Reasons for investment holdback in robot arm solutions at medium-sized organizations in the food industry.

Gilian Buis 2209241

University of Twente

Faculty Behavioural, Management and Social science

Program Master thesis Business Administration

Track Strategic Management and Digital Business

Examiners

Dr. A.B.J.M. Wijnhoven

Dr. R.P.A. Loohuis

UNIVERSITY OF TWENTE.

Abstract

Purpose and relevance - This qualitative study investigates the reasons that cause investment holdback in robot arm solutions at medium-sized organizations in the food industry. This study contributes to the literature on technology readiness levels, the Technology Acceptance Model (TAM), innovation in the food industry and robot arm solutions by providing information regarding the penetration into the market and integration into production processes of robot arm solutions.

Design - This study is based on semi-structured interviews (N=12) and one case study.

Results and contributions - The main reason for investment holdback is the misfit of robot arm solutions in the current production processes and production lines. Not working in-line, product and process diversity and the disability of robot arms to work in the production lines in this industry cause this misfit. Additionally, the combination of the critical functions of robot arm solutions and the products in this industry result in investment holdback. This study extends the technology readiness level literature by specifying on robot arm solutions in the food industry and by linking the technology readiness levels to investment plans and processes. Another contribution is the extending of the TAM literature by combining and relating the factors of the TAM model with the challenges of market penetration, production integration and investment decision making of robot arm solutions in the food industry. This study also has practical implications. Firstly, this study can function as guidance for potential investments in robot arm solutions in the food industry since this study discovered several challenges and solutions in the technology readiness levels. All levels are considered in this study. Secondly, this study can be useful for organizations regarding creating acceptance of robot arm solutions among production workers and technical staff.

Keywords - robot arm solutions, food industry, investment process, technology readiness levels, TAM model.

Acknowledgement

The end of the program business administration with track strategic management and digital business has arrived. This master's program provided me with new knowledge in the fields of smart industry, business-to-business marketing, entrepreneurship and innovation. Moreover, the master program helped me to work by myself as well as in teams and create new insights and ways of thinking, which I think will be useful throughout my upcoming career.

I would like to thank my examiner Dr. A.B.J.M. Wijnhoven, for his coaching, providing new insights, guidance and providing me with feedback throughout my master thesis period and for the willingness to examine this master thesis. Additionally, I would like to thank Dr. R.P.A. Loohuis for providing me with feedback on my thesis and for the willingness to examine this master thesis.

Gilian Buis – 2209241

11th of June, 2020.

Table of contents

1. Introduction

Over 200 years ago, the first industrial revolution was marked by the transition from hand production to production by machines, including the start of steam and water-powered machines. The second industrial revolution introduced electrically powered production in combination with man labor. The third industrial revolution's primary content was the use of electronics and IT to achieve more automation in manufacturing. This automation included robotics and mechatronics. Murphy (2000) describes robotics as “a mechanical creatures that can function autonomously.” Kodama (1986) describes mechatronics as “the combination of mechanics and electronics and is an example of technological fusion in which several different industries are involved.” In the 1980s, most robotic applications were used for welding, for example. This welding process consisted of a single constant handling on a constant fixed place (Day, 2018). The use of robotics has intensely increased in the last decade and robotics are almost fully implemented as a part of industrial automation in some industries (Neal, 1991). The main reasons for robotic automation are productivity increase, better safety, quality increase and failure decrease. Industries like the automotive, electric and metal industry have integrated robotic applications with great enthusiasm and fully embraced it as a part of their production process, according to the International Federation of Robotics (2018) and Pires (2006). The biggest growth in sales and applicability started around 2000 and is still growing. The number of robotic application sales doubled in 2017 compared to 2013 respectively. 381.000 units were sold in 2017, compared to 178.000 units in 2013 (IFR, 2017). In the meantime, the fourth industrial revolution has started. This revolution complements and improves the solutions of the third industrial revolution. This industrial revolution is called industry 4.0 or smart industry and exists of four main principles: Cyber-physical systems, Internet of Things, Internet of Services and Smart Factories. Industry 4.0 continues creating new opportunities by adding new internet-based technologies and cyber-physical systems to solutions of the third industrial revolution. An example of this is a combination of a smart robot-arm and an intelligent vision system which is connected to the internet (Noor Hasnan & Yusoff, 2018). In this example, the robot arm is from the third industrial revolution and the intelligent vision system which is connected to the internet is from the fourth industrial revolution.

Since 2000, robotic solutions have become more affordable, flexible and intelligent. These were important reasons for many companies to invest in robotics to improve, for example, the effectiveness of their production processes (Ahmad Nayik, 2015). However, companies in the food industry, with the exception of a few per cent of the multinationals, have not accepted these solutions as a part of industrial automation (Ahmad Nayik, 2015; Rüßmann et al., 2015).

When considering robot arm solutions specifically, possibilities are increasing as technological development progresses. This progress increases the desire to replace the human workforce by, for example, robot arm solutions. Ahmad Nayik (2015) states that “robots are especially desirable for certain work functions because, unlike humans, they never get tired; they can work in physical conditions that are uncomfortable or even dangerous; they can operate in airless conditions; they do not get bored by repetition; and they cannot be distracted from the task at hand. The robot is powerful, reliable and can be used in hot temperature areas where a human after working for a long time can become sick and exhausted.” In many cases, robot arm solutions are connected to new technologies such as Artificial Intelligence(AI) and Internet Of Things(IoT) in order to respond to impulses or share data. Technological development from these technologies progresses as well (Iqbal, Khan, & Khalid, 2017; Pfeiffer, 2017). This progress results in increased possibilities for the robot arm solutions (Jung & Oh, 2013; Pettersson et al., 2011). As a result, robot arm solutions are being used for more different functions and handlings (Hofmann & Rüsch, 2017).

However, robot arm solutions are less common in the food industry than in other industries (Ahmad Nayik, 2015). Several studies and models relate to this topic. Firstly, research about the readiness of technologies in certain industries has been done in which the technology readiness level model of Mankins (2009) has been used (Olechowski et al., 2020). Secondly, the Technology Acceptance Model (TAM) based studies have been performed regarding the acceptance of new technologies in certain markets (Pfeiffer, 2017; Qin & Ahmed, 2017). Thirdly, a study of Logatcheva, Bakker, Oosterkamp, Van Gaalen, & Bunte (2013) researched the innovation level of small and medium-sized enterprises in the food industry concerning new manufacturing technologies. Fourthly, different studies are performed concerning the possibilities of robotics and other technological developments in the food industry (Ahmad Nayik, 2015; Iqbal et al., 2017; Pettersson et al., 2011).

However, no detailed research has yet been done about the market penetration of robot arm solutions and the challenges of robot arm solutions in medium-sized enterprises in the food industry. The results of such a study could be useful to find out why less is invested in robot arm solutions in the food industry than in other industries. Therefore, this study will attempt to answer the next research question:

What are the reasons for not investing in robot arm solutions in medium-sized companies in the Dutch food sector?

One of the goals of this research is to contribute to the literature of technological innovations, technology readiness levels, TAM and robot arm solutions within the food industry by focusing on the challenges of the market penetration of robot arm solutions in the food industry. Another goal is to provide recommendations to practice. The contractor of this study lacks insights concerning the market penetration of robot arm solutions at medium-sized enterprises in the food industry, especially in relation to technical and sales possibilities, challenges and solutions. Therefore, the practical goal of this study is to provide new insights regarding the challenges of the market penetration of robot arm solutions in the food industry.

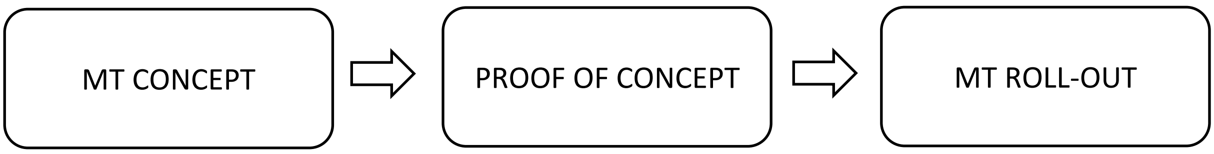
This research focusses specifically on medium-sized enterprises in the Netherlands and is performed in partnership with a company that provides food producing companies in the Netherlands and Germany with manufacturing technologies. Therefore, medium-sized food producing firms in the Netherlands and Germany are the scope of analysis of this research. The theoretical framework will be described in section 2, in which several models will be discussed. This section describes the literature, the relationships between the different models and literature studies and why it applies. Additionally, sub questions will be formulated concerning the literature and models in this section. The research design, research sample, data collection and analysis and the case study will be discussed in section 3. Thereafter, qualitative research will be done in order to answer the formulized sub questions and central research question. The results are presented in section 4. Finally, this study concludes and discusses in section 5.

2. Theoretical framework

2.1 MT investment decision process

The decision of whether to invest in a company is affected by many different factors. For example, intuition and experience of managers can play vital roles in investment processes (Hua Tan et al., 2006). Decisions regarding manufacturing investments are often challenging to make and even more difficult for new technologies. The delivery process of new manufacturing technologies (MTs) typically goes through three stages (Hua Tan et al., 2006). The first stage is the ‘MT concept’ stage, which describes the concept of the product and its functions. Stage two is the ‘proof of concept’ stage and includes prototype systems, testing and integration. The beneficial estimate of the second stage ‘proof of concept’ is a vital aspect of this process, since the concept must be beneficial for the investing party. The last stage is the ‘MT Roll-Out’ stage which focusses on the roll-out of the functioning product (Hua Tan et al., 2006). The three stages are shown in figure 1.

Figure 1: MT investment stages



The decision process in figure 1 shows the process of adaption and acceptance of a technology in an industry (Hua Tan et al., 2006).

The nine technology readiness levels of Mankins (2009) fit into these three stages. Mainly the first two stages apply since the third stage includes a sales function mostly focusses on sales. This application is because the technology readiness levels (TRLs) consider the process before a product is sold. The readiness levels describe the readiness of the technology for a particular market which, in turn, influences the decision to invest (Mankins, 2009). Mankins (2009) indicates that it is often difficult for managers to determine which technological investments to make. He states that “the challenge for system and technology managers is to be able to make clear, well-documented assessments of technology readiness and risks, and to do so at key points in the life cycle of the program.” For this research, the technology readiness levels and the investment stages are used to create structure and to place challenges and solutions in context. The framework for this study can be found in table 1. Generally, technologies go through the levels one-by-one until failure. However, since robotic arms are already present in several industries, including the food industry, this framework is used differently for this study. In this study, all levels are considered since similar solutions have moved through all the levels until roll-out and functioning at the location of the investor. This study will try to determine in which level most failures occur and why.

Table 1, the combination of stages and levels

Investment stages	**Technology readiness levels**
MT CONCEPT	TRL1 basic principles observed and reported
	TRL2 technology concept and/or application formulated
	TRL3 analytical and experimental critical function and/or characteristic proof-of-concept
	TRL4 component and/or breadboard validation in a laboratory environment
	TRL5 component and/or breadboard validation in the relevant environment
PROOF OF CONCEPT	TRL6 system/sub-system model or prototype demonstration in a relevant environment
	TRL7 system prototype demonstration in the expected operational environment
	TRL8 actual system completed and “qualified” through test and demonstration (Including the integration of new technologies into existing technologies, solutions and processes)
MT ROLL-OUT	TRL 9 actual system “flight proven” through successful mission operations

TRL one to TRL five belong to the concept stage since the concept is formed during these levels. TRL six, seven and eight belong to the proof of concept stage because proof of concept includes prototype development and proving the prototype/concept to work. The MT roll-out stage includes TRL nine since a system must be proven to work in order to roll-out and sell. As robot arms have been placed and used for several years in different industries, it is not necessary to elaborate on each readiness level equally. On the other hand, it is essential to describe, explain and discuss each of the three phases concerning the specific factors of the food industry, which could result in challenges for the market penetration of robot arm solutions. In the next three sub sections, the technology readiness levels will be explained more extensively.

2.2 Investment stage one: valuing the concept

The process of investment in manufacturing technologies starts at stage one, the concept stage. Five readiness levels belong to the concept stage, as shown in table 2. At this stage, the demands and requirements of the market must be taken into account to realize a product. The concept has to fit the needs of the industry.

Four manufacturing process types are the onset of this stage: (1) manual assembly, (2) flexible assembly, (3) semi-automated assembly and (4) fixed assembly (Michalos et al., 2015; Tsarouchi et al., 2014). The design of the production line depends on the flexibility, the number of variants, the batch sizes and the production volumes of the assembly or manufacturing line. The design of assembly systems determines the automation possibilities within a line, as a fixed assembly is much easier to automate than a manual assembly. The flexibility of assembly depends on the flexibility of, for example, product, operation, process, volume, expansion and labour (Tsarouchi et al., 2014). Within medium-sized enterprises in the food industry, the degree of flexibility is between the degrees of flexibility of big and small enterprises. Large enterprises often use fixed assembly for mass production and have a low degree of flexibility. Small enterprises, on the other hand, mainly use manual assembly to ensure differentiation by the craftsmanship and have a high degree of flexibility (Durst & Edvardsson, 2012; Logatcheva, Bakker, Oosterkamp, van Galen, & Bunte, 2013). Therefore, most production lines within medium-sized enterprises in the food industry are flexible assembly or semi-automated assembly.

Technology readiness level one (TRL1) considers the basic principles of the industry. As robot arm solutions are well integrated in some industries, the solutions meet many basic principles of different industries. Therefore, it is not necessary to elaborate on most of the basic principles. However, attention must be paid to two vital principles in the food industry, hygiene and food safety. Hygiene and food safety have proven to be significant challenges for technological solutions in the food industry

("Food Safety Hazards," 2012; Kotsanopoulos & Arvanitoyannis, 2017; World Health Organization/ FAO, 2003). Technological developments such as food grade coatings, special shaft designs and excess pressure systems have made it possible to place robot arm solutions at food production locations. (Holmes & Holcombe, 2010; Keller et al., 2018; Masey et al., 2010; Zhou et al., 2007). However, food safety and hygienic requirements still appear to be major challenges and holdback reasons for investors (Ahmad Nayik, 2015).

Technology readiness level two (TRL2) is about the formulation of the concept and its application, which depends on the manufacturing process of the customer. There are manual handlings necessary in medium-sized food production enterprises since the production is of flexible or semi-automated design. Semi-automated design means that employees work on and around the line to ensure the continuation of production (Tsarouchi et al., 2014). Handlings could be machine tending, material handling, painting and assembly, as well as picking, packing, palletizing and transportation within the production rooms (Neal, 1991). The people who are employed for these actions are swapped for robot arms in several industries, such as the car industry, as this is beneficial for companies in various ways (Ahmad Nayik, 2015; Caldwell, 2013; Shukla & Karki, 2016). According to Jørgensen et al. (2019) and Pettersson et al. (2011), the most frequently used functions for industrial robots in the food industry are pick and place functions. Not all manual handlings that people do, can be done by robot arms, because robot arm solutions are not suitable for all handlings yet (Jørgensen et al., 2019). As both people and robot arm solution work in the same production area, the safety of the company's employees needs to be secured. Collaborative robots can be used to realize this safety and are described as "a robot specifically designed for direct interaction with a human within a defined collaborative workspace" (Nemec et al., 2014). Different case studies call these Human Robot Collaborative (HRC) workplaces. Tsarouchi et al. (2016) developed a decision-making framework for HRC workplaces for the alignment of robot arm solutions and the human workforce. Implemented criteria of this framework are work floor place, robot reachability to passive resources, ergonomics, investment costs and safety. Other studies mainly focused on the safety of the human workforce, in which both physical and virtual boundaries are options. (Iqbal et al., 2017; X. V. Wang et al., 2017).

TRL 3 in the food industry consists of analytical and experimental critical functions or characteristic proof of concept like the gripper and a vision system (Neal, 1991; Sam & Nefti, 2010; Wang, Torigoe, & Hirai, 2017). The workings of the gripper and the vision are vital for the functioning of this application. The gripper is the food specific modification on the robot arm solution that is in contact with the product. Pettersson, Davis, Gray, Dodd, & Ohlsson (2010) convey that "food manufacturers have been slow to utilize the full benefits of robot automation. Most robots in the food industry today are used for handling products packed in primary or secondary packing and palletizing, few are used to handle unpacked products in the process" (Iqbal et al., 2017). Various studies, for example, the studies of Jørgensen et al. (2019) and Huang et al. (2017) show that grippers can pick up meat products one-by-one, but that the functioning depends on different factors. Caldwell (2013) explains the effect of vision systems in the food industry and describes that food products are harder to identify and record than fixed objects due to the variety in product contours and structures derived from biological organisms. The higher the variety of product characteristics, the harder it is for a robot arm to identify and handle the product (Bloss, 2013; Caldwell, 2013)

TRL4 and TRL 5 consist of the testing's of vital components such as the gripper and vision system. TRL4 focusses on a laboratory environment and TRL5 focusses on a relevant environment in industry setting. Mankins (2009) describes these levels as "the basic technological elements must be integrated with reasonably realistic supporting elements so that the total applications (component-level, sub-system level, or system-level) can be tested in a "simulated" or some-what realistic environment." Picking and placing packed food does not generally lead to problems in terms of continuance, hygiene and food safety. The problem occurs when unpacked food has to be picked up. Pettersson et al. (2010) and Russo et al. (2017) both performed a study concerning a gripper for food products, which resulted in a working gripper for certain kinds of firm fruits and vegetables, like apples and carrots. The gripper works through a soft gripper function. The gripper works, but causes a lot of extra production time per product, which results in a decrease in productivity. Other studies like the study of Pettersson et al. (2011) and Cramer, Cramer, Demeester, & Kellens (2018) focused on the hygienic and food safety (TRL1) aspect of food grippers.

Different studies have shown that it is possible to pick and place certain unpacked products with a gripper with a special vacuum or blowing function (Jørgensen et al., 2019; Zhou et al., 2007). Although these studies show that different things are possible in terms of food grippers, the studies also indicate that these factors still hold back investors in many cases (Iqbal, Khan, & Khalid, 2017; Lien, 2012). Furthermore, while possibilities are increasing based on technological developments, corresponding vision systems hold back market penetration as well (Bloss, 2013; Chiu et al., 2013). The kind of food and the method of delivery are vital aspects for vision systems. Fixed delivery (fixed pick places) and fixed products (such as firm apples) are easier to detect than, for example, soft meat products. In this situation, fixed implies that the characteristics cannot change per product but are defined by certain values (Jung & Oh, 2013; Pfeiffer, 2017).

The concept phase is vital for products to enter a market. This phase includes TRL1, TRL2, TRL3, TRL4 and TRL5. The concept phase describes several elements. Firstly, the basic principles that are in place. Secondly, the concept of the application, that is, what the robot arm solution must do. Thirdly, the analysis of the critical functions. Fourthly, the validation of the critical functions in a laboratory and a relevant environment. The different TRLs bring different content along. Several questions raised in this sub section, for example, “What are the requirements of the food industry and how do robot arm solutions meet these requirements?”, “Which assembly design is mainly active in the medium-sized food sector and how do robot arms fit within this design?” and “What are the critical functions and parts of robot arm solutions in the food industry?”

In order to understand the reasons that may holdback investors in robot arm solutions in the food industry, the next sub questions regarding this particular stage need to be answered:

1: “To what extend do the requirements of the food industry stop enterprises to invest in robot arm solutions and in what way? (TRL1)”

2: “Which applications can be formulated for robot arm solutions in the food industry? (TRL2)”

3: “To what extend do the challenges of the critical functions (gripper and vision) stop enterprises to invest in robot arm solutions and in what way? (TRL3, TRL4, TRL5)”

The last sub question covers TRL3, TRL4 and TRL5 since these three levels cover the working of the critical functions. After the concept stage, the concept must be proved in order to sell functioning concepts to enterprises. The proof of concept stage, which is discussed in the next section, could result in challenges regarding the market penetration as well. TRLs one till five are discussed in table 2. This table explains how the levels are reached and which elements are essential.

Table 2, TRL 1-5

TRL	HOW	Vital Elements
1	The observed and reported basic principles are known and met by the basic principles of functioning solutions in other industries. Additionally, hygiene and food safety are specific requirements to be met.	hygiene and Food safety
2	Firstly, the concept and application are formulated by different possibilities such as machine tending, material handling, painting, assembly and picking, packing, palletizing and other manual handling tasks. Secondly, the environment of the application is formulated by the flexible assembly design and HCR workplace.	manual handlings, machine tending, material handling, picking, packing, palletizing and safety of human
3	The analytical and experimental critical functions and characteristic proof-of-concept are gripper and vision systems possibilities, are completed by functioning solutions at operational locations in relevant other industries.	Working of the gripper and vision system
4 and 5	The validation of components and breadboard in a relevant environment and the expected operational environment is completed by functioning solutions at operational locations in relevant other industries.	Productivity and assurance of the gripper and vision system

2.3 Investment stage two: valuing the proof of concept

A proof of concept has the goal to verify assumptions and estimated potential, including tests. The main goal of investments in manufacturing technologies is to increase the firm's performance. Without improvement, an investment is not interesting and development will not continue. Many different factors influence the firm's performance and have to be positively affiliated with investments, especially when technologies are new, not entirely accepted by a large part of the employees, or do not have effects throughout the organization (Qin & Ahmed, 2017).

The necessary increase in firm performance is divided into a few aspects. According to Sohn, Gyu Joo, & Kyu Han (2007) firm performance can be measured as financial performance, technological performance, business performance, management performance and manufacturing performance. For investments in manufacturing technologies, the technological, manufacturing and eventually financial performance are most relevant because the improvements of these performances are the main reasons to invest in robot arm solutions (Dirican, 2015; Pires, 2006; Qureshi & Syed, 2014; Rao et al., 2011). Measurement variables of a firm's manufacturing performance are product quality, productivity, manufacturing costs, process control and standardization. Measurement variables of a firms technological performance are technological ability, technological progress, the conquest of a technological gap and the localization of a technology. Investments must result in an improvement of these types of performances, since an investment is of no use otherwise. This improvement must be shown through the proof of concept for the interested parties.

To verify the technology and to show the functionality, three levels of technology readiness coincide with the proof of concept stage. Firstly, the TRL6 system/sub-system model or prototype demonstration in a relevant environment. Secondly, the TRL7 system prototype demonstration in the expected operational environment. In this case TRL 7 is of higher value for two reasons. Firstly, in the food industry, the location of production is often very different from the sites of machine developers, concerning humidity, temperature and factors of production workers. Secondly, robot arm solutions are currently operational at developers' locations and in other industries than in the food industry. TRL6 and TRL7 are, according to Mankins (2009), not always necessary, because the advantages of creating a relevant environment do not outweigh the costs involved. Mankins (2009) states that "at this point the maturation step is driven more by assuring management confidence than by R&D requirements."

For this study, TRL6 (the relevant environment) and TRL7 (expected operational environment) will be merged into TRL6&7 because both are completed by functioning prototypes at representative organizations in food and other industries. It is unnecessary to go into each one separately. Mankins (2009) states "in case of TRL 7, the prototype should be near or at the scale of the planned operational system and the demonstration must take place in the actual expected operational environment … of course, not all technologies in all systems must be demonstrated at this level". For this reason, the demonstration integrated into the investors production process will not be taken into account. It is impossible to go into TRL7 as it includes the integration of robot arm solutions in the expected operational environment, which is part of TRL8. This action is supported by Olechowski et al. (2020), who conducted a research concerning the shortcomings of the technology readiness levels.

TRL8, the actual system completed and "qualified" through test and demonstration, can be seen as the end of system development. According to Mankins (2009), this level of readiness includes design, development, tests and evaluation. At this level, the integration of new technologies into existing technologies, solutions and processes can be considered, rather than developing whole new technologies (Mankins, 2009). In the case of robot arm solutions being integrated into existing manufacturing lines (processes), a satisfactory result of TRL8 is essential. As a result of robot arm integration into flexible and semi-automated production lines (assembly), current production lines and processes in organizations must be taken into account in this technology readiness level. The technology readiness levels six till eight are discussed in table 3. This table shows how these levels are reached and which elements are important.

Table 3, TRL 6-8

TRL	HOW	Vital elements
6 & 7	System/sub-system model or prototype demonstration in a relevant environment and in the expected operational environment.	product quality, productivity, costs, process control, standardization,
8	Actual system completed and "qualified" through test and demonstration	Production integration, costs

The proof of concept and the corresponding TRL six to eight are vital for technologies to enter industries. The content of this stage and its corresponding readiness levels, answer important questions like "what should an investment in a robot arm solution result in?" and "in which way can it be verified that the result of an investment has the desired result?" In order to answer the research question with the present theoretical framework, the following sub questions need to be answered:

4: " To what extend does the setup in relevant environments stop enterprises to invest in robot arm solutions and in what way? (TRL6, TRL7)"

5: “Which challenges of the integration into the current production processes and production lines stops enterprises to invest in robot arms and why? (TRL8)”

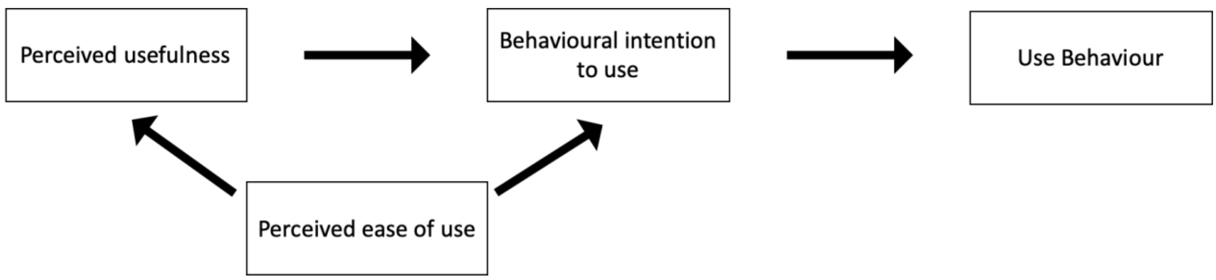
After the concept is proven, a technology roll-out must result in sales in order to bring the functioning concept to enterprises.

2.4 Investment stage three: valuing the technology roll-out

The roll-out plan includes the marketing and sales of the products, as well as TRL9: actual system “flight proven” through successful mission operations. During TRL8, the development is still occurring, while TRL9 is the level of use and production. Between TRL8 and TRL9 the product must be brought to customers. According to Hua Tan et al. (2006) a beneficial proof of concept is a requirement to reach the roll-out stage. Moreover, the beneficial factors of the product are the core of the technology roll-out. Fill & Fill (2005) described that the resonating focus proposition must focus on the offering’s superiority on the few elements where performance matters the most and that managers must be able to demonstrate and understand this. Besides the beneficial factors, the product must be accepted by management and employees.

The acceptance of technology among employees and managers is vital for investments in new technology, since both play a vital role within the decision to and acceptance of the process of investing in robot arm solutions for manufacturing processes. Thus, a technology roll-out must respond to the acceptance of the technology. The TAM has been developed to analyze the acceptance process and to measure of acceptance of technologies (Surendran, 2012). The general TAM consists out of three main variables: perceived usefulness (PU) and perceived ease of use (PEU), which both influence the behavioural intention to use (BIU) (Beer, Prakash, Mitzner, Rogers, 2011). The TAM can be found in figure 2.

Figure 2, TAM



An extended version of the TAM is specified on robot arm solutions in HRC workplaces by Beer, Prakash, Mitzner and Rogers (2011). Besides the creation of this version, other studies do confirm that this model is applicable for robot arm solutions in production areas (Beer, Prakash, Mitzner, & Rogers, 2011; Bröhl et al., 2016; Davis, 1989; Venkatesh & Davis, 2000). These studies investigate the TAM based on qualitative research and correlation studies. In the TAM specified on Human Robot Collaborative workplaces, the main factors consist of other subfactors than the standard TAM model.

These subfactors are specified to robot arm solutions in HRC workplaces and directly affect the factors perceived usefulness and perceived ease of use. The following sub factors significantly influence perceived usefulness: subjective norm (in general, the organization supports the use of the robot), image (people in my organization who use the robot have more prestige than those who do not), job relevance (the use of the robot is pertinent to my various job-related activities), output quality (the quality of the output I get from the robot is high) and result demonstrability (I have no difficulty telling others about the results of using the robot). The following sub factors significantly influence perceived ease of use: perceived enjoyment (I find using the robot to be enjoyable), social implication (I fear that I will lose contact with my colleagues because of the robot), legal implication (I do not mind if the robot works with me at a shared workstation), ethical implication (I fear that I will lose my job because of the robot), perceived safety (I feel safe when I use the robot), self-efficacy (I can use the robot, if someone shows me how to do it first), robot anxiety (robots make me feel uncomfortable) and technology affinity (I inform myself about electronic devices, even if I do not have the intention of purchasing them and I find it easy to learn how a new electronic device is working) (Beer, Prakash, Mitzner, Rogers, 2011; Bröhl et al., 2016). Table 4 shows how TRL9 is completed when considering robot arm solutions and which elements are vital.

Table 4, TRL 9

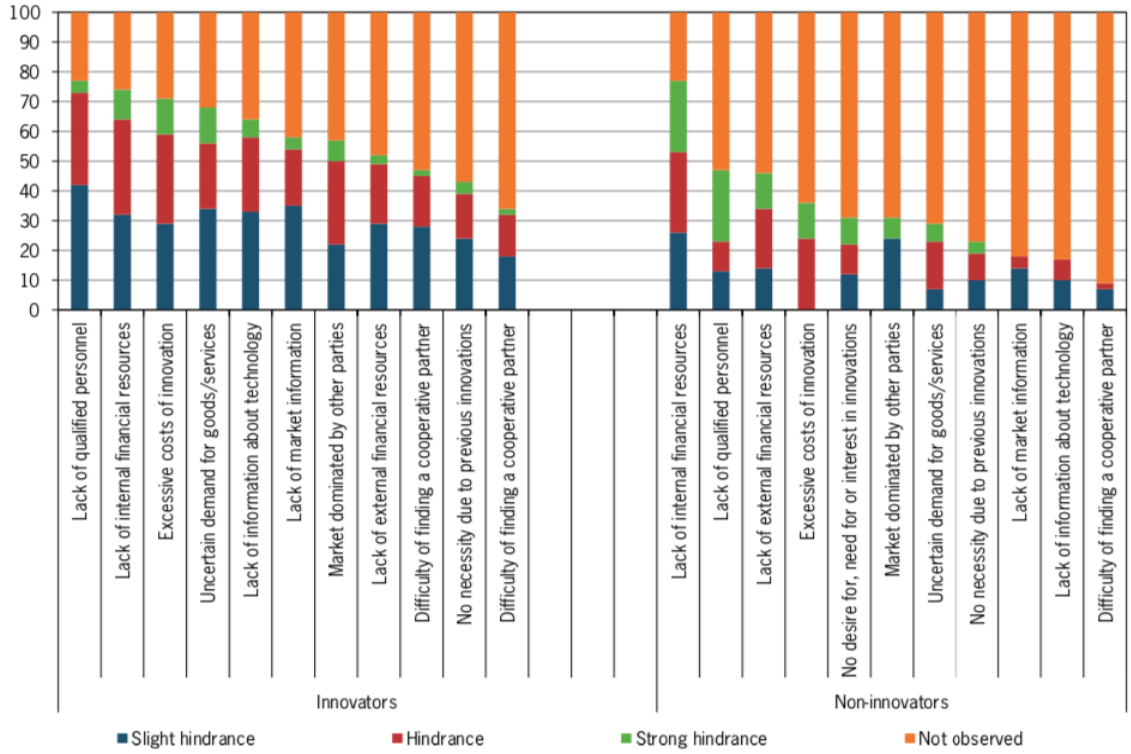
TRL	HOW	Vital elements
9	Functioning solutions at operational locations in relevant industries show a successful mission operation of the actual system.	Acceptance & benefits

During TRL9, the technology successfully entered the organization. At this level, no technical issues can arise since the technology functions and is integrated into the manufacturing processes. The roll-out of technology relates to several vital factors, demands and product components. Therefore, the question “what should the technology roll-out focus on and why?” has been discussed. In order to formulate an answer to the central research question, the next sub question concerning the challenges of the technology roll-out is:

> 6: “What challenges does the acceptance of robot arm solutions entail and how are they solved?”

To create more certainty about the possible challenges of technology investments, factors or reasons for innovation hindrance within the Dutch and Belgium food sector can give extra insights. Two studies regarding innovation in the food producing industry in the Netherlands and Belgium have been performed by Avermaete et al. (2004) and Logatcheva et al. (2013). A distinction is made between innovative and non-innovative companies, in the study of Logatcheva et al. (2013). One of the results was that small and medium-sized enterprises lag behind larger companies in terms of innovations and investments. Figure 3 shows the main reasons why innovations in the Dutch food industry do not come through.

Figure 3: innovation hindrance reasons



The combined (innovative and non-innovative) main hindrance levels are (1) lack of qualified personnel (2) lack of internal financial resources (3) excessive costs of innovation and (4) uncertain demand for goods/services (Logatcheva et al., 2013). The technology roll-out should consider these hindrances since the design of the roll-out can offer opportunities to reduce these factors, for example, leasing contracts to reduce the factor of future uncertainty, personnel training to reduce the disadvantages and risks resulting from a lack of qualified personnel (Allen, 1999; Ellis, 2010; Kroh et al., 2018).

The hindrance of innovation is to understand the market penetration of robot arm solutions. In this study, these hindrance levels, as well as the technology readiness levels, will be taken into account when answering the central research question.

3. Methodology

3.1 Research design

In order to answer the research question, a qualitative and explorative study will be performed, since the main goal is to explore the challenges of the market penetration of robot arm solutions in the Dutch medium-sized food sector. The design of the study is a combination of a theoretical framework/literature review, semi-structured interviews with stakeholders and a case study. Which stakeholders and the number of interviews will be described in section 3.2. The interviews include different subjects that have emerged from the literature study. In what way the interviews will provide data and how this data will be analyzed will be described in section 3.3.

3.2 Sample

The research takes both customer and supplier perspectives into account since both parties are involved in the sales trajectory of robot arm solutions. Furthermore, the different parties may have different opinions and by including both these two possibly different opinions will be taken into account. In determining which interviews should be held, two factors play vital roles: the number of interviews and with whom. To determine who should be interviewed, participants must meet various criteria that ensure only interviews are held within the scope of the study. Thus, participants must work for medium-sized enterprises in the Dutch and German food industry. The criteria are the number of employees, the location and the delivered product and can be found in table 5.

Table 5, study sample

Aspect / criteria	Requirement
Number of employees	50 - 250[1]
Location	The Netherlands and Germany
Product	Food

[1] Eurostat, small and medium-sized enterprises, 2018. https://ec.europa.eu/eurostat/web/structural-business-statistics/structural-business-statistics/sme

In order to eliminate the influences of partnerships between the client and the participants, interviews are conducted with employees from two companies. One where the contractor of this study did and one where the contractor did not sell equipment in the last three years. Besides the enterprise criteria, interviews must be held with decision-makers or employees who influence the decision (Eisenhardt & Graebner, 2007). For this study, not only members of the highest hierarchical level in the company will be interviewed but also informants of different hierarchical levels, functional areas and groups. Eisenhardt & Graebner (2007) indicate that research obtains information from different perspectives. Therefore, this study obtains information from the perspective of decision makers in production area's and strategic decisions makers from higher management, in order to get complete insights into the decision-making process. The (minimal) number of interviews must also be determined. Galvin (2015) indicates that, when qualitative research is performed, researchers must conduct at least three to twelve interviews, depending on the frequency level of the issue in the population (Galvin, 2015). The frequency level stands for the degree of how often something happens in a certain timeframe. This number will be taken as the point of saturation. In a qualitative study, saturation can be based on the reliability of the data that have been collected or analyzed hitherto, which makes further data collection or analysis unnecessary (Saunders et al., 2018). At this point, further collection of new data is unnecessary and no more interviews are needed to increase reliability. For the study to proceed within these guidelines, a minimum of twelve interviews will be conducted and interviews would continue until the last three interviews provide no new information.

3.3 Data collection, management and analysis

In this study, data will be collected through semi-structured interviews with both customers and suppliers. The interviews will be split up into several main themes which will have their own questions. The three main themes are the three stages of the decision process of technology investments: concept, proof of concept and technology roll-out. Each theme will consist of the different technology readiness levels that deal with that specific stage. Additionally, the acceptance of robot arm solutions and the patterns and behaviour of small and medium-sized enterprises regarding innovative investments in the Netherlands and Belgium are included into the questions.

The interview set up and questions will be according to the four-phase process of Montoya (2016) who indicates that interview questions must be made based on the following four phases: 1) ensuring interview questions align with research questions, 2) constructing an inquiry-based conversation, 3) receiving feedback on interview protocols, and 4) piloting the interview protocol (Castillo-Montoya, 2016). If it seems like other themes are also important, these will be discussed in the interview in which it appears and added to the literature study and the following interviews. After the discussion of the main themes, an overarching part of the interview will be held to find out if different challenges or difficulties are related.

The interviews will be transcribed and deidentified. The transcribing process will be done manually. This provides clarity and insights into the qualitative data (Ranney et al., 2015). The resulting transcripts will be converted into a standard structured format, in order to match and recognize differences and similarities. The transcripts will be read several times before analyzing them.

The approach of analyzing is inductive since the goal is to explore possible challenges of the market penetration of robot arm solutions in the Dutch food industry. Ranney et al. (2015) indicates that an "inductive approach allows for codes, themes, and ideas to arise from the narrative". In contrast to deductive analysis, in which themes and codes have been devised in advance (Ranney et al., 2015). In order to create maximum validity and reliability of the analysis, four steps will be made to operationalize this process. Those four steps are described by Ranney et al. (2015) as "1) starting with a review of the text within a coding category; 2) using data management software to compare the codes for different types of participants; 3) developing iterative, evolving lists of emerging themes, and revising the codes accordingly; and 4) collaborating with other researchers to compare and contrast emerging themes, finally achieving consensus regarding overarching theoretical constructs." Step one will be done by reading the interview transcripts several times in order to place answers under not yet known codes. Step two will be realized by analyzing and comparing the codes that have surfaced. Step three exists out of research about the codes in order to create lists of related codes and themes. The emerging themes and underlying codes will be displayed in 4. Results to increase understandability. Step four will be done by assigning two non-participating persons to check the coding results. Afterwards, an agreement must be made with these two persons to continue with the data collection and research.

3.4 Case study

In addition to the interviews, a case study will be conducted. The purpose of this case study is to supplement, clarify or refute the information retrieved from the interviews. Yin (1994) defines a case study as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context, when the boundaries between phenomenon and the context are not clearly evident, and in which the multiple source of evidence are used. It is particularly valuable in answering who, why and how questions in management research." The goal of the case study is to add insights from a practitioner's perspective. It will be performed through an actual assignment to deploy a robot arm in production. The case study will provide this study with information about challenges and possible solutions, including a description of why the investments will be made or not.

The investor demands that the human workforce will be replaced with a robot arm solution at the beginning of the line. At the beginning of the line, one production worker places the wraps on the conveyor belt one-by-one. The goal of the assignment is to create a working solution for this application with a robot arm solution. Since the purpose of this case study is not only to clarify and refute but also to supplement the retrieved information and to add new insights, the case study will have an inductive approach. This case study aims to find out which challenges rise from the assignment, why these challenges appear, to which technology readiness level these challenges belong and how to overcome these challenges, if possible. The case study will be performed at the location of the contractor of this research. A summary, including a description of the assignment, solution and challenges, is in appendix 1.

3.5 planning

Interviews will be held from mid-January 2020 until saturation, which is estimated to be at the end of February. In the meantime, a case study will be set up with a partner until the middle of March. After the final interview, the interviews will be analyzed. Editing starts after the first few interviews, to evaluate and possibly increase the quality of the following interviews. In March, the results will be written in the result chapter. The conclusion and discussion will be finished in the middle of April.

4. Results

This chapter displays, analyzes and compares the results of the 12 interviews. The sub questions of the different sections of the theoretical framework, which are all linked to one specific TRL, are discussed one-by-one. This study aims to find the main reasons for investment holdback, not to which technology readiness level the technology belongs. Therefore, if in some levels problems of implementation or integration occur, references are made to further technology readiness levels, since the underlying reasons occur at another level. Not all sub questions are discussed to the same extent because results from the theoretical framework show that not all technology levels are equally important. The main question will be discussed last.

Coding results from the analysis and quotations retrieved from the interviews are used to create clarity and display ratios which are emerged from the interviews combined. Participants will not be named or linked to an organization because of privacy regulations.

4.1 Results | Concept phase

This section aims to answer the sub questions of the concept phase. The first sub question related to this phase is “To what extend do the requirements of the food industry stop enterprises from investing in robot arm solutions and in what way?” and is linked to TRL1. Vital requirements of the food industry, which affect the investment in robot arm solutions, are hygienic and food safety regulations.

Nine of the twelve participants indicated that hygiene and food safety do not cause problems or that the levels of robot arm solutions in this area are sufficient to use it in production. Five participants indicated that robot arm solutions in production are beneficial in terms of hygiene and food safety. A project manager in technological innovations stated: “these are the main reasons to do invest in my opinion because with robot arms, personnel does not come in contact with fabrics.” Moreover, another manager stated: “the placement of robots results in less human workforce in the production and the human workforce creates hygienic and food safety problems.”

The majority of the participants indicated that hygienic and food safety requirements do not hold back investment in robot arm solutions. Moreover, coding analysis regarding the emerged theme “robot characteristic requirement for investment” displays that the code ‘IP69K’ has been listed several times. This means that the characteristic ‘IP19K’ is a vital requirement for robot arm solutions in the food industry. This characteristic belongs to the field of hygiene and food safety since the IP level of a solution indicates the resistance against high-power cleaning and cleaning fabrics (N.E.M.A., 2004). The theoretical framework showed that several industrial robot arms are of this level. Therefore, this should not lead to problems when purchasing solutions. Besides that, a robot arm solution must meet the basic principles, it must also be possible to formulate an application or a function for the robot arm solution.

Question two regarding the concept phase is “Which applications can be formulated for robot arm solutions in the food industry?” This sub question is linked to TRL2. The application in this case includes the activities of robot arm solutions. The analysis shows that it is possible to formulate application(s) for robot arm solutions in the food industry. Three quarters of the participants found the application of pick and place most interesting, specifically, pick and place solutions functioning as begin & end of line solutions and in-line pick & place applications. Pick and place solutions include picking and placing of both the products and the packages with and without product. The theoretical framework has shown that this is also possible for robot arms solutions in this industry. Therefore, the formulation of applications is no cause of investment holdback. The exact concept of picking and placing applications is not discussed in depth at this level for two reasons. Firstly, since it concerns all the possible applications of the concept, this study does not need to describe all of them. Secondly, the diversity of the organizations in this industry makes it impossible to describe one concept that fits all. More in dept defined concepts and the integration into current production processes is discussed in TRL8.

The third question is “To what extend do the challenges of the critical functions (gripper and vision) stop enterprises from investing in robot arm solutions and in what way?” and is linked to TRL3, TRL4 and TRL5. The main finding here is that the gripper and the vision in combination with two vital factors cause significant challenges and limitations.

Firstly, the kind of products produced in this industry. The vision and gripper capabilities do often not match the necessary characteristics to handle food products. The codes ‘kind of products’ and ‘gripper/vision’ have both come up four times under the coding subject ‘reasons to not invest in robot arms.’ Several quotes concerning this subject can be found in list 1.

List 1, quotes critical functions

"Two of the three possibilities will be impossible because there is no good gripper or there is no space"
"I think that the main reasons is that robots must handle products which are not made for robots"
"It must look good and robot arm cannot see that, that is impossible with a robot arm" (robot arm with vision)
"The product we use are like salami, salads, so everything is very individual so most of the picking and placing is made by hand due to the fact that it is difficult to get these pieces automated"

The main problem is that products in this industry are not fixed. They are all different in terms of size, hardness and other aspects since they are natural products. These elements are highly influential on how the gripper and vision functions. The limitations of the gripper and vision systems can cause a holdback in the investment of robot arm solutions when the product is simply impossible to be treated by gripper and vision.

Secondly, challenges that arise from gripper and vision limitations depend on the productions processes and production lines and the integration into this situation. This includes, for example, the way of stacking and the supply of products. In addition to the interviews, this is supported by the case study in which the gripper is not able to unstack wraps one-by-one because of the stickiness of the wraps. However, it does work when unstacked wraps are picked. A description of the case study can be found in appendix 1. The integration into the production processes are discussed in TRL8.

In addition to the working of the critical functions, the performance of the integrated critical functions is also of influence. Mankins (2009) states that the technological element must be integrated to establish concept-enabling levels of performance at the levels of the breadboard. Furthermore, this must be consistent with the requirements of potential system applications, which includes the performance levels of productivity and assurance. Two participants state that productivity or assurance could be reasons to hold back investments in robot arm solutions. At the same time, others do indicate that the main reason to invest in robot arm solutions is the increase in productivity and assurance. A participant explains: "it depends on the kind of line and product. When something arrives one by one, the robot can reach the productiveness, but when the process is difficult and the level of vulnerability is high, it will take longer than when people do it and the productivity demands will not be reached. This can be solved by another supply or more robot arms but then the investment will be too high." This quote implies that results of productivity and assurance depend on how well the gripper and vision function on the relevant product and the production line with associated equipment. This idea is supported by the case study in which productivity requirements are achieved in situations in which the gripper functions well. However, the gripper in the case study, did not function well in all cases which resulted in failures and low levels of productivity when the gripper did not function well. Productiveness and assurance are factors that can lead into a holdback of investment. However, the productiveness and assurance depend on the food product and the production processes and are further considered in section 4.2.

To summarize, the analysis shows that as long as robot arm solutions are of a sufficient level of cleaning and material resistance, hygienic and food safety regulations are no reasons to not invest in robot arm solutions. On the contrary, hygienic and food safety requirements can in fact be reasons to invest in robot arm solutions as the solutions are beneficial compared to the human workforce. Additionally, analysis shows that applications can be formulated for robot arm solutions at medium-sized organizations in the food industry. The most interesting applications are pick and place applications. In contrast to the first two technology readiness levels, the third level does pose challenges. Challenges concerning the working of the gripper and the vision come up which can lead to a holdback of investment. These challenges occur in two combinations. Firstly, the gripper and vision in combination with the food product and secondly, the gripper and vision in combination with the production processes and production lines.

4.2 Results | Proof of concept phase

The technology readiness levels of the proof of concept focusses on the solution in a relevant and an expected operational environment. The fourth question is linked to TRL6 and TRL7 and is: "To what extend does the (expected) setup in a representative operational environment stop enterprises from investing in robot arm solutions and in what way?" Four out of the seven participants, who thought about and looked at robot arm solutions for their production process, indicated that the (demonstrated) solution did not match the situation at the participants organization. This situation included the product, current production equipment, lines and spaces, as well as the demands concerning productivity and assurance. According to several participants, the solutions which are shown on exhibitions and demonstrations do not consider the production processes and lines at food producing organizations well enough. Therefore, these solutions do lack representativeness in relation to the situation at the organizations. Since this study aims at finding the reasons for investment holdback and not in which readiness level the technology belongs, this problem does not belong to TRL6 and TRL7, but to TRL8. The reason for this is that the production processes and lines causes this "mismatch" and a lack of representativeness. The next sub question concerning TRL8 includes this integration into the production.

The fifth question is related to TRL8 and reads as followed: "To what extend do the challenges of the integration into the current production processes and production lines stop enterprises to invest in robot arms and why?" Analysis has shown that the misfit between the robot arm solution and the way of production in the food industry is the main reason for investment holdback, which is also a vital factor for the results of TRL3, TRL4, TRL5 and the lack of representativeness concerning TRL6 and TRL7. All the participants who thought about investing (seven participants) in robot arm solutions indicate that the solutions did not fit into the way of production at their organization, in which mainly the critical functions play vital roles. There are several reasons why TRL8 causes an investment holdback.

The first reason why TRL8 causes a holdback is that the robot arm does not fit in the production processes. The production processes include all the handlings that belong to the production process from arrival, handling until packing and shipping. Seven out of the twelve participants admitted that robot arm solutions do not fit into the processes at medium-sized businesses in the food industry. Firstly, because they do not work with an in-line production program but with stand-alone machines. This eliminates the functionality of robot arm solutions since robot arms solutions are built to do repetitive in-line jobs. A participant stated the following concerning this topic: "many production processes are not in-line but exist out of different steps through the whole building and to integrate robot arms into this process is actually impossible." In processes which are not in-line, a lot of the work is done by employees who perform different tasks. These tasks are very diverse and often include more functions in one, such as a control and transportation function in addition to the core function. A participant said: "but sometimes it is impossible because the product needs to be brought from the first machine to the second and this can only be done by humans." Secondly, the diversity in terms of different products, product characteristics, speeds and processes cause holdback. Two quotes concerning this topic can be found list 2.

List 2, quotes diversity

"We change products on lines everyday a view times… if we change a person for a robot and we let the robot do the same thing it is something impossible because there is a gap in planning etc."
"We have a lot of different products, a lot of different forms and a lot of product shifts on one day since we don't have mass production."

This diversity leads to problems since robot arm solutions, mainly the critical functions, cannot handle diversity as they are programmed for repetitive tasks. This problem is supported by the case study as well, as the failure occurred only once in a while when the products were too sticky. Due to these particular failures, the robot arm solution did not work. In addition diversity often leads to a decrease in performance when using a robot arm solution. Balch (1999) had similar findings in his study and indicated that diversity is negatively correlated with performance.

The second reason why TRL8 causes an investment holdback is that the robot arm solution does not function (well enough) in the current production lines. Four out of the twelve participants stated that the current production lines are the cause of no investment in robot arms. Quotes can be found in list 3.

List 3, quotes line integration

"We have lines in which robot arm cannot be aligned"
"Can't handle the process with vision"
"Sometimes you can't do it like people can which is needed for this line"
"It must look good and robot arms cannot see that, that is impossible with a robot arm"

Furthermore, two participants indicated that it is impossible to integrate a robot arm solution in a production line because meat products arrive in crates and a robot arm cannot pick up meat products from a crate. The theoretical framework indicated that it is possible to pick and place meat and other products but that it depends on different factors (Jørgensen et al., 2019; Zhou et al., 2007). In this case, the line is the cause of a holdback since the stacked products at the beginning of the line cause the problem. The same problem occurred in the case study, in which wraps could not be picked up one-by-one from a stack. The case study concluded that the core of the challenge/problem is that the combination gripper, product and the way of in-line product supply results in a misfunction of the robot arm solution. More information about the setting, solution set-up, assignment and the problem of the case study can be found in appendix 1.

Many production processes and lines are designed for human work. At the same time, a common reason to invest in robot arm solutions is to decrease the level of human workforce in order to increase, for example, efficiency and quality. In order to place robot arm solutions in these processes, robot arm solutions need to have specific characteristics to realize a fit. Inductive coding resulted in the theme 'must have characteristics' concerning robot arm solutions in the food industry. Table 6 displays the codes that have emerged concerning this theme.

Table 6, robot arm solution must have characteristics

Coding one	Coding two	Times
Replacements of humans	Like human	4 x
Current production (lines/processes)	Handle current process	1 x
Multiple capabilities	More tasks at once	3 x
	Anticipate on diversity	1 x
	Flexible	2 x

Besides the four times 'like human' is coded, all codes are the strengths of humans. Those characteristics fit the processes and are a must for the processes. Unlike humans, robot arm solutions do not have these characteristics, as explained in the theoretical framework. This difference is also apparent in the case study, in which tests have shown that a robot arm solution cannot anticipate on the diversity within stacks of wraps like a human can. Therefore, robot arm solutions do not fit into the current production processes and production lines.

To summarize, the fifth question related to TRL6 and TRL7 resulted in an outcome that focusses on the representativeness of the (demonstrated) solution.

Analysis shows that robot arm solutions in relevant or expected operational environments do not fit into the production of food products. This misfit means that representative solutions cannot be found. However, it depends on the production processes and lines at the food producing organization, covered in the next technology readiness level, which concerns the integration into this production. It appears that robot arm solutions and the critical functions do not fit into the current production processes and lines. Firstly, because organizations do not work with an in-line production program, but with stand-alone machines and this eliminates the functionality of robot arm solutions. Secondly, because robot arm solutions cannot handle the diversity in production processes. These challenges rise up since many processes and lines are designed to collaborate with human workforce which feature different characteristics than robot arm solutions.

4.3 Results | Technology roll-out phase

The technology roll-out phase focusses on the market penetration and integration into processes of robot arm solutions. The technology readiness levels are levels that are accomplished one at a time. However, this study aims to show the reasons why investments are not made and not at in which readiness levels the technology belongs. Therefore, the roll-out phase is vital as well.

Six participants indicate that robot arm solutions are more interesting when investment in whole new production lines is an option, instead of investing in only robot arm solutions. The necessary adjustments which are needed to integrate robot arm solutions into existing lines do not have to take place when investment in new production lines takes place. Six participants mentioned that the alignment of the line equipment and robot arm solution(s) could be taken into consideration from the beginning and therefore will be much easier. This result means that sales should focus on new lines instead of on existing lines.

The sixth sub question, related to the roll-out phase, is “What challenges does the acceptance of robot arm solutions entail and how are they solved?” The analysis shows that production workers can have problems with robot arm solutions and that the creation of acceptance among production workers by management is difficult. The reason for this is that the production workers are afraid to lose their jobs because of the robot arm solution. The fear of losing jobs is part of the TAM, since this fear belongs to the subfactor ‘ethical implication’ which is a part of the main factor ‘perceived ease of use'. Five out of the seven participants indicated that explaining why robot arm solutions are beneficial to both the production workers themselves and the organization, can solve this problem. Creating other less heavy and monotonous jobs, improving technical health and safety and making clear that a growing organization is better for them than an organization in financial difficulties, are important factors in this case.

This explanation discusses the subfactor 'subjective norm', which addresses that the organization supports the use of robot arm solutions, because this explanation and the willingness to explain, shows that the organization supports the use of robot arm solutions. Additionally, this explanation discusses the subfactor 'perceived enjoyment', which addresses the enjoyment of using robot arm solutions, since eliminating heavy work creates a more enjoyable job. In the TAM model, both subfactors directly affect the main factor 'perceived usefulness' positively, which in turn has a positive effect on the behavioural intention to use robot arm solutions. The results of this study support this, as the solution by the management takes both subfactors into account. A participant stated that "we have explained it very well, that when this happens in the future, it will not be to fire our personnel but to decide which way to grow and to let that personnel work somewhere else in the company, that is the goal of the robot." Another participant indicated that robot arm solutions will make their production workers happier since it would make their work more manageable in terms of less heavy lifting and better technical health and safety.

In addition to the acceptance of employees, having qualified personnel is an important factor for the market penetration of robot arm solutions into this industry as well. Logatcheva et al. (2013) indicated that the main hindrance to innovate within the Dutch food sector is the lack of qualified technical personnel. Four out of the six participants indicated that a lack of qualified (technical) personnel is not decisive in the choice of whether or not to invest in robot arm solutions. Nevertheless, all participants indicated that it is essential to have qualified personnel when producing with robot arm solutions and that training is important to get the necessary (certain amount of) qualified personnel. The factor 'perceived ease of use' of the TAM is applicable in this aspect.

Two subfactors of 'perceived ease of use' play a role in this situation. Firstly, self-efficacy (I can use the robot, if someone shows me how to do it first), since training is a part of the subfactor 'self-efficacy'. Secondly, 'robot anxiety' (robots make me feel uncomfortable), since technical staff can be afraid to use or repair robot arm solutions. A participant stated that they “had to get this into people their minds to make sure it is okay .. of course when you destroy it, it will cost money but it would not mind you to do things with the robot.”

4.4 The size and complexity of the holdback

The previous sub sections point the challenges out that result in holdback of investment. However, the misfits and holdback reasons can be overcome by certain adjustments, changes and/or solutions. However, this entails such measures and costs and/or decrease in performance that it still leads to a holdback of investment. A participant indicated that it depends on the kind of line and product and that when products arrive one-by-one, a robot arm solution can reach the desired productivity, but when it becomes more difficult and the products become more vulnerable, this productivity cannot be reached.

To overcome this misfit investors have to invest in unprofitable expensive solutions and rebuilding’s, which result in an unprofitable investment. Highly expensive solutions include three different solutions or measures. Firstly, multiple robot arm solutions to achieve productivity. Secondly, new lines or line adjustments to create a working situation for gripper and vision. Thirdly expensive (gripper and/or vision) systems to be able to anticipate on product and/or production diversity. Inductive coding resulted in the theme ‘complexity’ concerning the integration of robot arm solutions into food production processes. Table 7 displays the emerged codes.

Table 7, complexity

Coding one	Coding two	Times
Lay-out changes	More space	4 x
	Rebuild	2 x
Line changes	New lines	3 x
	Line adjustments	7 x
Delivery	Change delivery process and procedures	1 x

These measures cause an uninteresting investment for the investor. The two next quotes support this: “Yes because it requires often such huge adjustment on the complete line that the investment will be too big and risky” and “It is not just the robot arm, there is more needed and that will cost more and the ROI will not be sufficient.”

5. Discussion and conclusion

This chapter gives the conclusion, the theoretical and practical implications and the relevancy and the limitations of this research as well as the possibilities for future research.

5.1 Conclusions

The goal of this study is to answer the following central research question: “What are the main reasons for not investing in robot arm solutions at medium-sized companies in the Dutch food sector?” By answering different sub questions, related to different technology readiness levels, insights have been obtained into the various factors that play a role in the investment of robot arm solutions. The central research question is discussed in the first sections which address two reasons for investment holdback. Additionally, other findings concerning this topic will be conveyed.

The first conclusion is that the misfit, or challenges concerning the fit, of robot arm solutions in the production processes and lines are the main cause of investment holdback. These challenges belong to technology readiness level eight. This fit can be split up into the fit into production processes and the fit into the production lines. The first fit with the production processes includes the integration (TRL8). It appears that primarily the diversity of work tasks and products causes challenges since robot arm solutions are built for repetitive jobs. Work tasks in food production are diverse, for example, in terms of activities, workplaces, speeds and quality requirements. These different tasks are done by human workforce that is able to do all these different tasks together. Robot arm solutions are not able to do this and therefore not suited for this. The diversity of products in this situation means that different products (product batches) are produced, instead of mass production of one product. Furthermore, the production with standalone machines results in investment holdback as a result of the impossibility or unprofitability of integration, because robots arm solutions are designed for in-line processes. The second fit is the fit into the production lines including the integration (TRL8). Robot arm solutions do not fit into the current production lines in this industry. Unlike humans, robot arm solutions do not meet the necessary characteristics to work on or with the production lines. Characteristics such as the ability to anticipate on task diversity, product diversity and flexibility are found to be vital for current production lines. Mainly the critical functions (TRL3) are limited in this sense.

Conclusion two is that the challenges of the critical functions (TRL3, gripper and vision system) related to food products are the second largest cause of investment holdback. Food products are natural products and therefore diverse, which causes challenges for the critical functions. The product characteristics can differ per product, for example, in terms of shape and hardness. This diversity has a negative effect on the working of the critical functions and subsequently on the working of the robot arm solution. Furthermore, the functioning of the gripper and the vision can depend on several other factors than the product, such as the production processes and lines.

It should be noted that, although this study has found critical challenges and reasons for investment holdback, this study also learned that these challenges can be overcome or abridged by certain adjustments. However, these measures can be so drastic and entail such costs that it results in a ROI over a too long time frame or an unbeneficial investment. Since investments are made to be profitable, this is not an option to take into consideration.

Conclusion three is that production workers can have problems with accepting robot arm solutions. However, an explanation that robot arm solutions are beneficial to both the organization and the production worker can help to create acceptance. This conclusion includes several factors of the TAM model specified on HRC workplaces and supports this TAM with regard to playing a role in this matter. The relevant subfactors in this matter are ‘ethical implication’, ‘subjective norm’ and ‘perceived enjoyment’, which affect the use of robot arm solutions by employees. Firstly, the factor ‘subjective norm’ implies that organizations do support the use of robot arm solutions. Secondly, the factor ‘perceived enjoyment’ implies that robot arm solutions create an easier and more enjoyable job for employees. Lastly, the factor ‘ethical implication’ implies removing the fear of losing a job because of investment in robot arm solutions. Besides the production workers, the technical qualified staff members do also influence the investment in robot arm solutions.

Conclusion four is that a lack of qualified (technical) personnel is not a determining factor when deciding whether or not to invest. However, it is important to have qualified personnel with knowledge about robot arm solutions. To ensure technical qualified personnel, training of technical personnel is important. ‘Self-efficacy’ and ‘robot anxiety’ are two subfactors of the TAM that play a role in this conclusion and whose role in the TAM is supported in this study. These factors concern daring and knowing how to use and repair robot arm solutions. Training will increase the dare to use robot arm solutions and the knowhow about robot arm solutions.

Conclusion five is that robot arm solutions are more interesting for new lines than for current production lines and processes. In situations in which investors consider new lines, the integration of robot arm solutions can be taken into consideration from the beginning. This consideration creates a situation in which the processes, production lines and line equipment can be aligned more easily with robot arm solutions. In this way, robot arm solutions can be a part of the total line instead of an addition to the line. Besides the easier alignment, costs of line adjustments at the current line do not have to be made when investing in whole new production lines including robot arm solutions.

Finally, the technology readiness levels that result in the most holdback of investment in robot arm solutions are TRL3 and TRL8. The combination of the critical components of both levels creates the main reasons for a holdback. Other levels do not seem to create challenges that could lead to investment holdback. Besides the reasons why investments in robot arm solutions lead to hold back in this industry, this study has led to various other results concerning the other phases of manufacturing technology investments and the belonging technology readiness levels. Firstly, hygienic and food safety regulations (TRL1) are found to be no reasons for investment holdback. On the contrary, robot arm solutions offer advantages in these areas such as fewer risks and higher securities as a result of a decrease in the human workforce. Secondly, applications are possible and can be formulated (TRL2). Pick and place applications are found to be the most interesting. Thirdly, investment holdback is in general not a consequence of productivity demands (TRL4 and TRL5). Productivity depends on the working of the solution and its critical functions on the production processes and lines and this is a result of the disciplines that address the critical functions (TRL3) and the production (TRL8). Finally, demonstrations in relevant and/or expected operational environments do lack representativeness since demonstrated solutions do not fit the production at the company (TRL6 and TRL7). However, this can be assigned as a consequence of the disciplines that address these aspects which are TRL3 and TRL8.

5.2 Theoretical implications

This study contributes to the literature of robot arm solutions, technical innovation, production technologies, technology readiness levels and the TAM in multiple ways. This study can provide an answer to why technologies, such as robot arm solutions, are struggling to penetrate into the food industry, with specific attention to medium-sized organizations in the Dutch (and German) food industry.

Firstly, the analysis of this study extends technology readiness level literature by specifying on robot arm solutions. Several studies addressed technology readiness levels in different industries such as aerospace, automation and energizing technologies. These studies content was mainly about the readiness of new materials and new technologies before entering a certain industry, such as the aerospace industry (Carmack et al., 2017; Li, 2008). This study focused on the challenges of existing technologies in a market, in which these technologies already partially entered. The combination of robot arm solutions and the food industry are added to the literature of technology readiness levels by this study (Mankins, 2009; Olechowski et al., 2020). The challenges of the food industry, which are specified on type and diversity of production processes, lines and food products, are an important contribution to this, as well as the limitations of robot arm solutions concerning these aspects.

Secondly, this study contributes to the knowledge and literature of technology readiness levels by linking these levels to investment plans and decision making processes considering manufacturing investments. The contribution is that this study supplements and extends the knowledge of technology readiness levels and manufacturing investment decision processes with findings of investment and integration processes of robot arm solutions in the food industry. These findings include in which technology readiness levels the most challenges rise and which challenges cause investment holdback. Olechowski et al. (2020) have concluded in which TRL's the most challenges come up. Their study concluded that development difficulty in TRL3 is the highest. This study supports this partially as TRL3 is the second biggest cause of investment holdback. However, Olechowski et al. (2020) conclude that development difficulty is low in TRL8, in contrast to this study in which TRL8 is the biggest reason of investment hold back. Moreover, the complexity of the challenges is mapped to provide theoretical insights into these challenges, the causes of these challenges and why particular challenges are not met or solved.

Lastly, this study extends the knowledge of TRL9 'MT ROLL-OUT" and the TAM literature by combining and relating the factors of the TAM with the challenges of robot arm solution investment and integration in the food industry. Within this extension the focus is on which (sub) factors of existing TAMs are applicable to both the problem and the solution. This contribution extends the TAM knowledge by addressing solution-oriented ways to create technology acceptance among production workers and technical staff, in which connections are made with (sub)factors of the TAM. Additionally, this study contributes the TAM knowledge by indicating which TAM factors are important when it comes down to robot arm solutions. ‘Subjective norm’, ‘perceived enjoyment’, ‘ethical implication’, ‘self-efficacy’ and ‘robot anxiety’ are the factors that are vital concerning robot arm solutions at food producing organizations.

5.3 Practical implications

Besides the theoretical relevance, this study has some practical relevance’s as well. This study aimed to be relevant for organizations in the food industry as well as for technology suppliers of these organizations. The findings from this research provide multiple useful practical implications for both technology suppliers and food producing companies.

The first practical implication is that this study can practice as a guidance tool for potential investments in robot arm solutions in the food industry, as this study moved through all the technology readiness levels and has discovered several challenges and solutions. This tool, that shows which elements are important and which challenges come up for each TRL, can be found in appendix 2. Results concerning the technology readiness levels generate knowledge of challenges which hold back investments in robot arm solutions, in which the focus is on the technical aspects. Several technical factors are highly influential, such as the functioning possibilities and limitations of gripper and vision systems, the productivity levels, the product and process diversity, the type of production process and the integration into this process. This knowledge can be used by food producing companies for different purposes. Firstly, to find out if investment in a robot arm solution for a certain production process or production line is possible. Secondly, to find out what challenges companies are likely to face when considering an investment. Besides the focus on the technical aspects, the acceptance among employees is a vital aspect as well.

The second practical implication is that this study can be useful for organizations to create technology acceptance among employees. This study provides solution-oriented information to create robot arm solution acceptance among both production workers and technical staff. Firstly, it appears that, explaining that investment in robot arm solutions is not only beneficial to the organization but to the production workers as well, is effective to create acceptance among production workers. In this explanation, the working arguments are the focus on better working conditions, more enjoyable work activities and explaining why a financially healthy organization is better for them than an unhealthy organization. Secondly, training technical personnel to understand robot arm solutions turns out to be a solution to decrease ‘robot anxiety’ among technical staff.

Furthermore, this study teaches organizations to focus on robot arm solutions for new lines to invest in, instead of the integration into current production lines. Moreover, this study teaches organizations not to think about replacing the human workforce with robot arm solutions since robot arm solutions do not have the same characteristics as the human workforce.

5.4 Limitations and future research

Despite the fact that this study has found useful theoretical and practical results, this study also has its limitations. This study has found insights concerning robot arm solutions in the food industry. However, some limitations have to be taken into account.

This study researched different reasons why organizations in the food industry do not invest in robot arms. One important reason is that the gripper and the vision, in combination with the food product, result in challenges that can lead into a holdback of investment. However, this study did not go into the characteristics of the products including which characteristics are most vital and which do not play a role in this case. Therefore, by not considering product characteristics, this study cannot show which products result in which challenges and why. However, only the characteristics of food products are challenging for the gripper and vision system. Future research concerning this topic could result in a study which tells which product characteristics should be treated/handled by which manners in order to find out how certain products can be handled in the most effective way. A central research question of this study can be the following: “what is the most effective way to deal with the different characteristics of food products?” Another research question, in relation to this study, could be “to what extend does the diversity of the characteristics of food products affect the ability of robot arm solutions to deal with food products?” Additionally, it could be useful to test the hypothesis ‘product diversity causes misfunction of robot arm solutions and the critical functions’, in order to qualitatively confirm one of the conclusions of this study.

Future research concerning this topic could be done in a quantitatively way, based on tests with robot arm solutions with different critical function components and different food products. These tests could result in failure and success ratio's per combination of critical functions and food products in order to find out which combinations are successful. The knowledge about which combinations are successful and which are not could be of value for organizations in the food industry considering an investment in robot arm solutions.

The focus of this study has mainly been on companies that have not integrated robot arm solutions into their processes as the focus was on the challenges and reasons why investments were not made. Addressing companies in which robot arm solutions are integrated could help to gain new insights. These insights could possibly include tactics/strategies and/or technical solutions that can overcome certain challenges. By juxtaposing this future study with this study, successful investments processes and unsuccessful investment processes can be compared in order to find out possible actions or changes that can help to turn unsuccessful investments into a success.

References:

Ahmad Nayik, G. (2015). Robotics and Food Technology: A Mini Review. *Journal of Nutrition & Food Sciences*, *05*(04). https://doi.org/10.4172/2155-9600.1000384

Allen, D. (1999). The role of risk in contract choice. *Journal of Law, Economics, and Organization*. https://doi.org/10.1093/jleo/15.3.704

Avermaete, T., Viaene, J., Morgan, E. J., Pitts, E., Crawford, N., & Mahon, D. (2004). Determinants of product and process innovation in small food manufacturing firms. *Trends in Food Science and Technology*, *15*(10), 474–483. https://doi.org/10.1016/j.tifs.2004.04.005

Balch, T. (1999). Impact of diversity on performance in multi-robot foraging. *Proceedings of the International Conference on Autonomous Agents*. https://doi.org/10.1145/301136.301170

Beer, J. M., Prakash, A., Mitzner, T. L., Rogers, W. a. (2011). Understanding Robot Acceptance. *Georgia Institute of Technology*.

Bertaux, D. (1981). From the life-history approach to the transformation of sociological practice. *Biography and Society: The Life History Approach in the Social Sciences*.

Bloss, R. (2013). Robots use machine vision and other smart sensors to aid innovative picking, packing and palletizing. *Industrial Robot*. https://doi.org/10.1108/IR-12-2012-450

Bröhl, C., Nelles, J., Brandl, C., Mertens, A., & Schlick, C. M. (2016). TAM reloaded: A technology acceptance model for human-robot cooperation in production systems. *Communications in Computer and Information Science*, *617*, 97–103. https://doi.org/10.1007/978-3-319-40548-3_16

Caldwell, D. G. (2013). Robotics and automation in the food industry. In *Robotics and automation in the food industry*. https://doi.org/10.1533/9780857095763

Carmack, W. J., Braase, L. A., Wigeland, R. A., & Todosow, M. (2017). Technology readiness levels for advanced nuclear fuels and materials development. *Nuclear*

Engineering and Design. https://doi.org/10.1016/j.nucengdes.2016.11.024

Castillo-Montoya, M. (2016). Preparing for interview research: The interview protocol refinement framework. *Qualitative Report*.

Chiu, Y. C., Chen, S., & Lin, J. F. (2013). Study of an autonomous fruit picking robot system in greenhouses. *Engineering in Agriculture, Environment and Food*. https://doi.org/10.1016/S1881-8366(13)80017-1

Cramer, J., Cramer, M., Demeester, E., & Kellens, K. (2018). Exploring the potential of magnetorheology in robotic grippers. *Procedia CIRP*. https://doi.org/10.1016/j.procir.2018.01.038

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly: Management Information Systems*, *13*(3), 319–339. https://doi.org/10.2307/249008

Day, C. P. (2018). Robotics in Industry—Their Role in Intelligent Manufacturing. In *Engineering* (Vol. 4, Issue 4, pp. 440–445). Elsevier Ltd. https://doi.org/10.1016/j.eng.2018.07.012

Dirican, C. (2015). The Impacts of Robotics, Artificial Intelligence On Business and Economics. *Procedia - Social and Behavioral Sciences*, *195*, 564–573. https://doi.org/10.1016/j.sbspro.2015.06.134

Durst, S., & Edvardsson, I. R. (2012). Knowledge management in SMEs: A literature review. In *Journal of Knowledge Management*. https://doi.org/10.1108/13673271211276173

Eisenhardt, K. M., & Graebner, M. E. (2007). Theory Building from Cases : Opportunities and Challenges Linked references are available on JSTOR for this article : THEORY BUILDING FROM CASES : OPPORTUNITIES AND CHALLENGES. *Organizational Research Methods*, *50*(1), 25–32. https://doi.org/10.1177/0170840613495019

Ellis, N. (2010). Business to Business Marketing: Relationships, Networks and Strategies. In *Oxford University Press*.

Fill, C., & Fill, K. (2005). Business-to-business Marketing: Relationships, Systems and Communications. *Prentice Hall*.

Food Safety Hazards. (2012). In *The Food Safety Hazard Guidebook* (pp. 1–6). Royal Society of Chemistry. https://doi.org/10.1039/9781849734813-00001

Galvin, R. (2015). How many interviews are enough? Do qualitative interviews in building energy consumption research produce reliable knowledge? *Journal of Building Engineering*. https://doi.org/10.1016/j.jobe.2014.12.001

Hofmann, E., & Rüsch, M. (2017). Industry 4.0 and the current status as well as future prospects on logistics. *Computers in Industry*, *89*, 23–34. https://doi.org/10.1016/j.compind.2017.04.002

Holmes, J. F., & Holcombe, W. D. (2010). Guidelines for designing washdown robots for meat packaging applications. *Trends in Food Science and Technology*. https://doi.org/10.1016/j.tifs.2009.08.003

Hua Tan, K., Peng Lim, C., Platts, K., & Shen Koay, H. (2006). An intelligent decision support system for manufacturing technology investments. *International Journal of Production Economics*, *104*(1), 179–190. https://doi.org/10.1016/j.ijpe.2005.02.010

Huang, S. J., Chang, W. H., & Su, J. Y. (2017). Intelligent robotic gripper with adaptive grasping force. *International Journal of Control, Automation and Systems*. https://doi.org/10.1007/s12555-016-0249-6

IFR. (2017). *Executive Summary World Robotics 2017 Industrial Robots*. World Robotic Report.

International Federation of Robotics, I. (2018). Robots and the Workplace of the Future. *IFR, International Federation of Robotics*.

Iqbal, J., Khan, Z. H., & Khalid, A. (2017a). Prospects of robotics in food industry. *Food Science and Technology*, *37*(2), 159–165. https://doi.org/10.1590/1678-457X.14616

Iqbal, J., Khan, Z. H., & Khalid, A. (2017b). Prospects of robotics in food industry. *Food Science and Technology*. https://doi.org/10.1590/1678-457X.14616

Jørgensen, T. B., Jensen, S. H. N., Aanæs, H., Hansen, N. W., & Krüger, N. (2019). An Adaptive Robotic System for Doing Pick and Place Operations with Deformable Objects. *Journal of Intelligent and Robotic Systems: Theory and Applications*.

https://doi.org/10.1007/s10846-018-0958-6

Jung, T. J., & Oh, J. H. (2013). Design of a robot gripper for a rapid service robot. *IFAC Proceedings Volumes (IFAC-PapersOnline)*, *46*(5), 319–324. https://doi.org/10.3182/20130410-3-CN-2034.00110

Keller, M., Baum, G., Schweizer, M., Bürger, F., Gommel, U., & Bauernhansl, T. (2018). Optimized Robot Systems for Future Aseptic Personalized Mass Production. *Procedia CIRP*. https://doi.org/10.1016/j.procir.2018.03.066

Kodama, F. (1986). Japanese innovation in mechatronics technology. *Science and Public Policy*. https://doi.org/10.1093/spp/13.1.44

Kotsanopoulos, K. V., & Arvanitoyannis, I. S. (2017). The Role of Auditing, Food Safety, and Food Quality Standards in the Food Industry: A Review. *Comprehensive Reviews in Food Science and Food Safety*, *16*(5), 760–775. https://doi.org/10.1111/1541-4337.12293

Kroh, J., Luetjen, H., Globocnik, D., & Schultz, C. (2018). Use and Efficacy of Information Technology in Innovation Processes: The Specific Role of Servitization. *Journal of Product Innovation Management*. https://doi.org/10.1111/jpim.12445

Li, N. (2008). Lead-alloy coolant technology and materials - technology readiness level evaluation. *Progress in Nuclear Energy*. https://doi.org/10.1016/j.pnucene.2007.10.016

Lien, T. K. (2012). Gripper technologies for food industry robots. In *Robotics and Automation in the Food Industry: Current and Future Technologies*. https://doi.org/10.1533/9780857095763.1.143

Logatcheva, K., Bakker, T., Oosterkamp, E., Galen van, M., & Bunte, F. (2013). *Innovatie in de Nederlandse levensmiddelenindustrie; De rol van het mkb*. https://www.wur.nl/upload_mm/8/4/4/e286a97b-288d-4e49-a344-2b9f599dd9e0_2013-025 Logetcheva_def_WEB VERSIE.pdf

Logatcheva, Katja, Bakker, T., Oosterkamp, E., Van, M., & Bunte, G. F. (2013). *2013-025 Innovation in the Dutch food industry; The role of the SMEs*.

Mankins, J. C. (2009). Technology readiness assessments: A retrospective. *Acta*

Astronautica, *65*(9–10), 1216–1223. https://doi.org/10.1016/j.actaastro.2009.03.058

Masey, R. J. M., Gray, J. O., Dodd, T. J., & Caldwell, D. G. (2010). Guidelines for the design of low-cost robots for the food industry. *Industrial Robot*. https://doi.org/10.1108/01439911011081650

Michalos, G., Makris, S., Tsarouchi, P., Guasch, T., Kontovrakis, D., & Chryssolouris, G. (2015). Design considerations for safe human-robot collaborative workplaces. *Procedia CIRP*. https://doi.org/10.1016/j.procir.2015.08.014

Murphy, R. R. (2000). Introduction to AI robotics. *BJU International*. https://doi.org/10.1111/j.1464-410X.2011.10513.x

N.E.M.A. (2004). Ansi/Iec 60529-2004. *National Electrical Manufacturers Association*, 8. www.nema.org

Neal, A. L. (1991). Improving productivity. *National Conference Publication - Institution of Engineers, Australia*, *91* pt *18*, 217–220. https://doi.org/10.4018/ijrat.2016010103

Nemec, B., Gams, A., Deniša, M., & Ude, A. (2014). Human-robot cooperation through force adaptation using dynamic motion primitives and iterative learning. *2014 IEEE International Conference on Robotics and Biomimetics, IEEE ROBIO 2014*. https://doi.org/10.1109/ROBIO.2014.7090536

Noor Hasnan, N. Z., & Yusoff, Y. M. (2018). Short review: Application Areas of Industry 4.0 Technologies in Food Processing Sector. *2018 IEEE 16th Student Conference on Research and Development, SCOReD 2018*. https://doi.org/10.1109/SCORED.2018.8711184

Olechowski, A. L., Tomaschek, K., Eppinger, S. D., & Joglekar, N. (2020). *Technology readiness levels : Shortcomings and improvement opportunities*. *January*, 1–14. https://doi.org/10.1002/sys.21533

Pettersson, A., Davis, S., Gray, J. O., Dodd, T. J., & Ohlsson, T. (2010). Design of a magnetorheological robot gripper for handling of delicate food products with varying shapes. *Journal of Food Engineering*, *98*(3), 332–338. https://doi.org/10.1016/j.jfoodeng.2009.11.020

Pettersson, A., Ohlsson, T., Davis, S., Gray, J. O., & Dodd, T. J. (2011). A hygienically designed force gripper for flexible handling of variable and easily damaged natural food products. *Innovative Food Science and Emerging Technologies*, *12*(3), 344–351. https://doi.org/10.1016/j.ifset.2011.03.002

Pfeiffer, S. (2017). The Vision of “Industrie 4.0” in the Making—a Case of Future Told, Tamed, and Traded. *NanoEthics*. https://doi.org/10.1007/s11569-016-0280-3

Pires, J. N. (2006). Robotics for small and medium enterprises: control and programming challenges. *Industrial Robot: An International Journal*, *33*(6). https://doi.org/10.1108/ir.2006.04933faa.002

Qin, Y., & Ahmed, F. (2017). A conceptual model for impact of employee readiness for E-business on technology acceptance. *2017 7th International Workshop on Computer Science and Engineering, WCSE 2017*. https://doi.org/10.18178/wcse.2017.06.231

Qureshi, M. O., & Syed, R. S. (2014). The impact of robotics on employment and motivation of employees in the service sector, with special reference to health care. *Safety and Health at Work*, *5*(4), 198–202. https://doi.org/10.1016/j.shaw.2014.07.003

Ranney, M. L., Meisel, Z. F., Choo, E. K., Garro, A. C., Sasson, C., & Morrow Guthrie, K. (2015). Interview-based Qualitative Research in Emergency Care Part II: Data Collection, Analysis and Results Reporting. In *Academic Emergency Medicine* (Vol. 22, Issue 9, pp. 1103–1112). Blackwell Publishing Inc. https://doi.org/10.1111/acem.12735

Rao, R. V., Patel, B. K., & Parnichkun, M. (2011). Industrial robot selection using a novel decision making method considering objective and subjective preferences. *Robotics and Autonomous Systems*, *59*(6), 367–375. https://doi.org/10.1016/j.robot.2011.01.005

Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, M. (2015). *Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries*.

Russo, M., Ceccarelli, M., Corves, B., Hüsing, M., Lorenz, M., Cafolla, D., & Carbone, G. (2017). Design and test of a gripper prototype for horticulture products. *Robotics and Computer-Integrated Manufacturing*. https://doi.org/10.1016/j.rcim.2016.09.005

Sam, R., & Nefti, S. (2010). Design and feasibility tests of multi-functional gripper for handling variable shape of food products. *Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics*. https://doi.org/10.1109/ICSMC.2010.5642431

Saunders, B., Sim, J., Kingstone, T., Baker, S., Waterfield, J., Bartlam, B., Burroughs, H., & Jinks, C. (2018). Saturation in qualitative research: exploring its conceptualization and operationalization. *Quality and Quantity*. https://doi.org/10.1007/s11135-017-0574-8

Shukla, A., & Karki, H. (2016). Application of robotics in onshore oil and gas industry-A review Part i. *Robotics and Autonomous Systems*, *75*, 490–507. https://doi.org/10.1016/j.robot.2015.09.012

Sohn, S. Y., Gyu Joo, Y., & Kyu Han, H. (2007). Structural equation model for the evaluation of national funding on R&D project of SMEs in consideration with MBNQA criteria. *Evaluation and Program Planning*, *30*(1), 10–20. https://doi.org/10.1016/j.evalprogplan.2006.10.002

Surendran, P. (2012). Technology Acceptance Model : A Survey of Literature. *International Journal of Business and Social Research*.

Tsarouchi, P., Makris, S., Michalos, G., Stefos, M., Fourtakas, K., Kaltsoukalas, K., Kontrovrakis, D., & Chryssolouris, G. (2014). Robotized assembly process using Dual arm robot. *Procedia CIRP*, *23*(C), 47–52. https://doi.org/10.1016/j.procir.2014.10.078

Tsarouchi, P., Spiliotopoulos, J., Michalos, G., Koukas, S., Athanasatos, A., Makris, S., & Chryssolouris, G. (2016). A Decision Making Framework for Human Robot Collaborative Workplace Generation. *Procedia CIRP*, *44*, 228–232. https://doi.org/10.1016/j.procir.2016.02.103

Venkatesh, V., & Davis, F. D. (2000). Theoretical extension of the Technology Acceptance Model: Four longitudinal field studies. *Management Science*, *46*(2), 186–204. https://doi.org/10.1287/mnsc.46.2.186.11926

Wang, X. V., Kemény, Z., Váncza, J., & Wang, L. (2017). Human–robot collaborative assembly in cyber-physical production: Classification framework and implementation. *CIRP Annals - Manufacturing Technology*, *66*(1), 5–8.

https://doi.org/10.1016/j.cirp.2017.04.101

Wang, Z., Torigoe, Y., & Hirai, S. (2017). A Prestressed Soft Gripper: Design, Modeling, Fabrication, and Tests for Food Handling. *IEEE Robotics and Automation Letters*. https://doi.org/10.1109/LRA.2017.2714141

World Health Organization/ FAO. (2003). Assuring Food Safety and Quality. *Who/Fao*.

Yin, R. K. (1994). Applied social research methods series. In *Case study research: Design and methods*.

Zhou, D., Holmes, J., Holcombe, W., Thomas, S., & McMurray, G. (2007). Design of a fresh meat packing robot for working in washdown environment. *IEEE/ASME International Conference on Advanced Intelligent Mechatronics, AIM*. https://doi.org/10.1109/AIM.2007.4412481

Appendices:

Appendix 1: Case study:

Table 8, case study

Sector	Convenience
Product	Wraps
Application	Pick and place
	From stack to belt
In-line	Yes, begin of line solution
Product characteristics	Sticky, vulnerable, flexible
Productivity requirements	30 pet minute

The assignment

The main goal of the customer was to eliminate the human workforce in the production by replacing them with robot arms. One person per line was assigned to pick and place wraps. The wraps arrived in plastic bags, in which 60 wraps are stacked on each other. The person takes the wraps out of the bags and picks and places the wraps one-by-one at the beginning of two lines. The two lines run parallel next to each other, with 15 centimeters space between the belts.

The plan/idea of the solution

The plan of the solution will be described in the different steps which describe the solution and how it works. The plan is to supply unbagged stacks of wraps on an extra conveyor belt. The reasons for this is that several bags can be unbagged and places on the belt so that production can continue without having to stop for wrap supply. The extra conveyor belt supplies the robot arm with stacks of wraps. The setup of the solution can be found in figure 4 and figure 5 at the end of this section.

When a stack comes within the range of the robot arm, the vision focuses on the new stack. A vision system has been selected to anticipate on the range of the robot arm, the height of the stack and the shape of the product. The stack of wraps must be unstacked one by one, by the robot arm and the attached gripper.

An industrial gripper with vacuum function has been selected to pick the products from the stack. A gripper with ‘fingers’ was not possible because the wraps are thin and stacked on each other. These characteristics make it impossible for an industrial gripper with finger joint to pick and place the products. The vacuum function sucks the wrap to the gripper, then the wrap can be moved and be placed on one of the two conveyor belts. Moving and placing the wraps was not a problem and went well. Without counting the failures, the productivity requirement of 30 per minute was met. The robot arm solution achieved an average 38 per minute. The problem occurred when picking up the wraps from the stack. The problem is explained in the next section.

Figure 4, case study set up

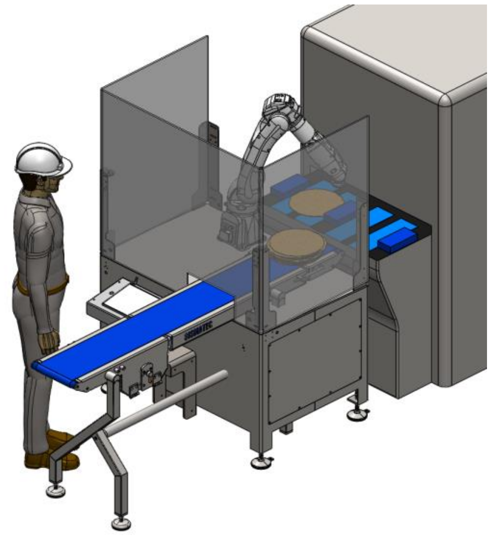
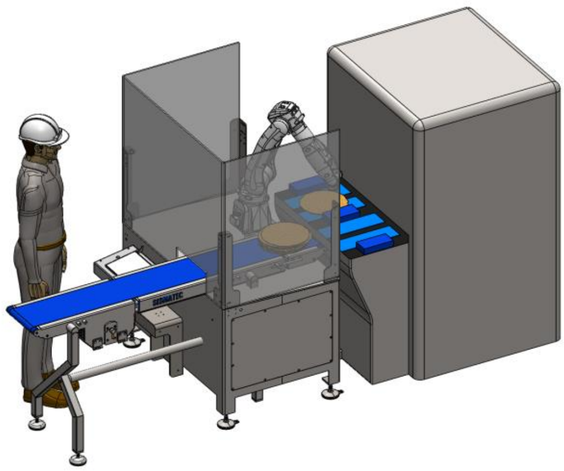


Figure 5, case study set up two



Challenge/problem

The problem was to pick up the wraps one-by-one from the stack. This is a challenge because the wraps are sticky and stick to each other when trying to take them apart. Due to the stickiness of the wraps, the wraps stick together. Because of this, the robot arm solution cannot pick up the wraps one-by-one. This problem occurred several times per stack. Therefore, the problem depends on the diversity of the products and the stickiness per product since not all the wraps stick together.

In this case, the reason that the robot arm solution does not work for this function is the combination of the gripper, product and the way of stacking in the line. However, the problem comes up because the products are stacked at the beginning of the line . Picking and placing wraps that are not stacked is possible and supported by tests. The way of the wraps are supplied, creates the problem with picking up the wraps. So, in this case study the reason for the misfunction is the combination of the gripper, the product and the line process. As the way of arrival and stacking of these products are part of the production line.

Next steps

No other solutions have been found to solve this unstacking problem. No mechanical solutions or other grippers are found that can handle this task. The problem is the stickiness of the wraps and that the wraps are stacked on each other. The next step would be to discuss with the wrap manufacturer if they can produce a less sticky wraps to create stacks of wraps that can be taken apart more easily.

However, due to the COVID-19 virus, the project has been put on hold and no further steps can be taken.

Conclusion

The assignment of automation at the investor was to realize a begin-of-line solution with a robot arm to pick and place wraps. A setup has been realized and tested. When testing, the problem of picking up the wraps from a stack came up. The wraps stuck together several times. Because of this, wraps could not be picked up one-by-one, which was necessary for the function. Until now no solutions are found to solve this problem. Therefore, this problem should be considered a reason for investment holdback, in this case study. The core of the problem is that the combination of the gripper, the product and the way of product supply in line results in a misfunction of the robot arm solution.

Appendix 2: Guidance tool

The results of this study can be combined in a guidance tool for organizations in the food industry considering to invest in robot arm solutions. In several TRL's challenges come up to consider before investing. This tool (figure 9) displays the important elements of the challenges that come up in all the levels and discusses if it can cause a holdback of investment.

Table 9, guidance tool

TRL1	
Content - basic principles observed and reported Vital elements - hygiene and food safety	Hygiene and food safety are two factors to pay attention to. Both are no reasons to hold back investment.
TRL2	
Content - technology concept and/or application formulated Vital elements - pick and place applications	Applications for robot arm solutions can be found in the food industry, but not all applications are possible. Pick and place solutions are most interesting and suitable.
TRL3, TRL4 and TRL5	
Content - analytical and experimental critical function and/or characteristic proof-of-concept - component and/or breadboard validation in a laboratory environment - component and/or breadboard validation in the relevant environment Vital elements - product diversity - functions and activities of the critical functions - productivity demands	Gripper and vision in combination with the production can cause problems concerning the investment. - Products: diversity of product batches and product characteristics create challenges. This gets better as the diversity becomes less. - Situation: the function/activities of the critical functions create challenges. This gets better as the feature becomes more standard and repetitive. - Productivity: productivity demands can become a problem as product diversity and the situation do create challenges.
TRL6 and TRL7	

Content - system/sub-system model or prototype demonstration in a relevant environment - system prototype demonstration in the expected operational environment Vital elements - representativeness of prototypes	There are hardly any prototypes in relevant and/or expected operational environments. The demonstrations/ prototypes do lack representativeness since demonstrated solutions do not fit the way of production at the company.
TRL8	
TRL8 - actual system completed and "qualified" through test and demonstration (Including the integration of new technologies into existing technologies, solutions and processes) Vital elements - degree of work task diversity - production with or without standalone machines - setup of current production lines	Challenges concerning the integration into production processes and lines can cause investment holdback. - Diversity of work tasks and products cause challenges since robot arm solutions are built for repetitive jobs. - Production with standalone machines can result in investment holdback as a result of integration challenges. - The setup of the current production lines can result in investment holdback since the ability to anticipate on task diversity, product diversity and flexibility are necessary in these lines. Robot arm solutions do not have these characteristics.
TRL9	

Content - actual system "flight proven" through successful mission operations Vital elements - acceptance amongst production workers and engineers - explanation why robot arm solutions are also beneficial for production workers - training	Acceptance amongst production workers is important when considering robot arm solution investment. - Production workers can have problems accepting robot arm solutions. - Explaining why robots arm solutions are beneficial for both the organization and the production workers is an effective manner to create acceptance. - Engineers can have problems concerning the dare to touch and repair robot arms. - Training creates knowledge amongst engineers which results in less robot anxiety.