100 | Production manager |
| I3 | food production machine manufacturer | 501-1000 | R&D Manager |
| I4 | Safes manufacturer | 101-250 | Manager OPEX and Production Development |
| I5 | Magnet solutions producer | 51-100 | CEO |

**Research and Development**

R&D is the process and efforts within a firm focused on exploring, gaining, and gathering information to expand their knowledge base across various fields such as technology, social sciences, and cultural understanding. It involves research, experiments, and prototype development to use for further exploration within their business (Heij et al., 2019; Miles, 2007). In Table 7, the most relevant quotes of respondents about R&D are presented.

The definition of R&D as given by the interviewees is very similar to that described in the theory. R&D is seen as the process of investing time, energy, money and skills to carry out relevant activities for the company. Efforts aimed at knowledge growth and innovation within the organizations. What is remarkable is that R&D is mainly customer-driven. Feedback or questions from customers often act as the driving force for R&D. This is instead of an internal vision. It is indicated that they also look at R&D from the company's perspective, but this is mainly driven by the customers and the market.

One interviewee describes the R&D process: *"they start with mechanical engineering, followed by 3D printing for prototype development, and finally, the product is milled from one large block of plastic for final production."* This results in the development of new products. It is described that R&D quickly moves on to the development of prototypes and new products.

It is indicated that, R&D is in some companies used as a separate department. R&D is an indirect layer there, where this department is not included in the cost price of products. However, in other companies, there is no separate R&D department. Instead, R&D is integrated

[1] All transcripts are in the additional appendix and can be requested from the researcher or supervisor.

into various functions within the company, which ensures less distance from the operational organization. This means that R&D is often done 'on the side' by employees who already have other primary responsibilities.

**Table 7.** *R&D Interview Statements*

| Ref. | Quote | Code |
|---|---|---|
| I3 | R&D even definiëren, maar dat zijn de mensen die tijd en energie hebben en geld hebben en de vaardigheden om activiteiten die relevant zijn voor het bedrijf te doen | Definition |
| I2 | de klant heeft een veel grotere impact dan dat we echt zelf zeggen | Customer driven |
| I2 | als we terugkoppeling krijgen is dat vaak de aanjager voor verbetering, dat is niet altijd visie. | R&D motivation |
| I4 | Wij kijken ook wel vanuit onszelf maar toch wel met name vanuit de klanten | Mainly customer driven |
| I1 | Dan beginnen we met mechanische engineering, vervolgens wordt het bijvoorbeeld 3D geprint, en daarna wordt het echt gefreesd uit één groot blok kunststof. | R&D process |
| I4 | R&D is bij ons een indirecte schil. Dat betekent dat ze niet direct in de kostprijs zijn meegenomen, maar onze R&D staat wel in heel nauw contact met onze productie. | R&D as an indirect shell |
| I2 | Het is niet zo dat wij een R&D-afdeling hebben die hier continu mee bezig is. | No department |
| I1 | we kijken ook veel naar de collega's, om zo informatie van buitenaf te halen. Kijk, de meeste dingen zijn al bedacht. Het is ook heel vaak toepassen, en kijken naar soortgelijke markten. | Open innovation |

Finally, the concept of open innovation is active among the interviewees. There is collaboration and information is obtained from external parties. They look at what has already been devised in similar markets. This indicates that most things have already been thought of; it is often a matter of applying it and looking at other markets. This allows them to apply existing knowledge and innovations to their own products, which would increase the effectiveness of R&D.

By bringing these different aspects together, a picture of how R&D functions within the companies are integrated emerges. The customer-oriented and open innovation perspective is reflected in all companies interviewed. The differences are mainly in how an R&D department is included within a company, explicitly as a department or as an additional task.

**Product Innovation**

Product Innovation involves the introduction of new or renewed products and services by a company to differentiate itself from the competition in the competitive landscape

(Dougherty, 1992; Bowen et al., 1994). Product Innovation can be either incremental, improving an existing product, or radical, introducing a new product to the industry (Holahan et al., 2013). Product Innovation is also a current topic among the interviewees, as indicated in Table 8.

**Table 8.** *Product Innovation Interview Statements*

| Ref. | Quote | Code |
|---|---|---|
| I4 | je moet op een gegeven moment je productportfolio groot genoeg hebben om de omzet in ieder geval te kunnen handhaven, desnoods het liefst te willen groeien natuurlijk. | Product portfolio growth |
| I1 | Ik denk dat wij nu geen nieuw product ontwikkelen dat we over 5 jaar geen bestaansrecht meer hebben. De markt vraagt continu nieuwe producten, ook door allerlei wetgevingen eisen. En daarom moeten we blijven innoveren, of het nu reinigbaarheid is of er komen gewoon nieuwe producten. | Need continuity |
| I4 | wij zijn onze kluizen steeds een stukje beter aan het maken, en daar zijn wij ook heel goed in. | Incremental Product Innovation |
| I5 | Wij zijn van het incrementeel. En dat is zo gekomen, en ik snap ook wat je wil vragen, maar de organisatie is niet groot genoeg om een soort van quantum leaps te maken. Het is niet zo dat we een groep kunnen opsluiten en aan iets nieuws kunnen laten werken. We worden ook wel geleefd door de waan van de dag, helaas. En we maken eigenlijk incrementele stappen. We doen aan een evolutie, geen revolutie. | Incremental Iroduct Innovation |
| I3 | als je daar een hele grote stap wil nemen, dan kan dat bijna niet want het risico is veel te groot | Barrier for radical product innovation |
| I1 | En dat is ook weer het voordeel van een relatief klein bedrijf. Dat gaat niet over 27 schrijven. Dat gaat heel direct gewoon zo van: zullen we dat gaan aanpassen, dan kunnen we dat product ook op de markt zetten en kunnen we er mee aan de slag. | Barriers for radical Product Innovation |
| I2 | Dus op basis van marktvraag passen wij ons product aan. Dus als die klant aangeeft dat daar een behoefte is, dan gaan we die dikwijls ontwikkelen. | Customer-driven |

The interviewees indicate that Product Innovation is a crucial part of their business strategy. They develop new products and see this as a necessary condition to remain competitive. One interviewee noted that if they do not develop a new product now, they will no longer have a right to exist in 5 years. This could be partly due to the market that continuously demands new products, and also due to all kinds of legislation.

Most Product Innovations within the companies interviewed are incremental. Interviewees describe how their products are continuously improved: *"We are always making our safes a little better"* This shows how companies focus on incremental Product Innovations rather than radical innovations. Radical Product Innovation is seen as too risky. One interviewee stated: *"If you want to take a very big step there, that is almost impossible because the risk is way too high"* This highlights the risks associated with radical Product Innovation, especially for smaller companies with limited resources.

However, the smaller size of companies also offers advantages in the product innovation process. As one interviewee noted, flexibility allows smaller companies to quickly respond to new ideas and market demands, without having to go through extensive procedures. Product Innovation is also strongly driven by customer demand. Customer needs and requests directly influence the direction of product development. A customer-oriented approach ensures that new products and improvements closely match the actual needs of the market, which increases the chance of success and acceptance.

In conclusion, this qualitative analysis shows that incremental and customer-driven Product Innovation play a crucial role in maintaining and strengthening a company's market position. Pisano (1994) described that even low stages of R&D can lead to Product Innovation. Not only the quantitative data, within this study, but also the interviewed respondents support this relationship. The statements that demonstrate this are included in Table 9.

**Table 9.** *R&D Influence on Product Innovation Interview Statements*

| Ref. | Quote | Code |
|---|---|---|
| I1 | Die innovaties zijn altijd nog het gevolg van Research. We gaan niet maar zo innoveren als de markt er niet naar is. Je moet wel echt altijd eerst onderzoek doen. Research doe je altijd eerst. En het wordt ook gedreven door onze klanten. Vaste klanten van ons geven aan: wij gaan die kant op, willen jullie ons daarmee helpen? | Cause-effect |
| I3 | je kan geen productinnovatie doen zonder fatsoenlijke R&D, dat kan gewoon niet. | Dependent |
| I1 | Dat is een op een, zeg maar. | Relation |
| I4 | waarbij de pijl gaat van Research en Development naar Product Innovatie | Relation |
| I5 | Op het moment dat de proof of concept staat, is R&D voor een groot deel gedaan en afgerond en ga ik eigenlijk door naar product en product engineering. | Proof of concept |
| I5 | R&D is gedaan, de techniek is bewezen en het verder verfijnen noem ik eigenlijk een stukje productontwikkeling. | Relation |

Interviewees indicate that Product Innovation is a direct result of R&D. Research first needs to be done before Product Innovations can be made. Another interviewee states that Product Innovation is impossible without decent R&D. A direct relationship between R&D and Product Innovation is described: *"That's one on one, so to speak"* and *"where the arrow goes* *from Research and Development to Product Innovation"*. These quotes illustrate how R&D leads to Product Innovation, where one activity follows after the other.

The R&D process involves developing a proof of concept, after which the focus shifts to product development and refinement. As one interviewee stated: "*Once the proof of concept is ready, R&D has largely been done and completed and I actually move on to product and product engineering"*. This shows that after proving feasibility through R&D, the emphasis shifts to further development and refinement of the product.

R&D and Product Innovation are closely related. R&D forms the basis and first step in the process, while Product Innovation follows successful research and the needs of the market and customers. The relationship between R&D and Product Innovation is clearly emphasized by respondents endorsing the first hypothesis (H1).

**Smart Manufacturing**

Smart Manufacturing represents the collaboration and integration between the Industry 4.0 base technologies and the traditional manufacturing machinery. Smart Manufacturing facilitates an automated and efficient manufacturing process where sensors, robots, data collection, and processing work autonomously. Smart Manufacturing allows autonomous decision-making and an automated process ensuring optimal performance and responsiveness. Smart Manufacturing makes the process more flexible and improves productivity. Smart Manufacturing is a change compared to the traditional work process and requires new capabilities from employees. Table 10 shows the Smart Manufacturing statements of the interviewees.

Smart Manufacturing is an innovative approach to manufacturing that uses advanced technologies to optimize the production process. Interviewee's statements provide detailed insight into the elements and benefits of Smart Manufacturing within their company. Some form of automation is active in all companies. Mainly robots are used, which is part of a partially fully automated production process. *"To illustrate, we have approximately 13 to 14 robots running in production."*, and *"We only use robots, several robots, robot arms and axes with which we place and manipulate things."* The use of robots ensures a reliable production process and reduces human errors. Robots can perform repetitive tasks with high precision and speed.

Another interviewee mentions the integration of CAD/CAM systems. This technology makes it possible to use digital designs in, for example, benches that automate human setup operation with a less cumbersome process from scan design to production. Smart Manufacturing results in higher quality and constant speed in the production process.

**Table 10.** Smart Manufacturing Interview Statements

| Ref. | Quote | Code |
|---|---|---|
| I1 | Volledig automatisch de grondstof uit de stelling halen en het onderdeel wordt geproduceerd, de rest stof wordt afgevoerd, en het onderdeeltje ligt op de werkbank | Fully automatic |
| I4 | Ter beeldvorming we hebben ongeveer 13 tot 14 robots in de productie draaien. | Robots |
| I3 | dat echt alle bewerkingsmachines echt CAD/CAM zijn. Die kunnen met de modellen omgaan om te weten waar ze moeten kanten en afzagen. | CAD/CAM |
| I5 | wij gebruiken alleen robots, een aantal robots, robotarmen en assen waarmee we dingen plaatsen en manipuleren. | Robots |
| I1 | Goede kwaliteit is eigenlijk het belangrijkste de snelheid en snelheid zegt eigenlijk ook alweer iets over de kosten, maar kwaliteit is eigenlijk het belangrijkste. | Higher quality |
| I2 | Die Robot die wordt niet moe dus die loopt op een constant tempo en als die robot loopt dan kan die medewerker eromheen het proces gaan organiseren. | Constant quality/speed |
| I5 | Van mensen worden andere competenties gevraagd en verwacht. … wij hebben letterlijk robotoperators die spullen in de robot moeten produceren, leggen. En ze er ook weer uit moeten halen. Die mensen daar worden echt wel extra competenties van gevraagd. ... Dat vraagt een stukje vertrouwen van mensen in de systemen, en de uitkomst van die systemen. | Influence employees |

Smart Manufacturing also influences the role of employees and the skills expected of them. A respondent indicated: *"Different competencies are required and expected from people. ... we literally have robot operators"* Employees have to learn new skills to be able to use the technologies.

Smart Manufacturing integrates advanced technologies such as robots and CAD/CAM systems to optimize the production process. This results in partly or completely automated processes, increased efficiency, constant production quality, and a more competitive production process. The influence of this on R&D and Product Innovation, according to the interviewee is included in quotes in Table 11.

Smart Manufacturing influences Product Innovation through advanced manufacturing methods, which open up new possibilities and enhance the efficiency of the innovation process. Innovation in the production environment shapes opportunities for product development. As one interviewee indicates: *"The more innovative the production environment in which you outsource, the more innovative you can develop."* This underscores the significance of advanced manufacturing technologies in facilitating innovative product development, illustrating how these techniques create opportunities for Product Innovation possibilities.

**Table 11.** Smart Manufacturing Influence on R&D and/or Product Innovation Interview Statements

| Ref. | Quote | Code |
|---|---|---|
| I1 | hoe innovatiever de productieomgeving is waarin je uitbesteedt, hoe innovatief je ook kunt ontwikkelen. We kunnen hele fancy dingetjes gaan bedenken maar als het niet te maken is dan heeft het ook geen zin. | Production dependent |
| I1 | Met het product innoveren moet je rekening houden met welke fabricagemogelijkheden er zijn en of het überhaupt te produceren is. … We zijn nu bezig met iets dat vroeger uit 5 of 6 onderdelen bestond. Die laten we nu RVS gieten. | New possibilities |
| I5 | Ik heb minder risico op fouten. Laat ik het zo stellen: als ik iemand moet laten werken, dan is er nog altijd een theoretische kans dat er iets fout gaat. Een robot programmeren doe je een keer goed en dan ben je volledig klaar. Een keer programmeren. | Minimize risk |
| I4 | mensen die met Smart Manufacturing werken, dat zijn over het algemeen mensen met een iets hogere opleiding dus dan praat je echt nog wel over een MBO 4, dat zijn echt nog wel capabele mensen om goed naar te kunnen denken en verbanden te kunnen leggen en op die manier is mijn ervaring dat zij op die manier in staat zijn een bijdrage te leveren aan het R&D-proces. | Smart Manufacturing employees |
| I4 | Eerder moesten we echt al een product maken om vervolgens weg te gooien omdat het niet werkte. Is het nu in de digital twin kunnen we kijken of het werkt of niet werkt. Dus wat dat betreft heeft het veel effect op de productinnovatie. | Digital (twin) check |
| I3 | Dus daar is het wel zo dat de bewerkingstechnologie, de printer in dit geval, nieuwe mogelijkheden geeft. | 3d opportunities |
| I2 | Als we investeren in nieuwe machines met hoogwaardige technieken … kunnen we de klant dingen bieden die we nu niet kunnen bieden. | Possibilities of high-quality techniques |

For instance, 3D printing and high-quality processing machines can contribute to Product Innovation. One interviewee indicated: *"So it is true that the processing technology, the printer in this case, offers new possibilities."* and: *"If we invest in new machines with high-quality techniques... we can offer the customer things that we cannot offer at the moment."* This emphasizes how advanced technologies enable innovations that were previously unrealizable. Particularly with modern techniques like 3D metal printing or metal casting, not just an average modern lathes.

Specifically, the influence on the relationship between R&D and Product Innovation, for example, the Digital Twin, can have a positive influence on Product Innovation process. A respondent notes: *"Earlier we really had to make a product and then throw it away because it didn't work. Now that it is in the digital twin, we can see whether it works or not."* This makes the innovation process more efficient.

Smart Manufacturing opens up new possibilities for R&D through advanced manufacturing technologies and digital simulations. This allows R&D teams to explore and develop innovative product concepts that were previously not feasible, which seems to support hypothesis 2.

Smart Manufacturing influences both Product Innovation and the relationship between R&D and Product Innovation. It offers new possibilities, reduces risks, and improves the efficiency of the innovation process, resulting in a more streamlined R&D and/or Product Innovation process. Finally, employees hired for or trained in Smart Manufacturing contribute to Product Innovation, supporting hypothesis 4. This employee perspective overlaps with Smart Working, suggesting a potential synergy effect.

**Smart Working**

Smart Working represents the evolution in work, adopting and making use of the new cultures and technologies that arise. Smart Working emphasizes flexibility, collaboration, and innovation among employees (Badnár & Welch, 2019). Smart Working facilitates employees to work agile, dynamic, and emergent. This results in a more an increased flexible manufacturing process and motivating learning process for employees resulting in a business and employee benefit (Bednár & Welch, 2019). The Statements about Smart Working of the respondents are included in Table 12.

Keeping work interesting and motivating is essential for employee satisfaction and is what Smart Working is all about. Respondents explain that variety, and providing responsibility is the key to keeping work interesting and keeping employees involved in their work.

The extent to which Smart Working plays a role among respondents varies. In some cases, it is not relevant or is limited to digital techniques that could support Smart Working by providing more insight. Some also deploy production employees in working groups, for example, to come up with new ideas.

Other respondents describe that they go further within their company by using a skill matrix or capability matrix to manage and develop the skills of employees. An attempt is made to encourage people to work in challenging roles across multiple areas. This results in motivated employees and enhanced production flexibility. The matrices provide an overview of employees' skills and workplaces, stimulating them to broaden their competencies and further develop. A respondent also talked about a platform for innovation and ideas from employees. With more involvement, motivation, and feeling about the product by employees. Giving employees a voice and taking their ideas seriously increases their involvement and motivation.

**Table 12.** Smart Working Interview Statements

| Ref. | Quote | Code |
|---|---|---|
| I5 | puur afwisseling, motivatie, het interessant houden van je werk. Het terugduwen van verantwoordelijkheden in de organisatie. Dat ze niet voor elke vloek en zucht toestemming hoeven vragen. | Keep work interesting |
| I3 | En je ziet nu geen enkele tekening meer in de fabriek, geen een. We laten nu zoveel mogelijk model based doen. | Digital/model-based |
| I4 | wij hebben ook een soort skill matrix gemaakt. Dat is eigenlijk een tabel met alle namen en alle werkplekken en daarmee proberen wij de mensen te stimuleren om op meerdere plekken goed te scoren. … doordat het overzichtelijk en inzichtelijk is, merken wij dat mensen van nature al meer motivatie hebben om ook op andere plekken te leren. | Skill matrix |
| I5 | wij proberen eigenlijk door een stukje skill-ontwikkeling. Dat is een capability matrix die we binnen de organisatie hebben opgericht, mensen te scholen die het inzicht hebben om multifunctioneel te werken. | Skill- development |
| I5 | Er is meer betrokkenheid, meer motivatie, meer betrokkenheid bij het product. Meer betrokkenheid bij de klant. Maar ook mensen een podium geven om hun eigen ideeën te opperen. | Innovation podium |
| I4 | maar het heeft te maken met de mensen inzicht geven. Zorgen dat mensen zich flexibel in kunnen zetten en ook dat het over de hele breedte verbetert. | Provide insight |
| I4 | dat wij mensen minimaal op 3 tot 5 plekken inzetbaar maken. Daardoor hebben wij die flexibiliteit in de productie echt wel verhoogd. | Flexible line production |

Smart Working combines digital transformation, autonomy, skills development, and flexible employability to create a more efficient and engaged work environment. This leads to increased motivation, better product quality, and improved customer focus. The influence of Smart Working on R&D and Product Innovation was also discussed with the interviewee. The most relevant quotes about this relationship are included in Table 13.

**Table 13.** Smart Working Influence on R&D and/or Product Innovation Interview Statements

| Ref. | Quote | Code |
|---|---|---|
| I1 | Hoe inzichtelijker je het maakt, hoe meer mensen gaan meedenken en hoe meer draagvlak je hebt. | Contribution commitment |
| ID | Dat komt heel vaak echt uit de vloer. Zij bouwen dit elke dag. | From the workplace |
| I4 | Door Smart Working zien we dat ze door de fouten die ze maken, de volgende dag ook zelf tegenkomen als ze op een andere werkplek staan. … Vervolgens hebben die mensen later wel een oplossing hoe het verbeterd kan worden. | Flexible line production increasing insight |
| I3 | die afstand is nog hetzelfde. De fabriek is nog steeds de fabriek. En die staat vrij ver af van productinnovatie | Distance innovation and factory |
| I4 | In dat daily management koppelen ze dat terug. Dan geven ze aan: ik heb gisteren daar gewerkt en vandaag werk ik hier, ik merk daar een probleem | Daily management feedback |
| I5 | Het zit dichter bij productinnovatie denk ik | Influence |
| I5 | als Pietje die het idee bedacht heeft met de engineer kan sparren is dat gewoon slimmer, handiger en leuker voor beide partijen. | Influence employee |
| I4 | Dus een pijltje van Smart Working op Product Innovatie. En waarom ik dat zeg is omdat Product Innovatie nog wel iets concreter is. Dus je hebt al een product en de mensen vanuit de productievloer die weten wat dat inhoudt. | Incremental Product Innovation |

Smart Working increases the involvement and support among employees for Product Innovation. As one respondent notes: *"The more comprehensible you make it, the more people will start thinking along and the more support you will have"* This insight ensures that employees support the innovation process.

Innovations can also come from the practical experience of the employees: *"That often really comes out of the manufacturing floor. They build this every day"*. This approach promotes a culture of improvement and innovation in the workplace. This flexibility allows employees to share their experiences and insights and contribute to product improvements.

Smart Working facilitates direct involvement of employees in Product Innovation: *"If Pietje, who came up with the idea, can spar with the engineer; it is simply smarter, more convenient and more fun for both parties"* This shows that direct interaction between production floor and engineers not only improves efficiency, but also ensures higher motivation. However, this does not necessarily apply to all companies. Another respondent, from the largest company interviewed, indicated that there has been no change in their contribution: *"That distance is still the same. The factory is still the factory. And that is quite far removed from Product Innovation"*.

Finally, at companies where Smart Working efficiently plays a role, interviewees indicate an impact on (Incremental) Product Innovation: *"So an arrow from Smart Working to*

*Product Innovation. And why I say that is because Product Innovation is a bit more concrete. So you already have a product and the people on the production floor who know what that means."* The practical knowledge and experience of employees contribute to the refinement and improvement of existing products. Which they can achieve with encouragement, thanks to the tools that Smart Working offers.

Smart Working seems to play a role in facilitating Product Innovation by increasing employee involvement and input. In particular, the direct influence (hypothesis 5) seems to be suggested by direct incremental Product Innovations proposed by employees. The indication that it paves the way or makes more possible for R&D is not perceived (hypothesis 3). It seems to depend on the relationships between production employees and engineering departments; the extent to which Smart Working is embedded in the organization and suggestions are facilitated and supported.

**Additional quotes**

The interviews also included the following additional quotes that were not directly used in the connections but could still be interesting. The size of a company seems to influence the agility of Product Innovation. In addition, there is also frequent talk about collaborations, mainly with universities. Finally, the vision of investors also seems to influence R&D activities. The additional quotes are included in the Table 14.

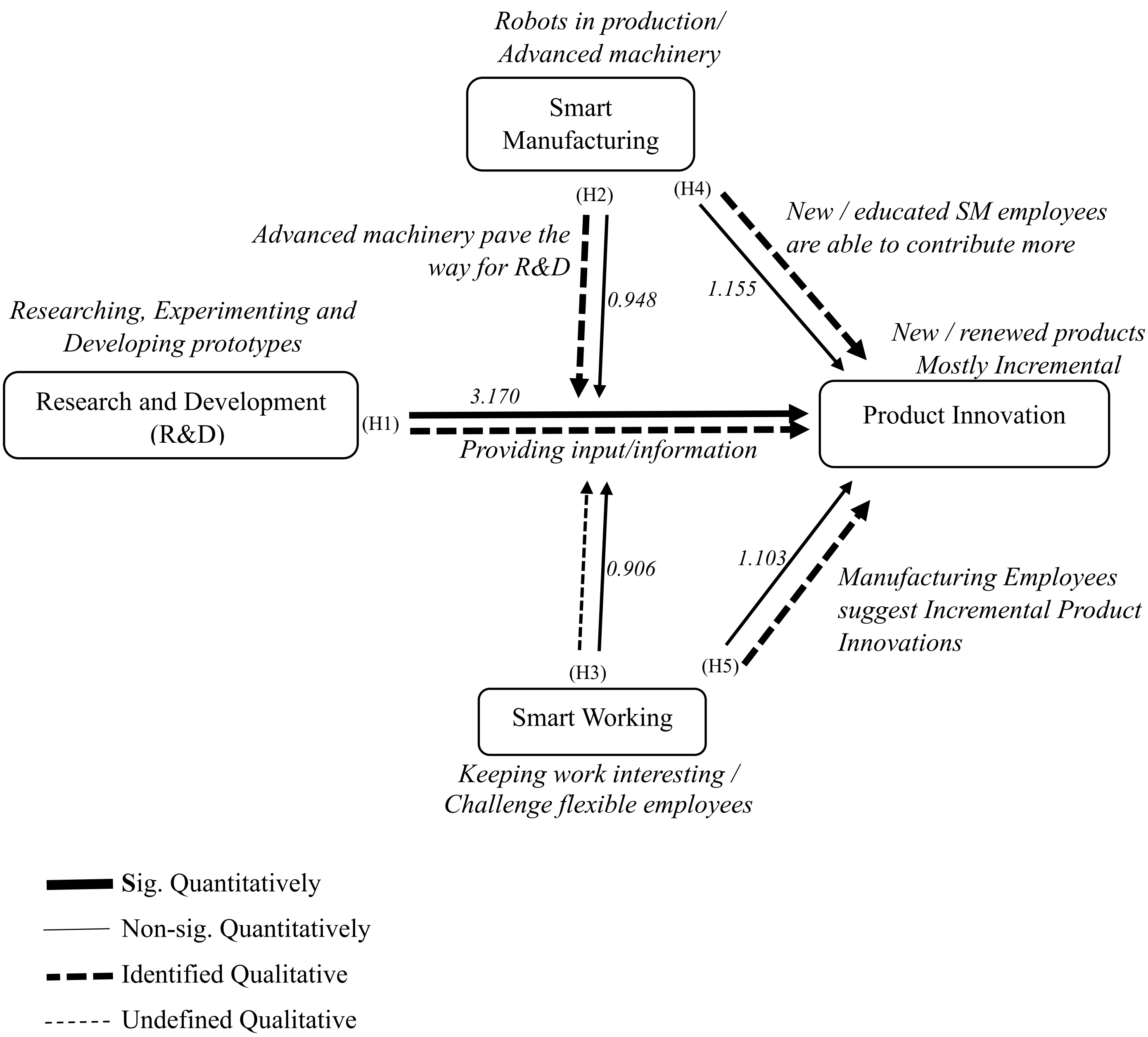
**Table 14.** *Additional quotes*

| Ref. | Quote | Code |
|---|---|---|
| I1 | omdat we kleine of kleinere spelers zijn. Zo kunnen wij snel schakelen en beter inspelen op de wensen van de klant | Small and agile |
| I1 | Als je iets nieuws ontwikkelt en je doet dat stiekem, dan krijg je het niet verkocht, intern niet en ook niet bij klanten. Je moet het transparant houden. | Create support |
| I1 | De winst in de kosten kun je het meeste halen door slim te engineeren. Dingetjes weg te laten of dingentjes anders te engineeren. | Smart Engineering |
| I3 | Als we het nodig vinden benaderen we diegene die wij nodig hebben. En dat kan Universiteit Wageningen zijn of de Technische Universiteit Eindhoven zijn. | University collaborations |
| I4 | De nieuwe aandeelhouders heel erg korte termijn gedreven zijn en daardoor sneller vraagtekens zetten bij R&D-activiteiten | Private equity |
| I5 | We hebben ook samenwerkingen met de TU Twente en Radboud Universiteit. | Collaborations |
| I5 | de TU toch een autonome body is die ons kan voorzien van een second opinion, een onafhankelijke beoordeling. | University collaborations |

### 4.3 Graphical representation of the quantitative and qualitative results

To make the conceptual model with results more transparent, a graphical representation of the various quantitative and qualitative findings has been created. The solid lines represent the quantitative relations and the dotted lines the qualitative ones. The thickness of the line is also important. For the quantitative, this indicates whether it is significant or not. For the qualitative, it represents identified relations and undefined relations. The graphically represented model is shown in Figure 2. The quantitative odds ratios and qualitative keywords retrieved are also shown to provide an overarching picture.

**Figure 2.** *Graphical representation of the quantitative and qualitative results*



# 5. Conclusion and Discussion

Within this research the following question consisted of the foundation: *'Do Smart Manufacturing and Smart Working have a moderating effect on the relation between R&D on Product Innovation within manufacturing firms, and how are these relationships organized by the (SME) manufacturers?'*. This question arose because while some research suggests that Smart Manufacturing and Smart Working can increase efficiency, flexibility, and overall innovation capacity, other research indicates that these technologies could lead to more generic business processes, potentially reducing unique competitive advantages. clarification was the aim of this research, which used quantitative data from the EMS survey and qualitative interviews were held with 5 manufacturing companies.

The quantitative analysis has shown us that there is only a significant direct positive relationship between R&D and Product Innovation. The Logistic Regression analysis has shown that as soon as a company does R&D, the Chance of Product Innovation increases by a factor of 3.161. The other hypothesis in which the influence of Smart Manufacturing and Smart Working was tested on this relationship and directly on Product Innovation, did not show any significant results. Nevertheless, the interviewees were able to endorse the positive influences of the Smart techniques and we saw a positive odds ratio of the Smart techniques, but these are not significant and we cannot accept the relationship generically for the entire population. All interviewees were also able to endorse the significant relationship that R&D leads to more Product Innovation as also shown in the quantitative analysis. It has been described by the interviewees in line with the theory of R&D as the basis for well-founded Product Innovation.

## 5.1 Discussion and Implications

Although four of the five hypotheses cannot be accepted, the qualitative analysis provides valuable context and insights into the hypothesized relationships from both theoretical and practical perspectives.

Theoretically, Smart Manufacturing appears to increase R&D capacity for Product Innovation through techniques such as Metal 3D printing and digital simulations. These technologies smooth the innovation process and expand the possibilities for Product Innovation. This aligns with the pillars of Kusiak (2017) about the enhancement of new machinery and data enrichment to improve decision-making.

Smart Working can lead to incremental Product Innovation by leveraging employees' interactions with the production process. These companies also stimulate feedback from manufacturing employees, overlapping with the theory described by Bednar and Welch (2019). However, the effectiveness depends on how well Smart Working is integrated into the company's processes and culture. Leonard-Barton (1992) emphasizes that the effectiveness of these technologies depends on how well they are integrated within the company. The anchoring of Swart Working within the company is crucial for the Product Innovation process. If the factory continues to be regarded as 'the factory', the Smart Working process will not reach its full potential. The EMS Survey indicates limited reward systems for employee-driven innovations, This shows that Smart Working is still underrated, as also noted by Frank et al. (2019).

The regression analysis showed that, although these influences cannot be generalized due to their non-significance, the odds ratios for Smart Manufacturing (1.155) and Smart Working (1.103) suggest these concepts influence Product Innovation. Follow-up research with a larger data set may further investigate and demonstrate this. There also appears to be a split in the type of Product Innovation (radical versus incremental) according to Holahan et al. (2013) and the different dependent variables in this study. Although these differences have not been investigated, it is a recommendation for future research.

The combination of Smart Manufacturing and Smart Working appears to create a synergy effect, contributing to Product Innovation to the fullest. This synergy was outside the scope of this research but could be a focus for further research.

The research also provides practical insight into how the concepts are applied. All the interviewed companies have some degree of automation, mainly with robots. Technologies such as 3D metal printing make it possible for R&D to develop products that they were not able to produce before. Digital twins facilitate digital prototyping, making the innovation process more efficient and faster. Consistency in quality, described by all interviewees, is a benefit of automated machines.

Companies that have implemented Smart Working appear to use skills matrices to stimulate and broaden employee capabilities, resulting in more engaged employees and flexible operations. The skill matrices provide insight into employees' performance across different places of the production line, encouraging employees to score well in many places resulting in a more motivated employee. Who also sees more than his/her fixed place and this broader product knowledge would have a positive effect on feedback towards Product Innovation. Digital screens in the workshop on which these individual and team performances are presented provide both mutual competition and collaboration, as only team performance is assessed at the end of the day.

The interviewed companies generally avoid radical Product Innovations due to high risks. For SMEs, a large portion of resources are put at risk if they have to present a radically different product. This is often avoided and suits the character of an SME, according to an interviewee. While Smart Manufacturing and Smart Working seem to drive Product Innovations, the implementation may require radical process changes that companies are reluctant to implement. Larger companies such as ASML are known for their groundbreaking innovations. Although it was outside the scope of this research, signals emerged that the interviewed SMEs also collaborate with other companies and universities, which may also contribute to more innovative Product Innovations. Further research is needed to conclude this.

### 5.2. Limitations, Implications, and Ethical Considerations

The multi-method approach used has provided an overarching view of the concepts improving validity and reliability. However, it is important to note that the Hosmer and Lemeshow Test, based on the quantitative analysis, presents a significant output indicating a lack of fit. Also, qualitative insights into the relationships were provided. It should be noted that only 5 interviews were conducted with a wide variation in the type of manufacturing companies; therefore, no saturation was achieved. This note, that the results are not generalizable, is important to notice when interpreting the results. Also, only one representative from each company was interviewed. Which may not provide a comprehensive view of the concepts discussed. Since the interview are guided by a (theory-based) script, omitted factors can influence the relationships. To prevent this, respondents were also asked for additions, contributing to the validity of the study. It is also important to note that this research does not aim to establish causal relationships between Smart Manufacturing, Smart Working, R&D, and Product Innovation. The aim is to explore the influences of these Industry 4.0 techniques on the relationship between R&D and Product Innovation

Ethical aspects were taken into account throughout the entire process. For the quantitative research, respondents of the EMS survey were informed that the EMS survey would be used for third-party research such as this one. The respondents have been informed of this by the EMS representatives (APA, n.d.; Smith, n.d.). Potential interviewees for the qualitative analysis were approached respectfully, and rejection was handled professionally. For those interviewed, their anonymity has been and will continue to be guaranteed that no sensitive information is unintentionally presented (Smith, n.d.). For all forms of literature used within this research, a thorough authorial reference has been provided to give the author the correct appreciation for their work (Smith, n.d.). This not only gives the correct credentials to the authors but also makes the research more representative given that the origin of the data is described in this way (APA, n.d.). This thesis's text, relationships, and insights come from the author or referenced sources. AI in any form is only used in limited form as a sparring partner but has never served as direct or leading input in any form within this research. In addition, grammar checker Grammarly was used with possible forms of AI in it.

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# Appendix

## Appendix A - Interview Script

| |
|---|
| Mijn naam is X, student aan de Radboud Universiteit; Doel van dit interview is inzicht krijgen in de thema's R&D en Product Innovatie voor mijn master scriptie.<br>Mag ik dit interview opnemen; alleen voor transcriptie, geheel anoniem en niet identificeerbaar rapporteren (bv machinebedrijf X)?<br>Het gesprek zal ongeveer een uur duren. Heeft u vragen vooraf? |
| **Wie bent u en wat is uw rol binnen het bedrijf?**<br>(functie, ervaring algemeen, binnen bedrijf) |
| **Wat voor bedrijf is het?**<br>(Grootte, hoofdproduct(en)? Aanvullende diensten? Bedrijfstak?) |
| **Ondernemingsstrategie: Wat probeert uw bedrijf vooral te bereiken in de komende 5 jaar? Binnen welke markt(en) opereert uw bedrijf vooral?**<br>(Welke kernactiviteiten worden uitgevoerd, wat onderscheidt bedrijf van andere bedrijven?) |
| **Op welke manieren bent u betrokken bij innovatie activiteiten in uw bedrijf ?**<br>(Productie? Productontwikkeling? Innovatiestrategie? Focus op werkzaamheden/ activiteiten?) |
| |
| **We beginnen het interview door Research en Development binnen uw bedrijf te bespreken. Onder R&D of Onderzoek en Ontwikkeling worden activiteiten verstaan die een organisatie onderneemt om nieuwe informatie te vergaren en deze toe te passen voor de verdere groei en/of exploratie van het bedrijf.** |
| **Welke R&D activiteiten worden er uitgevoerd binnen uw bedrijf?**<br>(Eigen onderzoek & ontwikkeling? Welke functies/ afdelingen zijn op welke manier bij betrokken? Externe partijen?) |
| **Hoe zou u de resultaten van R&D binnen uw bedrijf omschrijven?**<br>(Invloed op process/ product ) |
| **Zijn er samenwerkingen met andere partijen voor R&D?** (Resultaten, wat voor partijen, (Concurrenten, consultants, universiteiten?) |
| |

| |
|---|
| **We vervolgen het interview met het onderwerp Product Innovatie. Het gaat om het proces waarbij een bedrijf nieuwe of verbeterde producten ontwikkelt en deze op de markt brengt.** |
| **Op welke manieren speelt product innovatie bij uw bedrijf?** (innovatie? worden (Producten verbeterd? Worden er nieuwe producten ontwikkeld?) |
| **Betreft het incrementele product innovatie (innovatie van oorspronkelijke product), radicale product innovatie (een geheel nieuw product op de markt zetten) of allebei? En hoe komen deze tot stand?**<br>(Bestaand product/ nieuw product/ nieuw voor het bedrijf/ nieuw voor de industrie. Eigen R&D? Welke functies/ afdelingen zijn op welke manier bij betrokken? Externe partijen, consultants (hoe, waarom)?) |
| **Wat is de invloed van R&D op Product Innovatie?**<br>(Hoe ziet u de relatie, positief/negatief, hoe, waarom?) |
| |
| **Dan gaan we het nu over Smart Working hebben; onder smart working valt het aanwakkeren van aspecten zoals flexibiliteit, vaardighedenverbetering en samenwerking van en tussen de medewerkers.** Het gaat om het optimaliseren van de manier waarop mensen binnen het productieproces werken door middel van zowel digitale technologieën als niet-technologische benaderingen, zoals het bevorderen van een flexibele werkcultuur en het stimuleren van samenwerking tussen medewerkers. |
| **Wordt er en zo ja op welke manier wordt er Smart Working ingezet en aangeboden in uw bedrijf?**<br>Flexibele werktijden? Digitale platforms voor samenwerking? Methode om Vaardigheden van medewerkers te verbeteren? Medewerkers aan te wakkeren mee te denken aan innovaties? Uit te dagen meer te leren? (Eventueel technieken met? Bijvoorbeeld: Augmented reality (AR), Collaborative robots (CR), Virtual reality (VR), Wearable devices (WD), Environment and machine sensors (SENS), Automation (AUT), Voice-enabled assistant (VEA), Digital Twin (DT), Smart decision support systems (SDSS), Automated Guided Vehicle (AGV), Computer Vision (CV), Industrial social networks (ISN), Exoskeletons (EXO), Visual Analytics (VA), and Artificial intelligence (AI)) |

| |
|---|
| **Wat is de invloed van deze Smart Working* op uw bedrijf?**<br>(Positief/ negatief? Invloed op de werknemers, efficiënter werken, afstemming betrokken partijen, veranderingen in het werk zelf?)<br>**benoemde Smart Working aspecten van respondent* |
| **Op welke manier beïnvloed Smart Working* Product Innovatie?** (Positief/Negatief? Geeft het medewerkers meer ruimte, wordt innovatie meer gestimuleerd, leren medewerkers meer over, zijn ze meer gemotiveerd of juist niet?)<br>**benoemde Smart Working aspecten van respondent* |
| **Op welke manier beïnvloed Smart Working* de relatie die R&D op product innovatie heeft?** (Denken medewerkers meer mee met R&D/ zijn ze flexibelere in aanpassingen van hun werk? Heeft het nadelige effecten?)<br>**benoemde Smart Working aspecten van respondent* |
| |
| **Tot slot gaan we het hebben over Smart Manufacturing;** Optimaliseren van productieprocessen met technologieën zoals IoT, AI en robotica, gericht op automatisering, data-driven besluitvorming en interconnectiviteit tussen machines en processen. |
| **Worden er Smart Manufacturing technieken ingezet in uw bedrijf?**<br>(Het gaat hierbij om volledig geautomatiseerde productie process onderdelen. Welke technieken/ afdelingen en op welke manier?) |
| **Wat is de invloed van deze Smart Manufacturing technieken op uw bedrijf?**<br>(Invloed op de werknemers, efficiënter werken, minder afval, veranderingen in het werk zelf?) |
| **Op welke manier Beinvloed Smart Working* Product Innovatie?** (geeft het medewerkers meer ruimte, worden de producten unieker of meer generiek?)<br>**benoemde Smart Manufacturing technieken van respondent* |
| **Op welke manier beïnvloed Smart Manufacturing* de relatie die R&D op product innovatie heeft?** (denken medewerkers meer mee met R&D/ zijn ze flexibelere in aanpassingen van hun werk?)<br>**benoemde Smart Manufacturing technieken van respondent* |
| Vriendelijk bedankt!<br>Afspraken herhalen en bevestigen (anonimiteit)<br>Ontvangen van eindverslag ? |

**Appendix B – Quantitative Descriptive Analysis**

**Appendix B.1 - Frequency Table** firm size

| | | Size number of employees 2021 | lnSize number of employees 2017 (log) |
|---|---|---|---|
| N | Valid | 186 | 186 |
| | Missing | 0 | 0 |
| Mean | | 246,8871 | 3,9287 |
| Std. Error of Mean | | 161,13299 | ,07871 |
| Median | | 45,0000 | 3,8067 |
| Mode | | 25,00[a] | 3,22[a] |
| Std. Deviation | | 2197,56097 | 1,07349 |
| Variance | | 4829274,198 | 1,152 |
| Skewness | | 13,561 | 1,535 |
| Std. Error of Skewness | | ,178 | ,178 |
| Kurtosis | | 184,571 | 6,090 |
| Std. Error of Kurtosis | | ,355 | ,355 |
| Range | | 29990,00 | 8,01 |
| Minimum | | 10,00 | 2,30 |
| Maximum | | 30000,00 | 10,31 |
| Sum | | 45921,00 | 730,74 |

**Appendix B.2 - Frequency Table Sectors**

*Statistics*

| | | Metal | Food | Textile | Construction |
|---|---|---|---|---|---|
| N | Valid | 186 | 186 | 186 | 186 |
| | Missing | 0 | 0 | 0 | 0 |
| Sum | | 49,00 | 14,00 | 30,00 | 8,00 |

*Statistics*

| | | Chemical | Machinery | Electronic |
|---|---|---|---|---|
| N | Valid | 186 | 186 | 186 |

| | | | | |
|---|---|---|---|---|
| | Missing | 0 | 0 | 0 |
| Sum | | 38,00 | 35,00 | 12,00 |

a. Multiple modes exist. The smallest value is shown

**Appendix B.3** – Frequency Table R&D
*dRD performing research and development (R&D) or award R&D contracts to external partners in 2021*

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | ,00 no | 98 | 52,7 | 52,7 | 52,7 |
| | 1,00 yes | 88 | 47,3 | 47,3 | 100,0 |
| | Total | 186 | 100,0 | 100,0 | |

**Appendix B.4** – Frequency Table Product Innovation
*ProductInnovation*

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | ,00 | 96 | 51,6 | 51,6 | 51,6 |
| | 1,00 | 90 | 48,4 | 48,4 | 100,0 |
| | Total | 186 | 100,0 | 100,0 | |

**Appendix C – Measurement models**
**Appendix C.1** - Frequency Table Smart Working Indicators
*Statistics*

| | | oi_ChangeOverTime Organizational concepts - Fixed process flows to reduce setup time or optimize change-over time | oi_WorkInstruction Organizational concepts - Standardized and detailed work instructions | oi_DisplayBoards Organizational concepts - Display boards in production to illustrate work processes and work status |
|---|---|---|---|---|
| N | Valid | 186 | 186 | 186 |
| | Missing | 0 | 0 | 0 |
| Sum | | 52,00 | 91,00 | 86,00 |

*Statistics*

| | | oi_QualityMeasures Organizational concepts - Methods of assuring quality in production | oi_EmployeeInnovation Organizational concepts - Employee involvement in innovation development | oi_EmployeeBonus Organizational concepts - Employee bonus systems in production |
|---|---|---|---|---|
| N | Valid | 186 | 186 | 186 |
| | Missing | 0 | 0 | 0 |
| Sum | | 136,00 | 112,00 | 55,00 |

*Statistics*

| | | oi_CertifiedEnvironmentMS Organizational concepts - Certified environmental management system | oi_CertifiedEnergyMS Organizational concepts - Certified energy management system |
|---|---|---|---|
| N | Valid | 186 | 186 |
| | Missing | 0 | 0 |
| Sum | | 60,00 | 18,00 |

**Appendix C.2** – Reliability Analysis Smart Working

*Reliability Statistics*

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

**Appendix C.3** – Frequency Table Smart Manufacturing Indicators

*Statistics*

| | | ti_MobileDev Technology - Mobile/wireless devices for programming and operation | ti_DigSolutions Technology - Digital solutions for providing drawings, work schedules or work instructions directly on the shopfloor | ti_ProdPlanning Technology - Software for production planning and scheduling |
|---|---|---|---|---|
| N | Valid | 186 | 186 | 186 |
| | Missing | 0 | 0 | 0 |
| Sum | | 70,00 | 94,00 | 118,00 |

*Statistics*

| | | ti_IntLogistics Technology - Systems for automation and management of internal logistics | ti_DigExchange Technology - Digital Exchange of product/process data with suppliers / customers | ti_PLCsystems Technology - Product-Lifecycle-Management-System |
|---|---|---|---|---|
| N | Valid | 186 | 186 | 186 |
| | Missing | 0 | 0 | 0 |
| Sum | | 55,00 | 62,00 | 30,00 |

*Statistics*

| | | ti_RealtimeControl Technology - Near real-time production control system | ti_manuRobots Technology - Industrial robots for manufacturing processes | ti_handRobots Technology - Industrial robots for handling processes |
|---|---|---|---|---|
| N | Valid | 186 | 186 | 186 |
| | Missing | 0 | 0 | 0 |
| Sum | | 45,00 | 42,00 | 51,00 |

*Statistics*

| | | ti_3Dprototype Technology - Additive manufacturing 3D for prototyping | ti_3Dprint Technology - Additive manufacturing 3D for products components etc | ti_softProdDesign Technology - Software for product design simulation |
|---|---|---|---|---|
| N | Valid | 186 | 186 | 186 |
| | Missing | 0 | 0 | 0 |
| Sum | | 41,00 | 29,00 | 52,00 |

*Statistics*

| | | ti_softAdvComp Technology - Software for advanced computations, data analysis High-Performance Edge computing | ti_softProcess Technology - Software for simulating production processes |
|---|---|---|---|
| N | Valid | 186 | 186 |
| | Missing | 0 | 0 |
| Sum | | 28,00 | 20,00 |

**Appendix C.4** – Reliability Analysis Smart Manufacturing

*Reliability Statistics*

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

**Appendix D** - Model Fit Logistic Regression Analysis

*Omnibus Tests of Model Coefficients*

| | | Chi-square | df | Sig. |
|---|---|---|---|---|
| Step 1 | Step | ,387 | 1 | ,534 |
| | Block | ,387 | 1 | ,534 |
| | Model | 45,002 | 12 | ,000 |

*Model Summary*

| Step | -2 Log likelihood | Cox & Snell R Square | Nagelkerke R Square |
|---|---|---|---|
| 1 | 212,655[a] | ,215 | ,287 |

*Hosmer and Lemeshow Test*

| Step | Chi-square | df | Sig. |
|---|---|---|---|
| 1 | 22,701 | 8 | ,004 |

*Contingency Table for Hosmer and Lemeshow Test*

| | | ProductInnovation = ,00 | | ProductInnovation = 1,00 | | |
|---|---|---|---|---|---|---|
| | | Observed | Expected | Observed | Expected | Total |
| Step 1 | 1 | 16 | 16,997 | 3 | 2,003 | 19 |
| | 2 | 13 | 15,296 | 6 | 3,704 | 19 |
| | 3 | 15 | 13,567 | 4 | 5,433 | 19 |
| | 4 | 15 | 11,704 | 4 | 7,296 | 19 |
| | 5 | 14 | 10,316 | 5 | 8,684 | 19 |
| | 6 | 5 | 8,822 | 14 | 10,178 | 19 |
| | 7 | 7 | 6,921 | 12 | 12,079 | 19 |
| | 8 | 2 | 5,578 | 17 | 13,422 | 19 |
| | 9 | 9 | 4,583 | 10 | 14,417 | 19 |
| | 10 | 0 | 2,215 | 15 | 12,785 | 15 |

*Classification Table*[a]

| | | | Predicted | | |
|---|---|---|---|---|---|
| | | | ProductInnovation | | |
| | Observed | | ,00 | 1,00 | Percentage Correct |
| Step 1 | ProductInnovation | ,00 | 75 | 21 | 78,1 |
| | | 1,00 | 23 | 67 | 74,4 |
| | Overall Percentage | | | | 76,3 |

a. The cut value is ,500

**Appendix E -** Logistic Regression Analysis

*Variables in the Equation*

| | | B | S.E. | Wald |
|---|---|---|---|---|
| Step 1[a] | number of employees 2017 (log) | ,106 | ,180 | ,351 |
| | Industry sector | | | 17,382 |
| | Industry sector(1) | ,749 | ,712 | 1,108 |
| | Industry sector(2) | ,920 | ,536 | 2,948 |
| | Industry sector(3) | -1,091 | 1,151 | ,898 |
| | Industry sector(4) | 1,602 | ,543 | 8,706 |
| | Industry sector(5) | 1,283 | ,504 | 6,484 |
| | Industry sector(6) | 2,247 | ,800 | 7,881 |
| | index of innovative practices in process organization used | ,098 | ,117 | ,697 |
| | index of digitalization process innovations used | ,144 | ,119 | 1,478 |
| | performing research and development (R&D) or award R&D contracts to external partners in 2021(1) | 1,154 | ,354 | 10,653 |
| | i_cDiPoXdRD | -,053 | ,153 | ,120 |
| | i_cProOrgXdRD | -,099 | ,158 | ,388 |
| | Constant | -2,967 | ,847 | 12,264 |

*Variables in the Equation*

| | | df | Sig. | Exp(B) |
|---|---|---|---|---|
| Step 1[a] | number of employees 2017 (log) | 1 | ,554 | 1,112 |
| | Industry sector | 6 | ,008 | |
| | Industry sector(1) | 1 | ,293 | 2,116 |
| | Industry sector(2) | 1 | ,086 | 2,510 |
| | Industry sector(3) | 1 | ,343 | ,336 |
| | Industry sector(4) | 1 | ,003 | 4,965 |
| | Industry sector(5) | 1 | ,011 | 3,608 |
| | Industry sector(6) | 1 | ,005 | 9,462 |
| | index of innovative practices in process organization used | 1 | ,404 | 1,103 |
| | index of digitalization process innovations used | 1 | ,224 | 1,155 |
| | performing research and development (R&D) or award R&D contracts to external partners in 2021(1) | 1 | ,001 | 3,170 |
| | i_cDiPoXdRD | 1 | ,729 | ,948 |
| | i_cProOrgXdRD | 1 | ,534 | ,906 |
| | Constant | 1 | ,000 | ,051 |

a. Variable(s) entered on step 1: i_cProOrgXdRD.