The work described in this thesis focuses on the development of a structured approach to empower organizations to individually implement Industry 4.0 based on their corporate culture, challenges and needs using the existing human and material resources within the organization. Thereby, the Smart Retrofitting approach has been conceived which supports the hypothesis that the retrofitting of existing equipment is the most practical and suitable solution for any size of organization to engage in the implementation of Industry 4.0. The Smart part of the Smart Retrofitting focus on spreading the Industry 4.0 throughout an organization independent of its size through a continuous implementation process and a Top-down Bottom-up strategy. Implementing aspects of Industry 4.0 in their existing production equipments fulfilling the organization's established targets and demands for Industry 4.0 is the main target of the Retrofitting part of the Smart Retrofitting approach.

A change management model was developed based on the Smart Retrofitting Approach aiming to fulfill its values and purposes. The Smart Retrofitting Change Management model pursues the involvement of all employees within an organization. In order to implement the desiered Industry 4.0 vision, the Smart Retrofitting Change Management Model promotes a roadmap Smart Retrofitting Roadmap assembled in a Top-down Bottom-up strategy. In this model, the middle and lower hierarchical employees will design and execute short-, medium- and long-term projects for the implementation of Industry 4.0 within their daily business activities following the Industry 4.0 vision of their organization. In addition, the Smart Retrofitting Change Management Model suggests that the organization creates a Smart Retrofitting Agent Network which shall empower the employees from all different hierarchical levels of the organization to exchange knowledge and support each other in their activities concerning the implementation process of Industry 4.0.

The validation of the Smart Retrofitting approach occurrs gradually by applying it at a single production equipment up to a global acting organization like Henkel AG & Company, KGaA at their Adhesives Technologies business unit.

ISBN 978-3-98555-041-8

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Smart Retrofitting as a Structured Approach for an Organization to Implement Industry 4.0 Using its Existing Resources

Bruno Vallarelli Guerreiro

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Edition Wissenschaft
Apprimus

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Implementierung von Industrie 4.0-Ansätzen in Organisationen durch Smart Retrofitting unter Nutzung bestehender Ressourcen

Von der Fakultät für Maschinenwesen
der Rheinisch-Westfälischen Technischen Hochschule Aachen
zur Erlangung des akademischen Grades eines
D o k t o r s d e r I n g e n i e u r w i s s e n s c h a f t e n
genehmigte Dissertation

vorgelegt von

Bruno Vallarelli Guerreiro

Berichter/in:

Univ.-Prof. Dr.-Ing. Robert Heinrich Schmitt
apl. Prof. Dr.-Ing. Thomas Prefi

Tag der mündlichen Prüfung: 18. August 2021

Diese Dissertation ist auf den Internetseiten der Universitätsbibliothek online verfügbar.

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Smart Retrofitting as a Structured Approach for an Organization to Implement Industry 4.0 Using its Existing Resources

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Band 3/2022

WZL | RWTH AACHEN UNIVERSITY

Fraunhofer IPT

Bibliografische Information der Deutschen Nationalbibliothek
Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über https://portal.dnb.de abrufbar.

Bruno Vallarelli Guerreiro:

Smart Retrofitting as a Structured Approach for an Organization to Implement Industry 4.0 Using its Existing Resources

1. Auflage, 2022

Gedruckt auf holz- und säurefreiem Papier, 100% chlorfrei gebleicht.

Apprimus Verlag, Aachen, 2022
Wissenschaftsverlag des Instituts für Industriekommunikation und Fachmedien an der RWTH Aachen
Steinbachstr. 25, 52074 Aachen
Internet: www.apprimus-verlag.de, E-Mail: info@apprimus-verlag.de

Printed in Germany

ISBN 978-3-98555-041-8

D 82 (Diss. RWTH Aachen University, 2021)

"Those who dare to fail miserably can achieve greatly."

- John F. Kennedy

Preface

This dissertation was written in the course of my activities as a Research Assistant at the Laboratory for Machine Tools and Production Engineering (WZL) at the RWTH Aachen University and at the Fraunhofer Institute for Production Technology (IPT). This work was supported by CAPES-Coordenação de Aperfeiçoamento de Nível Superior, of the Education Ministry of the Brazilian Federal Government to which I am very thankful.

The work described in this thesis focuses on the development of a structured approach to empower organizations to individually implement Industry 4.0 based on their corporate culture, challenges and needs using the existing human and material resources within the organization. Thereby, the Smart Retrofitting approach has been conceived which supports the hypothesis that the retrofitting of existing equipment is the most practical and suitable solution for any size of organization to engage in the implementation of Industry 4.0.

First of all, I would like to thank Univ.-Prof. Dr.-Ing. Robert Schmitt for inviting me to accomplish a Doctorate at the RWTH Aachen University which has been a dream that I had since the beginning of my studies at the University Center of FEI at São Bernardo do Campo. Likewise, I want to thank apl. Prof. Dr.-Ing. Thomas Prefi for agreeing to act as second examiner and Univ.-Prof. Dr. rer. nat. Werner Karl Schomburg for agreeing to act as Assessor. Additionally, I want thank Univ.-Prof. Dr.-Ing. Christian Hopmann for agreeing to act as chairman of the examination committee.

I would also like to thank a lot Dr.-Ing. Dr. h. c. (BR) Professor h. c. (TJ) Dr. h. c. (E), Univ.-Prof. i.R. Tilo Pfeifer and Dr.-Ing. Reinhard Freudenberg for motivating and supporting me through my journey in Aachen.

I would like to give special thanks to Elke Behrendt and Dr.-Ing. Dipl.-Phys. Andreas Janssen for their motivation and support during my time in Aachen which resulted in a friendship for life. I also want to thank my dear friends Wilfried Wilhelm Kübler, Micheal Krieg, Stephan Sauer, M.Sc. Maan AlSalmi, Dipl.-Ing. Alex Lüdero, Dipl.-Ing. Jacson Doering, Dr. Jianing Sun, Mazé, M.Sc. Xintao Zhu and Luisa Ferraz do Amaral for all adventures and long talks that we had during my time in Aachen.

I am immensely grateful to Dipl.-Ing. Danilo Curtolo and M. Sc. Mayara B. Rossini, who have been helping and supporting me since our studies at the University Center of FEI which continued during our time at the RWTH Aachen University. I also want to immensely thank B. Sc. Florisa Zanier who supported and helped me during my entire time in Aachen and which friendship I will carry for my entire life. In addition, I want to thank Prof. Arthur Tamasauskas, Jorge Rudney Atalla, LL.M. Giovani Ravagnani, Caio Passini, Ing. Bruno Fausto Julio, M.Sc. Guilherme Gall Silva, BBA, Ing. Bruno de Castro Adhmann, B.Sc. Fernando Priore de Almeida, Cristina Gutierrez Valarelli, Dipl.-Ing. Axel Demmer, Dr. Dipl.-Ing. Jörg Schwelberger, Prof. Dr. Ing. Dr. h.c. Bernd Friedrich, Prof. Dr. phil. Eva-Maria Jakobs and Dipl.-Ing. Eggert Langfeldt, each of them impacted my life in a wonderful way that contributed me to accomplish this work.

I am grateful for the entire Henkel team for being part of their big community and allowing me to work and validate my Smart Retrofitting Approach within their organization. I am especially greatful to Jo Licht, M.Sc. Marcus Davis, M.Sc. Shan Lu, M.Sc. Christian Staudt, B.Sc. Neelima Rajesh, M.Sc. Shanshan Zheng. I am extremlly grateful to B.Eng. Sandeep Sreekumar who was my mentor within Henkel and which friendship I will carry for my entire life. Additionally, I want to thanks B.Eng. Subramanyam Kasibhat from the company Vegam Solutions which I had the great pleasure to work with during my time at Henkel.

I am greatful for the entire team of thyssenkrupp Rothe Erde Brasil for allowing me to perform one of my case studies within their facilities. I am specially greatful to Dr.-Ing. Wilfried Spintig, B. Ing. Francis Rocha, B. Ing. Paulo Vitor Coco, João Luís Marassi. I want to thank Univ.-Prof. Dr.-Ing Romulo Gonçalves Lins and his team for the great collaboration that we had in this case study.

I want thank a lot Janey Aparecida Maniero Atalla who, despite the circumstances of the coronavirus pandemic, has attended my Ph.D. defense and has always been present in my life. Thank you very much.

I would like to thank Dr.-Ing. Sergio Stefano Guerreiro, Monica Vieira Vallarelli Guerreiro, Gabriela Vallarelli Guerreiro, Father Paulo de Arruda D' Elboux, S.J., Asst. Prof. Dr. Kevin Begcy and Oliver Vallarelli Begcy which are my beloved family and are the most valuable and important people in my life. Without their support and love I would not have come successfully this far.

Summary

The work described in this thesis focuses on the development of a structured approach to empower organizations to individually implement Industry 4.0 based on their corporate culture, challenges and needs using the existing human and material resources within the organization. Thereby, the Smart Retrofitting approach has been conceived which supports the hypothesis that the retrofitting of existing equipment is the most practical and suitable solution for any size of organization to engage in the implementation of Industry 4.0. The Smart part of the Smart Retrofitting focus on spreading the Industry 4.0 throughout an organization independent of its size through a continuous implementation process and a Top-down Bottom-up strategy. Implementing aspects of Industry 4.0 in their existing production equipments fulfilling the organization's established targets and demands for Industry 4.0 is the main target of the Retrofitting part of the Smart Retrofitting approach.

A change management model was developed based on the Smart Retrofitting Approach aiming to fulfill its values and purposes. The Smart Retrofitting Change Management model pursues the involvement of all employees within an organization. Therefore, it is composed of a Top-down Bottom-up management approach in which the organization's own created vision and the direction to be followed is given by the highest hierarchical employees. The Industry 4.0 vision is based on current and upcoming challenges and needs that the organization faces. In order to implement the created vision, the Smart Retrofitting Change Management Model promotes a roadmap —Smart Retrofitting Roadmap— assembled in a Top-down Bottom-up strategy. In this model, the middle and lower hierarchical employees will design and execute short-, medium- and long-term projects for the implementation of Industry 4.0 within their daily business activities following the Industry 4.0 vision of their organization. The Smart Retrofitting Change Management Model has five phases: Unfreezing, Moving, Unfreezing 2.0, Refreezing and Smart Retrofitting Actions. In addition, the Smart Retrofitting Change Management Model suggests that the organization creates a Smart Retrofitting Agent Network which shall empower the employees from all different hierarchical levels of the organization to exchange knowledge and support each other in their activities concerning the implementation process of Industry 4.0. Consequently, such engagement of the employees will generate a motivational effect between them and will minimize possible internal resistances during the implementation process of Industry 4.0 within the organization.

The validation of the Smart Retrofitting approach occurrs gradually by applying it at a single production equipment up to a global acting organization. Therefore, the first case study targeted the execution of the Smart Retrofitting Approach on an over forty-year-old developed equipment which is exclusively used by the metallurgical industry sector to purify Aluminium. The second case study was accomplished at thyssenkrupp Brazil Ltda. –Division Rothe Erde– and consisted in the implementation of Industry 4.0 in their large slewing bearing production line dedicated to the wind energy industry sector. Finally, the third case study was accomplished on a global scale at Henkel AG & Company, KGaA at their Adhesives Technologies business unit.

Zusammenfassung

Diese Arbeit konzentriert auf die Entwicklung eines strukturierten Ansatzes, um Organisationen zu befähigen, Industrie 4.0 basierend auf ihrer Unternehmenskultur, ihren Herausforderungen und Bedürfnissen unter Verwendung der vorhandenen personellen und materiellen Ressourcen innerhalb der Organisation individuell umzusetzen. Dabei wurde der Ansatz Smart Retrofitting konzipiert, der die Hypothese stützt, dass die Nachrüstung vorhandener Produktionsanlagen die praktischste und geeignetste Lösung für jede Unternehmensgröße ist, um sich an der Implementierung von Industrie 4.0 zu beteiligen. Der Smart-Teil des Smart Retrofitting konzentriert sich auf die Verbreitung von Industrie 4.0 in einem Unternehmen unabhängig von seiner Größe durch einen kontinuierlichen Implementierungsprozess und eine Top-Down/Bottom-Up-Strategie. Die Implementierung von Aspekten von Industrie 4.0 in ihre vorhandenen Produktionsanlagen, die die festgelegten Ziele und Anforderungen des Unternehmens für Industrie 4.0 erfüllen, ist das Hauptziel des Retrofitting-Teils des Smart Retrofitting-Ansatzes.

Basierend auf dem Smart Retrofitting Approach wurde ein Change-Management-Modell entwickelt, das darauf abzielt, seine Werte und Zwecke zu erfüllen. Das Smart Retrofitting Change-Management-Modell verfolgt die Einbeziehung aller Mitarbeiter innerhalb einer Organisation. Daher besteht es aus einem Top-Down/Bottom-Up-Managementansatz, bei dem die von der Organisation selbst erstellte Industrie 4.0-Vision von den höchsten Hierarchieebenen erstellt wird. Die Industrie 4.0-Vision basiert auf aktuellen und bevorstehenden Herausforderungen und Bedürfnissen des Unternehmens. Um die erstellte Vision umzusetzen, bietet das Smart Retrofitting Change-Management-Modell eine Roadmap (Smart Retrofitting Roadmap), die in einer Top-Down/Bottom-Up-Strategie zusammengestellt ist. In diesem Modell entwerfen und führen die Mitarbeiter der mittleren und unteren Hierarchieebenen kurz-, mittel- und langfristige Projekte zur Implementierung von Industrie 4.0 im Rahmen ihrer täglichen Geschäftsaktivitäten gemäß der Industrie 4.0-Vision ihrer Organisation durch. Das Smart Retrofitting Change-Management-Modell besteht aus fünf Phasen: Unfreezing, Moving, Unfreezing 2.0, Refreezing und Smart Retrofitting Actions. Darüber hinaus schlägt das Smart Retrofitting Change-Management-Modell vor, dass die Organisation ein Smart Retrofitting Agent-Netzwerk erstellt, das die Mitarbeiter aller verschiedenen Hierarchieebenen der Organisation in die Lage versetzt, Wissen auszutauschen und sich gegenseitig bei ihren Aktivitäten bezüglich des Implementierungsprozesses von Industrie 4.0 zu unterstützen. Folglich wird ein solches Engagement der Mitarbeiter einen motivierenden Effekt zwischen ihnen erzeugen und mögliche interne Widerstände während des Implementierungsprozesses von Industrie 4.0 innerhalb der Organisation minimieren.

Die Validierung des Smart Retrofitting-Ansatzes erfolgt schrittweise, indem sie an einer einzelnen Produktionsanlage bis zu einer global agierenden Organisation angewendet wird. Daher zielte die erste Fallstudie auf die Durchführung des Smart Retrofitting Approach an einer über vierzigjährigen Produktionsanlage ab. Die zweite Fallstudie wurde bei thyssenkrupp Brazil Ltda –Division Rothe Erde– durchgeführt. Schließlich wurde die dritte Fallstudie weltweit bei der Henkel AG & Company, KGaA im Geschäftsbereich Adhesives Technologies durchgeführt.

I Content

II List of Abbreviations

Abbreviation	Description
AI	Artificial Intelligence
BMWi	German Federal Ministry for Economic Affairs and Energy
CAPEX	Capital expenditure
CCTV	Closed Circuit Television
CDO	Chief Digital Officer
CEO	Chief Executive Officer
CFO	Chief Financial Officer
CPS	Cyber-Physical System
DLSR-camera	Digital single-lens reflex camera
HMI	Human-machine interaction
HR	Human resources
IR camera	Infrared camera
ICT	Information and communications technology
IT	Information technology
M2M	Machine-to.machine
OEE	Overall equipment effectiveness
OPE	Overall plant effectiveness
SCOR	Supply chain operations reference
SHE	Safety, health and environment

SMEs	Small and medium-sized enterprises
TQM	Total quality management

III List of Symbols

Symbols	Unit	Description
C_s		Impurity in the solid phase
C_L		Impurity concentration in the liquid phase
C_0		Impurity concentration
D	m^2/s	Diffusion coefficient of the impurity in the base metal
k		Impurities' distribution coefficient
k_{eff}		Effective distribution coefficient
m		Slope of the solidus line in a binary phase diagram
T	K	Temperature
V	m/s	Velocity of the freezing interface
δ	m	Thickness of the diffusion layer

IV List of Figures

V List of Tables

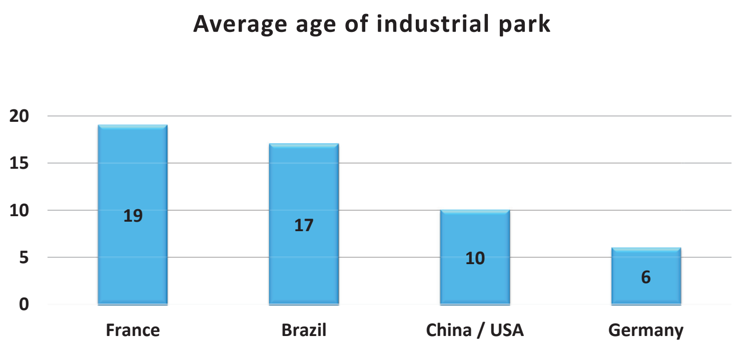
1 Introduction

A journey of a thousand miles begins with a single step.

Lao Tzu

The fourth industrial revolution took its breakthrough in 2013 in Germany [KAGE13; BAUE14b]. Approximately five years before, the hardest financial crisis in the last seventy years took place worldwide and its consequences are still being notice today [CHEN19]. In contrast to the financial crisis which reduced the economic activity worldwide, the fourth industrial revolution —Industry 4.0— has the potential to increase the economic activity and expand it to higher levels than prior to the 2008 crisis by creating new markets and business models for organizations. The successful roll-out of the fourth industrial revolution will have a direct impact on the economic and social prosperity of a country and therefore, it does not limit itself to maintain or increase a market position of a certain organization.

Many of the industrialized countries today have old industrial parks (see Figure 1-1) that still completely fulfill the production requirements and in many cases are mostly amortized. Therefore, it is not mandatory to substitute most of the production equipments to continue its market presence, but these industrial parks do not operate according to new possibilities that the fourth industrial revolution can provide.



Based on the content of [HAGE14; SCHM17b]

Figure 1-1 Average age of industrial parks of some industrialized countries

Besides the fact that organizations might have in common industrial parks not designed for the fourth industrial revolution, each organization mostly has an unique corporate culture which reflects the execution of its daily business and the way it reacts to future challenges and changes in the industrial and financial world [SIMO03].

The two above mentioned observations were the main drivers for the development of a structured approach to empower organizations to individually implement Industry 4.0 based on their corporate culture, challenges and needs using the existing human and material resources within the organization.

Especially SMEs are in competitive disadvantage in terms of available resources compared to larger organizations for the implementation of Industry 4.0 [WISC15]. This fact reinforced even further the author of this dissertation to offer an approach to implement Industry 4.0 through a retrofitting perspective using all available resources in the organization, valid for organizations of all sizes including SMEs. The importance of offering to SMEs an approach to implement Industry 4.0 is of extreme importance for Germany, for instance, since over 90% of the German companies have less than 250 employees and so are classified as SMEs [LICH18].

Motivated by the above described scenarios, this dissertation seeks to implement aspects of Industry 4.0 and answer the following research questions:

Main research question

Is it possible to use a Smart Retrofitting Approach to guarantee that aspects of Industry 4.0 can be applied to technologically outdated machine parks?

Sub-research questions

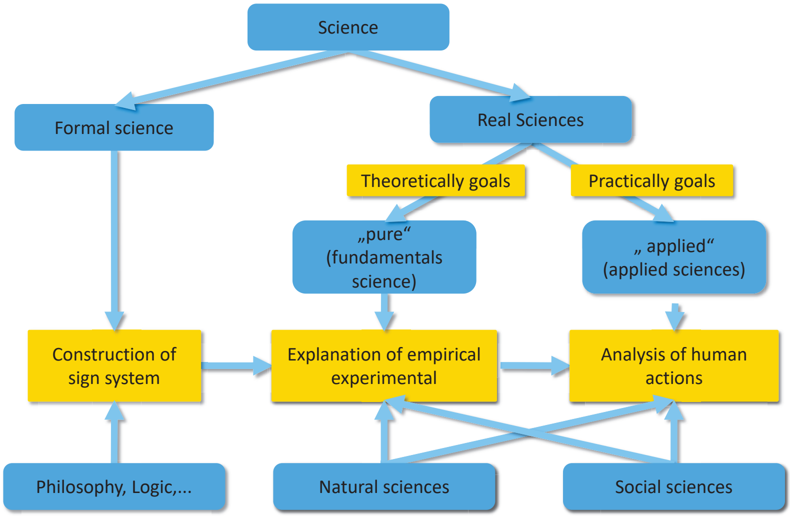
1. *What is the main characteristic of an operational Industry 4.0 machine park?*
2. *Which aspects of Industry 4.0 can be transferred to a technologically outdated machine park?*
3. *How does Smart Retrofitting differ from classic retrofitting?*
4. *How would the approach or the methodology look like for a Smart Retrofitting to be carried out in an outdated machine park in an organization?*

2 Scientific-technical framework and definition of terms

This chapter will shortly explain the scientific foundations of engineering science (see Chapter 2.1) and based on these foundations the structure of this dissertation will be explained (see Chapter 2.2). At last, some fundamental terms used within this dissertation will be defined (see Chapter 2.3).

2.1 Scientific theory

At the core of the science is the development of theoretical analyses and scientifically based results, which enables the proposed research questions to be answered. As defined by Ulrich, science can be divided into two main categories: formal and real sciences (see Figure 2-1) [ULRI76].



Following the style and content of [ULRI76, S. 305]

Figure 2-1 Initiation of science according to Ulrich

The formal science focuses on the acquisition of basic knowledge in order to describe, explain and predict the behaviour of formal structured systems. For this, the development of theory is used so that causal relationships in the examined system are explained based on general legalities and fundamental principles [BUNG74; KUBI76; ULRI76; ULRI81]. Philosophy, logic and mathematics are the application fields of formal science (see Figure 2-1) [ULRI76].

In contrast, the real sciences intend to describe and explain practical problems [KUBI76]. The real sciences are divided into two sub-categories: fundamental and applied sciences (see Figure 2-1) [ULRI76]. Fundamental sciences are dedicated to describing and explaining observable incidents, events and phenomena. In contrast, the applied sciences is focused on the analysis of alternative action in order to design social and technical systems [ULRI76; ULRI81; KUBI76]. Consequently, the engineering science is attributed to the applied sciences [BUNG74; ULRI76].

According to ULRICH, there are four different options for setting goals within business sciences which consequently can be applied to real science and therefore to the engineering sciences:

1. Elaborate content-related solutions to concrete practical problems,
2. elaborate solution processes for concrete practical problems,
3. design models to change the social reality,
4. elaborate rules for the development of such design models in the practical setting on its own.

[ULRI81, S. 11]

Concerning the previously mentioned main research question (see Chapter 1) and the procedure developed in the following sub-chapters to answer this question (see Chapter 2.2), this dissertation can essentially be regarded as belonging to the third point above.

2.2 Structure of the dissertation

As defined by Ulrich, a research work in applied sciences is carried out through seven steps. However, these seven steps are not to be carried out strictly linear and therefore iterations between them are considered and necessary [ULRI81]. How these seven steps are respective and followed in this dissertation is illustrated in the figure below (see Figure 2-2).

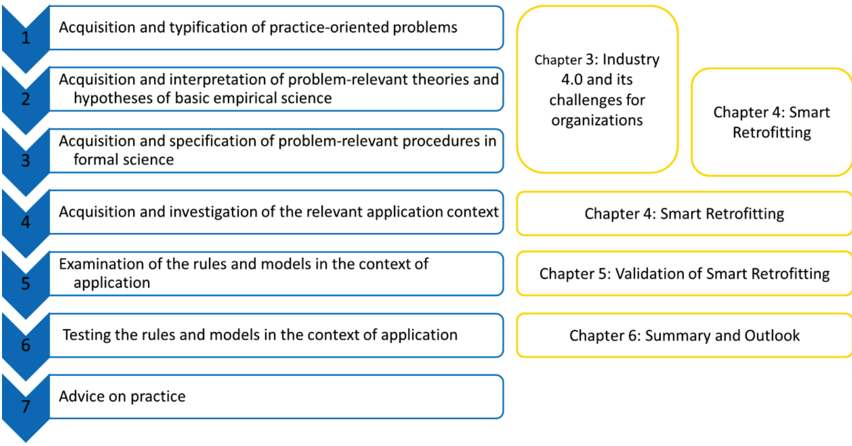


Figure 2-2 Structure of the dissertation based on Ulrich

The third chapter describes the problematic and challenges that current organizations are facing to implement Industry 4.0. Since there is not a consolidated definition of Industry 4.0, the third chapter provides an interpretation of the several existing interpretations of Industry 4.0.

Additionally, the third chapter answers the first and the second sub-research questions presented in the introduction of this dissertation.

The fourth chapter presents in its first sub-chapter all characteristics and the two components that compose the Smart Retrofitting Approach. The tailor-made developed change management model of the Smart Retrofitting Approach is explained in the second sub-chapter. Further details concerning the nineteen steps of the Smart Retrofitting Change Management Model are provided in the third sub-chapter. The third and the fourth sub-research questions are answered in this chapter.

All three validation case studies are explored in the fifth chapter of this dissertation and the last chapter summarizes the entire dissertation providing an outlook for further research needs in the implementation approach of Industry 4.0 and answers the main research question.

2.3 Definition of terms

This sub-chapter is dedicated to defining some terms that are from crucial importance for this dissertation and will support the understanding of the proposal Smart Retrofitting Approach. The definition and classification concerning Industry 4.0 will be provided in detail in the following chapter (see Chapter 3.1) and therefore will be not explored in the following text.

2.3.1 Change Management

Change management deals with the implementation of changes within an organization which can be triggered internally or externally [JICK03; LAUE14; MORA01; DOPP98]. Additionally, the cause for a change can be related to individuals, products, technology and market [BOYA06; LAUE14] and will have an impact on the strategy, processes, structures and culture of an organization [SPIC16].

There are several change management models within the academic community. Nevertheless, all of them intend to accomplish a change with the involvement of employees that shall be affected by those changes and therefore avoiding possible resistance of employees concerning the change [LAUE14; DOPP08; MENT02a]. In addition, all models present individual steps which are strategically planned, controlled, monitored and stabilized to enable the accomplishment of the desired change [MENT02a; MÜLL13b; DOPP08; BURN04b; JICK91; JICK93; KOTT12; KOTT08; LAUE14; SPIC16]. Nevertheless, each change management model has its own characteristics and therefore can tend to have a management or socio-psychological oriented approach [SCHU11]. However, they all possess the three fundamental elements within their models [LAUE14; DOPP96; KOST09]:

- Structure
- Culture
- Individual

2.3.2 Corporate culture

The anthropologist Alfred Louis Kroeber and Clyde Kluckhohn summarized and defined culture as: The set of habitual and traditional ways of thinking, feeling, and reacting that are characteristic of the ways a particular society meets its problems at a particular point in time. [KROE52, S. 56]. Similarly, to the definition of culture, the corporate culture is a pattern of beliefs and expectations shared by the organization's members which produce norms that powerfully shape the behaviour of individuals and groups in the organization [SCHW81, S. 33]. Additionally, Kotter suggests that corporate culture can be divided into two levels which differ themselves regarding their visibility and their resistance to change [KOTT92].

The first level of a corporate culture —that is also the most visible— is related to the behaviour patterns and style of an organization in which new employees are automatically encouraged to follow by their fellow co-workers [KOTT92]. To trigger a change within this first level is challenging and required great sensitivity from the leaders of an organization to realize the desired change. Nevertheless, it is much easier to trigger a change within the first level of a corporate culture then it is at its second level [KOTT92], since this level of the corporate culture is consciously maintained by the employees of the organization.

The second level —less visible— of a corporate culture is much deeper embedded within the organization and can be attributed as the unique identity of an organization. Consequently, this level of a corporate culture is extremely unfavourable for changes [KOTT92]. This is given from the fact that the values of the organization are so deeply embedded at the daily business activities of an employee that she or he considers them unconsciously.

2.3.3 Top-down Bottom-up management approach

As the name suggests the Top-down Bottom-up management approach is composed by two management approaches which are applied to increase the probability of executing a change process. To better understanding of the Top-down Bottom-up management approach each of its management approach will be defined separately.

A Top-down management approach is the most traditional spread within the corporate environment since, it intends to fulfill a change process which is triggered and lead by the highest management level of an organization [KOST09]. Therefore, the Top-down management approach tend to segment the organization into small rule-driven units which results to a command-and-control management style [BURN04a]. Additionally, the Top-down management approach triggers a change process from the perspective of the employees —high management— which are not directly involved with the causes that the changes will generate within the organization and therefore allowing some miss-judgment of what should be changed.

Unlike the Top-down management approach in which the trigger for the change process comes from the higher management, within the Bottom-up management approach such change process is promoted by the lower employees who identify opportunities to optimize their production processes and products. In addition, these lower employees can identify new goals and targets that the organization shall be chasing to satisfy current or future needs from the costumers [GOFF20; LAUE14].

So, within a Top-down Bottom-up management approach the higher management will provide a direction in which the change shall go, and the lower employees will be setting the goals and task that shall be achieved to fulfill the requirements established by the higher management. Additionally, the employees from lower levels will be the ones that will be elaborating and executing the projects to accomplish the established goals and tasks.

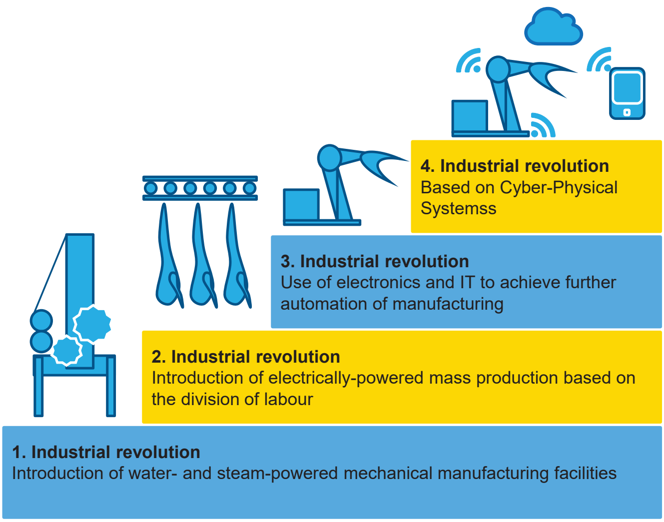
.

3 Industry 4.0 and its challenges for organizations

In the scientific community, as well as in the industry, there is no unified definition of Industry 4.0 and therefore almost each country and big organization adopts its own interpretation of the topic. Consequently, this chapter provides a summary of the main aspects and principals of Industry 4.0 (see Chapter 3.1) which shall support an organization on the elaboration of its own Industry 4.0 vision (see Chapters 4.2.6.2 and 4.3.11). In addition, the challenges that Small and Mid-sized Enterprises (SMEs) face with the implementation of Industry 4.0 will be emphasised (see Chapter 1). The reason of prioritizing in this chapter the SME is given from the fact that big multinational conglomerates are commonly composed of numerous business units which are generally also composed by several SMEs and therefore this analysis covers almost the entire current industrial scenario. Nevertheless, the importance of implementing Industry 4.0 for countries to maintain their economic and social prosperity will be also highlighted (see Chapter 1).

3.1 Industry 4.0

The first industrial revolution occurred around the middle of the eighteenth century with the introduction of water- and steam-powered mechanical manufacturing facilities in Great Britain [BAUE14b; KAGE13] (see Figure 3-1).



Following the style and content of [HENN 13, S. 13]

Figure 3-1 Illustration of the four industrial revolutions

The second industrial revolution is defined by the introduction of assembly lines in slaughterhouses in Cincinnati which initiated the concept of mass production based on the division of labour [KAGE13; VOGE17a] (see Figure 3-1). A milestone for the beginning of the third industrial revolution and the automation of the industry at a high level is the introduction of the first programmable logic controller —Modicon 084— in 1969 [HENN13; BAUE14a] (see Figure 3-1).

In contrast to the three previous industrial revolutions, the fourth industrial revolution —Industry 4.0— has been announced. The first time that the term Industry 4.0 appeared publicly was in an article of the VDI on Abril 1st of 2011 [KAGE11a] but its big breakthrough was after the Hannover fair in 2013 with the publication of the acatech report "*Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0*" [KAGE13; BAUE14b; MACD14]. This dissertation approaches the part of Industry 4.0 dedicated to the manufacturing designated by some authors and institutions as Smart Factory [KAGE13; BISC15; REIN17a; HOLZ17; GRAN18]. However, different interpretations of the topic Industry 4.0 are not limited only to the nomenclature. Instead, several countries launched their own interpretation of the new ongoing industrial era, for example [ZHON17; LIU16; ISAJ17]:

- Industrial Internet Consortium - United States of America
- Smart Manufacturing Leadership Coalition SMLC - United States of America
- Made in China 2025 - China
- Industrial Value Chain Initiative - Japan

Regardless of the different focuses of Industry 4.0, they all promise with the use of Industry 4.0 technologies the following cost reductions within an organization and its corresponding related processes [BISC15; DAIS17; GRAN18]

- Material costs
- Production costs
- Logistics costs
- Inventory costs
- Maintenance costs

Nevertheless, the benefits that Industry 4.0 promises are not related exclusively to cost savings, instead it can support and even increase the competitiveness and the market position of an organization through [BISC15; SCHM20]:

- an individualization of production and products according to the market,
- quality improvement of the products and services,
- and customer interaction during the entire production process.

Additionally, it is of extreme importance for an industrialised country to implement successfully Industry 4.0 within its industrial segment to maintain or even increase its global market footprint [KAGE16].

In contrast to what was believed by some politicians and unions in the earlier stages of the discussion of Industry 4.0, that considered the substitution the employees in a large scale, the opposite is aimed within this industrial era [WAGN18; REIN17b]. In fact, Industry 4.0 seeks to completely integrate, empower and support the employees on the execution of her or his daily business activities [REFF16; GEIS12b; BROY10; MONO16].

Industry 4.0 will be accomplishing the above promises through a vertical and horizontal integration within an organization [KAGE13; BAUE14b; BISC15; HENN13; REIN17b; STAU16; SCHM17b; SCHM17a]. The vertical integration focuses on the integration of production steps and departments in a production facility (see Figure 3-2) [RÜßM15; WAGN18]. In contrast, the horizontal integration focuses on the integration throughout the entire value network of an organization [BAUE14c; RÜßM15; WAGN18]. Such integration is made possible with the use of the following aspects of Industry 4.0 [SCHM20; SCHM12; SCHM07; WAGN18; ERBO17; BROY10; BREC14; WEYE15; BAUE14b; PETS14; LEE15a]:

- Cloud computing
- Decentralized production control and management
- Human-machine interaction (HMI)
- Machine-to-machine interaction (M2M)
- Machine-to-object interaction
- Wireless communication
- Smart Objects/ Smart Devices
- Smart Data
- Data analysis: Big Data, Data mining, etc.
- Artificial intelligence (AI)
- Self-organization and self-optimization

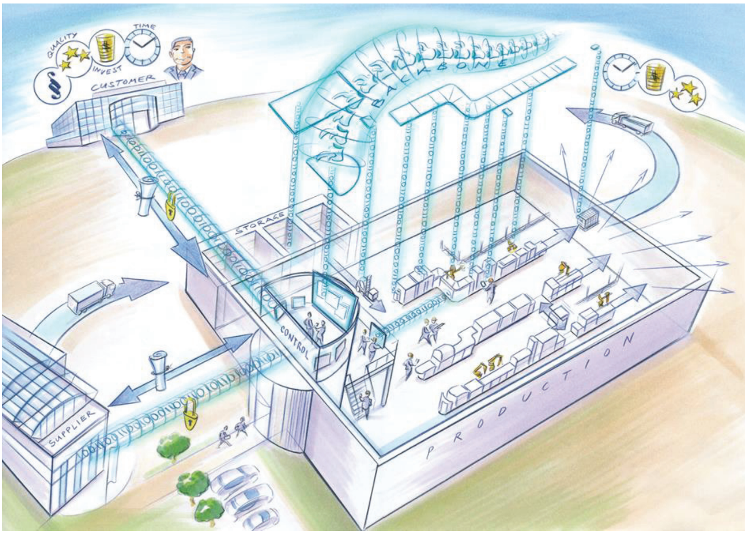
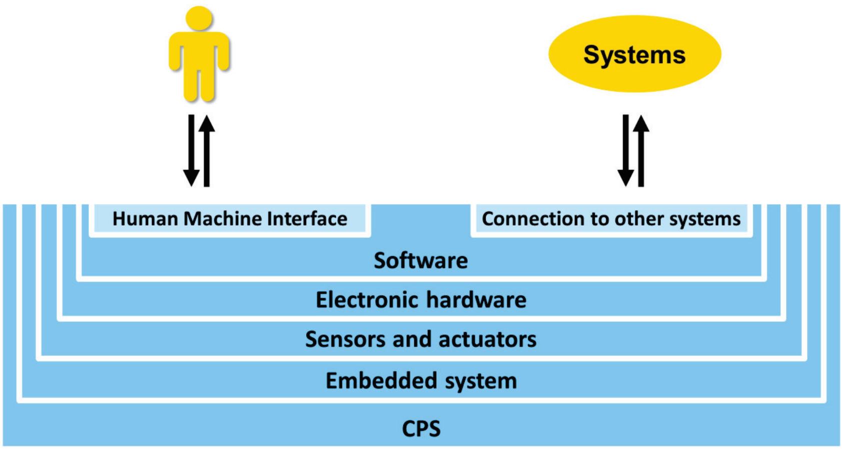


Figure 3-2 Vertical and horizontal integration throughout the supply chain of a certain organization (artistical art-work performed by Heyko Stöber).

The big enabler and contributor for each mentioned aspects of Industry 4.0 is the Cyber Physical Systems (CPS) [GEIS12a; JAZD14; GEIS12a; BROY10; BROY11; SCHM17b]. The creation of a CPS enables the interaction between the physical and virtual world (see Figure 3-3). Such interaction occurs through a network of sensors which will collect data regarding information of the physical world to be analysed in the virtual world through the use of Data mining, machine learning and other data analysis techniques applied to Big Data [WU14; DAVE13; LOHR12; ADEL99; BROY10; MATU16]. These analyses will result on an interaction between both worlds by means of actuators which can result in the self-organization of the supply chain and the self-optimization in real-time of manufacturing processes [SCHM07; FRAN04]. In addition, these analyses will enable the HMI, M2M and Machine-to-object interaction and the communication between them will occur mainly through the use of the following wireless technologies [KIM19; VOGE17a; SCHM18]:

- 4G or 5G
- WLAN
- Bluetooth
- Radio frequency
- GPS
- Among others



Following the style and content of [BROY10, S. 24]

Figure 3-3 Onion skin structure of the CPS

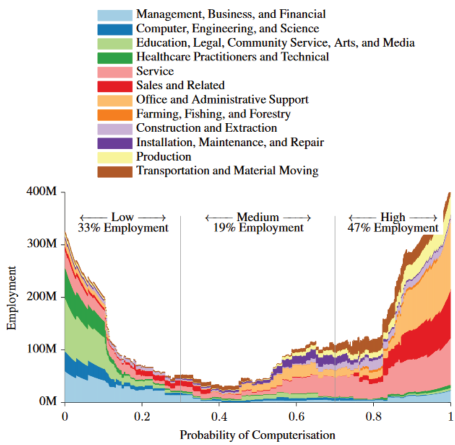
The software and hardware which will realize the analysis process between the physical and the virtual world do not necessarily have to be installed in the company [MADA15]. Instead, they can make use of the cloud computing which offers the three following main services models for Industry 4.0 and CPS [BIDG10; VOGE17b]:

1. Infrastructure-as-a-Service (IaaS): The service provider only provides basic resources such as CPU, memory, etc.
2. Platform-as-a-Service (PaaS): The service provider provides a platform on which the user can develop or run their own programs or those of third parties.
3. Software-as-a-Service (SaaS): The service provider provides one or more applications that the user uses directly via a client, such as a web browser.

3.2 Challenges faced by organizations in implementing Industry 4.0

This chapter gives an analysis about the importance for a country and also for SMEs up to multinational conglomerates to implement Industry 4.0. So, if a country is not able to adapt quickly to the challenges and changes that Industry 4.0 will bring with its implementation, this certainly will cause a destabilization in its economic power and consequently will put in risk its privileged social accomplishments. As earlier mentioned, this quick adaptability is of extreme importance, for instance, for Germany since 99.6% of all companies in Germany are SMEs [LICH18]. In addition to this, a study done with German companies shows that 20% of them currently believe that Industry 4.0 has an enormous importance in keeping their competitive position in the respective economy as well as the country itself in the global industrial market. But this percentage dramatically changes to 56% when asking the German companies what importance Industry 4.0 could have in Germany in five years from now [KOCH14].

An analysis of the social issues that Industry 4.0 can generate in a society is mainly linked to possible job cutting even though it is very difficult to predict such consequences for sure. According to Frey and Osborne, 47% of the employment in the United States are under risk of being substituted by machines and consequently automation (see Figure 3-4) [FREY17]. Similar scenarios can be founded in countries like Germany, United Kingdom of Great Britain and Northern Ireland and Brazil [LUO18; FLYN17; SILV18].



[FREY17, S. 267]

Figure 3-4 Illustration of the probability of computerisation in the different employment areas. Please note that the total area under all curves is equal to the total US employment

Accordingly, this might have an enormous impact for multinational conglomerates as well since they might be composed of several different SMEs with huge diversity of products and different digitalization levels in their daily business activities. Consequently, the multinational conglomerates must elaborate a strategy that fits to nearly all needs and challenges their related SMEs might face. One of the first challenges that a multinational conglomerate, or a single SME, will face is to identify what the existing production lines really need and would benefit from the Industry 4.0 vision. This will also support to define how to distribute the investments. In comparison to SMEs, such multinational conglomerates are usually in a stronger position to support and follow fast technological changes —Industry 4.0— when the main issue is capital expenditure.

SMEs will be enormously challenged by Industry 4.0. Usually, a SME does not have enough manpower to investigate new technologies which are not directly linked to their daily production activities or products [FALL15]. Further to this, SMEs often cannot afford the high IT infrastructure costs that Industry 4.0 requires [TUTU12]. Hence, SMEs tend to have a slower response time to implement Industry 4.0

As Tutunea elucidates, the change of a business strategy is particularly critical for SMEs compared to multinational conglomerate [TUTU12]. This can be linked to the possible financial and internal structures usually available for bigger multinational conglomerates in comparison to smaller companies. A major negative factor for both types of organizations is the fact that the existing production lines were not designed for the vision of Industry 4.0. Moreover, data security and standardization are critical key factors that concern both organizations and unfortunately both areas have a huge deficit regarding an international standard. A major concern that is unclear by the full implementation of Industry 4.0 is about its profitability [KAGE16]. How will the incremented costs be transferred to the products and are the customers going to be willing to pay for it?

To better understand the current state of the art of SMEs around the world ─especially in the European landscape─ regarding Industry 4.0, a SWOT analysis was performed [KOCH14; GAUS16; BISC15; SPAT13; SCHR16; KAGE16] (see Figure 3-5). After a brief overview of the SWOT analysis the author of this dissertation comes to the same conclusions as Anderl in his “Guideline of Industry 4.0 for SME”; that the large majority of the companies perceive Industry 4.0 more as a challenge rather than a chance or an enabler for new business models [ANDE15]. At this point, it is important to make an evaluation of each quadrant of the SWOT analysis that created this fear.

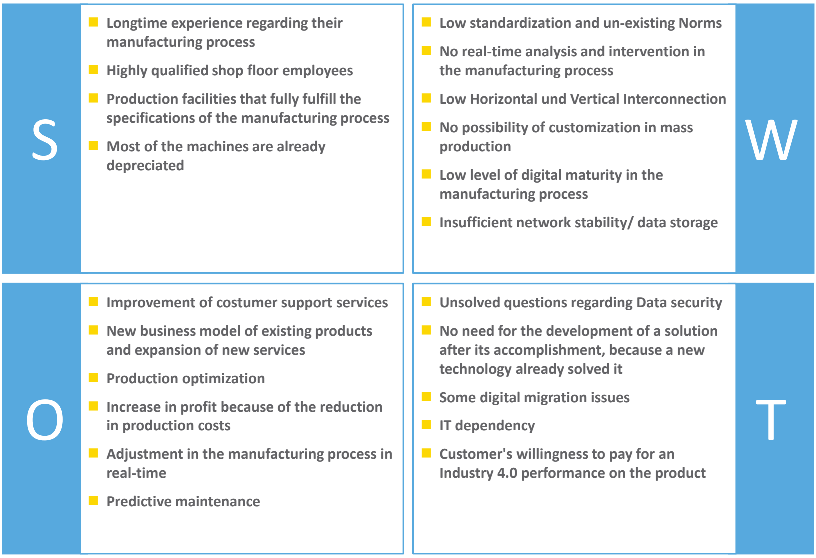


Figure 3-5 SWOT analysis regarding Industry 4.0 in companies

Strengths

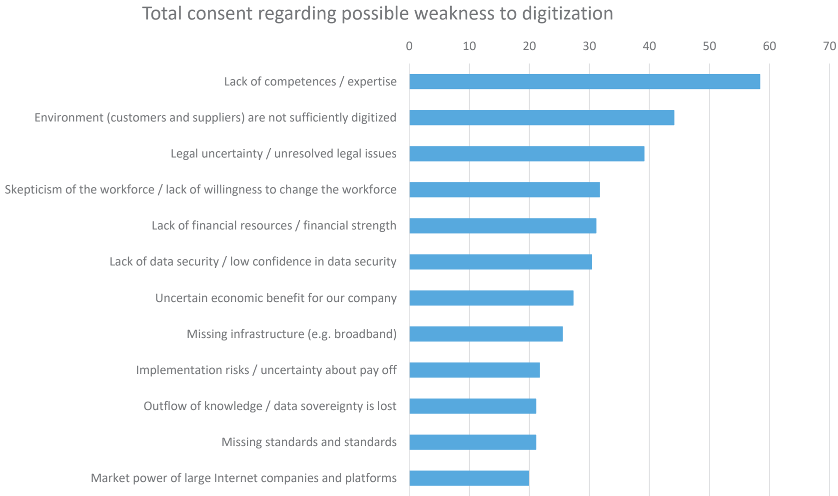
In general, the companies' strengths rely on two central and key elements for their current and future success. The first is the highly qualified employees that the companies have in their core businesses. This kind of value is not readily available to buy; it is developed over the years and in some cases decades. This is especially the case in German SMEs which are mostly family-owned businesses. Normally, the employees work for more than a decade in these companies and pass their knowledge forward in a so-called professional formation program to younger employees that fill the next generation.

The second element is one of the core motivations for the elaboration of the Smart Retrofitting approach and relies on the fact that the majority of the machines available in SMEs are mostly depreciated. Even though they completely fulfil the current demands and the future processes, they do not operate with Industry 4.0 characteristics because they were not designed for it. The majority of these machines are still capable to accomplish future technological demands but need an update to be able to operate under the Industry 4.0 vision.

Weaknesses

A fundamental weakness for companies to implement Industry 4.0 in a short period of time is the missing financial resources. One of the main consequences of this fact was the global economic crises of 2008 [CLIN10]. Between the end of 2008 and the middle of 2009 companies elaborated several recovering strategies, which unfortunately did not include the budget for the implementation of the Industry 4.0 vision because this was born in the 2011[KAGE11b].

Another weakness that the companies are facing is the lack of standardization concerning Industry 4.0. In this way companies cannot make acquisitions that would give them quick and universal solutions to digitalize their entire value chain. Thereby, there are doubts about communication protocols and interfaces to use regarding a long-term period. On the other hand, this is the consequence of a low use of information and communication technology –ICT [LICH18]– inside their value chain. In addition to this, a fact that is not directly related to the companies is shown by Lichtblau in his study that is the lack of staff with appropriate skills in the field of digitalization which represents the biggest obstacle for the surveyed SMEs to overcome (see Figure 3-6) [LICH18].



Following the style and content of [LICH18, S. 57–57].

Figure 3-6 Illustration regarding possible weaknesses to digitalization

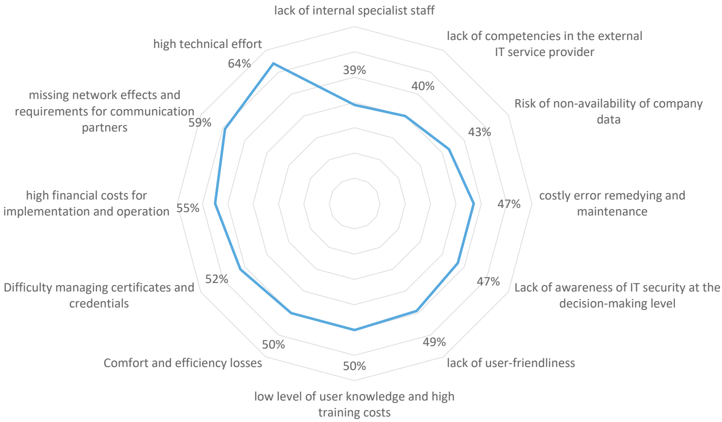
Opportunities

The biggest opportunity for Industry 4.0 will be found in the production field [KAGE16], where new information and knowledge will be generated through embedded systems from the manufacturing processes [BISC15]. In the near future, the versatility of embedded systems available in the market with a low acquisition cost will increase dramatically. In addition to this, it will be possible to generate different information and knowledge by using only one device. This will be possible by the steadily increasing improvement in the areas of deep learning and machine learning. For example, cameras will be able to make the quality check of a product and at the same time calculate the OEE by crossing information with other systems. An incredible example of this is the current surveillance program of the Chinese government [HARR18] that can make analyses and predict behaviour of a person by crossing several different types of data. Consequently, the companies will be able to develop projects that will allow them to perform real-time adjustments in their production lines and consequently increase productivity by following the same approach of the chine's government. In addition to this, they will be able to realize predictive maintenance that will also contribute to the productivity gain and cost reduction [KÖHL18; LEE15b; WEBE16; WEHL15]. The information gain in their production line and end product will also allow them to expand the customer support services and to reach out for new business models and markets [HINR13].

Threats

Basically, all the threats are linked to efforts and challenges that will be generated by digitalizing a company. For SMEs, the challenges will be bigger since their production is a mix of manual and hybrid activities and therefore, they will have additional difficulties to implement a high degree of automation in their production lines [SCHR16]. Further to this comes the fact that their value chains are not interconnected and act mostly as several different and independent units and thereby, the communication protocols are not standardized. In this way, bypasses are being made to assure the communication between the different devices. At a first glance, this can be seen as a quick and functional solution; however, it leads to security issues. A BMWi study indicates that companies in various countries perceive data security as a threatening element in the implementation of Industry 4.0 [BISC15]. In addition to this study, Kagermann points out that in a survey with participants from Germany, the United States of America, South Korea, Japan and Great Britain, the biggest economic risks of Industry 4.0 is data security [KAGE16]. If this scenario is focused on the size of the company, it shows that 57% of the large companies and 69% of the SMEs see the assurance of data security as the biggest obstacle of IoT [MICH17].

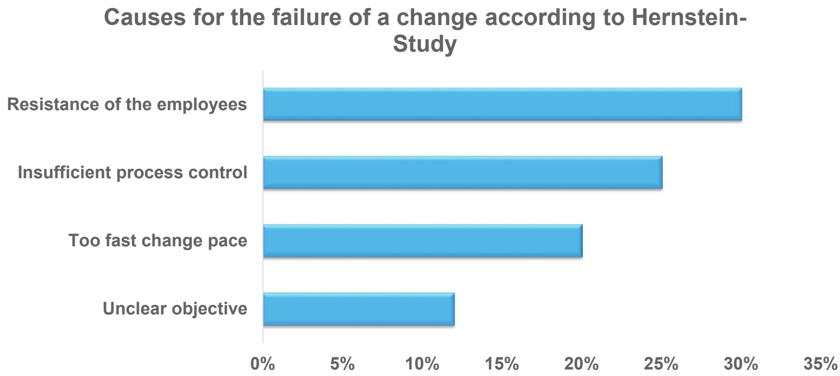
As a possible solution that has been offered to the IT security issues is the implementation of encrypted communication, but, like Goldhammer shows in his study, the industry has its own concerns here too [GOLD18]. Due the fact that the encryption of the communication system requires high levels of investment and in the current scenario there is not enough specialists who can give support to companies, but on the other hand the majority of the SMEs do not see a sacrifice in the productiveness by implementing Industry 4.0 (see Figure 3-7) [GOLD18].



Following the style and content of [GOLD18, S. 16]

Figure 3-7 Response of the BMWi study participants to the question: What were / are the biggest challenges in implementing encrypted communication in your company?

Until now, all threats pointed out are linked to internal issues in the companies. At this point, it is important not to underestimate the external threats, for example, the two main issues that are linked to the customers mentioned. First of all, will the customer be willing to pay for the possible gain that the digitalization will bring to the product [LICH18]? In addition to this, does the customer see this gain as a key element for his needs? Another threat is the possibility that the developed solution will not be further needed or outdated soon after its accomplishment. These questions are very specific for each company and market. However, companies should make thoughts about it before taking any action regarding Industry 4.0. In addition to the external threats, there is the question if the suppliers are willing and able to share their data to allow the entire interconnection of the value chain of a product.



Following the style and content of [SCHO05, S. 169]

Figure 3-8 Hernstein study regarding the causes that lead to the failure of a change

However, the most critical and challenging aspect of the implementation of Industry 4.0 is the fact that it will be a huge change process in all structures of the company and in the way that the company will act from the moment the change process starts. The Hernstein study shows that the main factors that lead to the failure of a change process are related with the employees [SCHO05]. Other key factors are illustrated in the following figure (see Figure 3-8).

3.3 Conclusion

This Chapter summarizes what Industry 4.0 stands for and the challenges faced by organizations in its implementation. In addition, two hypotheses are established concerning the two first sub-research questions, presented in the introduction of this dissertation.

Regarding the first hypothesis which is related to the first sub-research question, the main characteristic of a machine park producing according to the principles of Industry 4.0 is its ability to collect operational data from the physical world and to analyse them in the virtual world with the objective of acquiring knowledge and information which can result in an immediate or upcoming optimization of the production activities within the organization. Besides that, it aims to empower the interaction between human, machine and Smart Objects.

And finally, the second hypothesis concerning the second sub-research question, the utilization aspects of Industry 4.0, for instance, vertical and horizontal integration of an organization, self-optimization of the production processes and self-organization of activities within the supply chain can be achieved with the implementation of Industry 4.0 and are directly linked to the goals established and the technical characteristics of the currently available embedded systems.

4 Smart Retrofitting

The secret of change is to focus all of your energy, not on fighting the old, but on building the new.

Socrates

Inspired on the above quote from Socrates, the Smart Retrofitting proposes not fighting to replace the old within an organization. Instead, it proposes to be the foundation to enable the implementation of Industry 4.0 and to support the change process that it will unleash throughout the organization.

The Smart Retrofitting Approach promotes results in the long term as well as in the short term of the implementation process of Industry 4.0 within an organization (see Chapter 4.1). It offers a tailor-made change management model based on a Top-down Bottom-up management approach (see Chapters 4.2 and 4.3). The Smart Retrofitting Approach and its respective tailor-made change management model takes the individuals of an organization in all phases of the change process in a central role. A decisive factor for the successful application of Smart Retrofitting in an organization is the extent to which employees are involved as carriers of knowledge, as designers and as implementers of Smart Retrofitting (see Chapters 4.2).

4.1 What is Smart Retrofitting Approach

The one who wants to align the organization to the continuously and rapidly changing needs of the market, ongoing adaptation and change of its organization is not the exception but the rule.

Klaus Doppler and Christoph Lauterburg [DOPP96, S. 92]

Roblek, Meško and Krapež highlighted in their work the importance and the impact that Industry 4.0 has on the present moment and will have most strongly in the entire industrial environment in the near future [ROBL16]. This scenario described by Roblek, Meško and Krapež reinforces the need to design the Smart Retrofitting Approach which was part of the motivation to create a methodology to support companies to implement Industry 4.0. An additional motivational factor is the lack of methodologies offered to organizations to implement Industry 4.0 by themselves using an implementation strategy which focuses on their current needs, on the corporate culture and their available resources within their production facilities. Moreover, the target group of the Smart Retrofitting Approach can be one single production line or an entire multinational conglomerate, but the Smart Retrofitting Approach is also valid for the case of one single equipment, as it will be demonstrated later in one of the validation cases. The implementation of Industry 4.0 will bring benefits opening new possibilities to the daily activities as well as adding value to their products and services. This can occur either by acquiring new production equipments or retrofitting existing ones. As mentioned earlier, the Smart Retrofitting Approach does not necessarily need the acquisition of new production equipment to enable the implementation of Industry 4.0 in an organization (see Chapter 2.7). This is motivated by two main factors. First, as it was highlighted earlier, the majority of organizations own production equipments that fully fulfil their production specifications and requirements and are in some cases already depreciated (see Chapter 1). Second, not all organizations can afford the acquisition of completely new production equipments to enable Industry 4.0 within their daily business activities and having only a few production equipments operating with aspects of Industry 4.0 generating isolated solutions within the value chain will only partially impact the supply chain of the organization. Consequently, two of the main elements of Industry 4.0 — vertical and horizontal integration — could not be embraced in their total potential (see Chapter 2 and 3.1). Hence, the production equipments within a production facility or even organization will not be able to exchange data that would contribute to the optimization of the production.

Nevertheless, if the organization can afford to buy new equipments, it might face challenges to integrate the new production equipments into the existing production lines, like undesired production stoppages to remove the old production equipment and to install the new ones. Further to this, it can take some time to make all necessary adjustments and set-ups to integrate the new equipment into their production line. In addition to this, and as mentioned earlier, isolated equipment operating with aspects of Industry 4.0 will be not contributing to the spread of the benefits of Industry 4.0 across the company. In the case an organization decides to implement Industry 4.0 exclusively acquiring new production equipments, it will tend to build an entire new plant or production line. This scenario is mostly not desired throughout the industrial environment also due to the high CAPEX involved.

So, the Smart Retrofitting Approach supports the hypothesis that the retrofitting of existing equipment is the most practical and suitable solution for any size of organization to engage it in the implementation of Industry 4.0. The Smart Retrofitting Approach will focus its efforts simultaneously on two separate fronts which compose its nomenclature:

- Smart: Spread the Industry 4.0 throughout an organization independently of its size in a continuous and progressive way
- Retrofitting: Implementing aspects of Industry 4.0 in their existing production equipments fulfilling the organization’s established targets and demands for Industry 4.0.

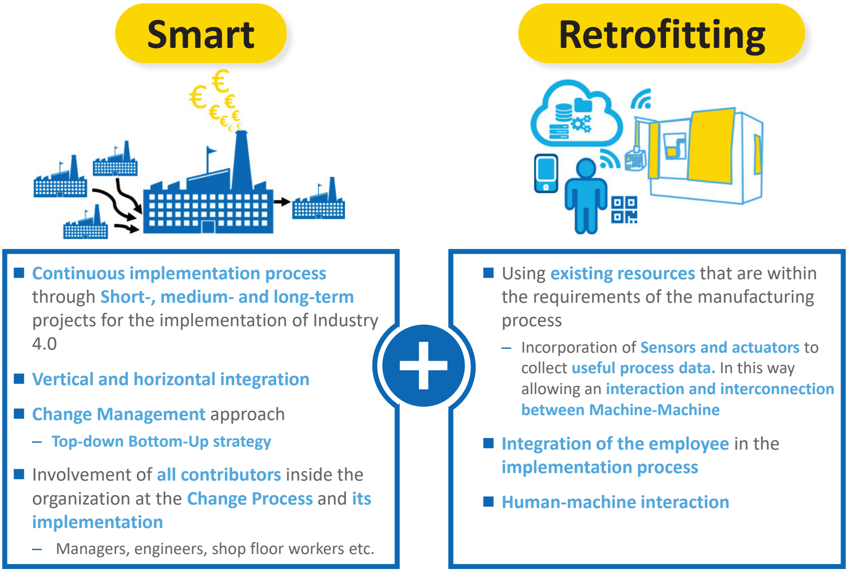


Figure 4-1 Inspiration for the term Smart Retrofitting

The Smart component of the Smart Retrofitting Approach

The Smart component is dedicated to all activities related to spread Industry 4.0 throughout an organization. The focus of the Smart component relies on the elaboration of a strategy to fulfill the implementation of Industry 4.0 considering that it will unleash a permanently change process in an organization (see Figure 4-1). In the view of this thesis, Industry 4.0 is not only limited to the digitalization of the production and administrative processes. Instead, Industry 4.0 requires a completely new mindset concerning how all employees will perform their daily business activities to add even more value to the products as well as services for the customers. Therefore, Industry 4.0 will open new business opportunities that might not have even be part of the core business of an organization [BURM15; IANS14; RUDT14]. Moreover, the implementation of Industry 4.0 has the potential to solve existing problems that the organization might be facing in their daily business [RAMA16]. The engagement of the employees is fundamental for the success of the change process which will take place in an organization.

The Smart Retrofitting Approach was inspirited by two existing key tools used by managers which focus on improvement and changes inside the organization. These are the Total Quality Management-TQM and the Change Management. Indeed, the entire aim of the Smart Retrofitting Approach was deeply influenced by the definition of TQM given by the British Standards Institution below [BS92]:

“TQM is a management philosophy and company practices that aim to harness the human and material resources of an organization in the most effective way to achieve the objectives of the organization.”

Such strong influence is given from the fact that TQM, as well as Smart Retrofitting, gives the human and material resources the same importance to achieve their aim. However, the main difference between them is that the objective in Smart Retrofitting is fixed and is the implementation of Industry 4.0 throughout an organization by using available resources. Hence, Smart Retrofitting makes use of the management philosophy and the methods that integrate the TQM:

- Kaizen
- Total employee involvement
- Business process reengineering

The entire framework of how Industry 4.0 will roll out following the Smart Retrofitting Approach is strongly based on the Kaizen philosophy which prioritizes the continuous improvement of products and processes through small steps executed by the employees with the participation of all different hierarchical levels of an organization [IMAI92; LING98]. The Smart Retrofitting embraces the continuous improvement in the implementation of aspects of Industry 4.0 within an organization by means of several small, medium and large projects which will be working in parallel.

The Smart component is not based on a continuous improvement concentrated on innovation. It tends to have a higher investment cost and low participation of employees which could contribute to the stabilization of the innovation, and consequently tend to decline over time (see Figure 4-2) [IMAI92; FARR13].

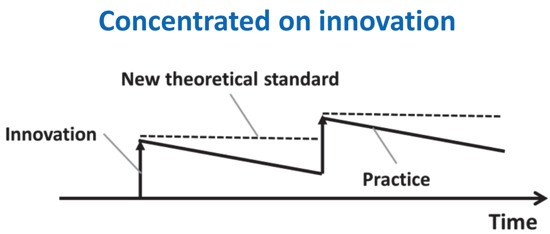


Figure 4-2 Accomplishment path of a continuous improvement process mainly concentrated on innovation

Continuous improvement concentrated on continuity follows a long-term strategy which stimulates the creation of several small steps to reach its aim. The necessary investment can be divided in small and medium amounts reducing the risk of investing in wrong initiatives, once the investment is progressively done according to the achievements. Additionally, it fosters the involvement of several employees from diverse hierarchical levels throughout the entire improvement process. Furthermore, to stabilize and create an uninterrupted improvement process, multiple iterations of the PDCA cycle —also known as Deming Cycle— are incorporated to the entire continuous improvement process [IMAI92; FARR13; LING98] (see Figure 4-3).

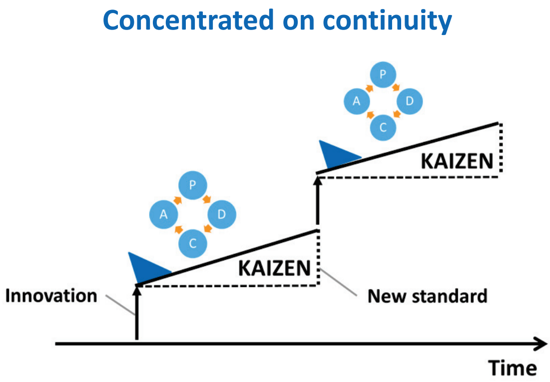


Figure 4-3 Accomplishment path of a continuous improvement process mainly concentrated on continuity

The Smart Retrofitting Approach is based on the continuous improvement process concentrated on continuity which empowers the employees and stimulates the execution of several small, medium and large projects at the same time (see Chapter 4.2.8). Nevertheless, some modifications are proposed for the accomplishment of the Smart Retrofitting Approach. One slight modification is the use of PDSA instead of the PDCA cycle or other existing variation within the Kaizen philosophy [DEMI18; SCHM15; IMAI12] (see Figure 4-4). This has been motivated by the sequence of actions which the Smart Retrofitting Approach recommends being performed to implement Industry 4.0 on a specific production equipment or production line as well as throughout an organization (see Chapter 4.2.8).

The Smart Retrofitting Approach will lean on a Top-down Bottom-up management approach to implement Industry 4.0 throughout an entire organization (see Figure 4-4). Therefore, its starting point will be always the production equipments or a lower stage within the value chain of an organization with the implementation of aspects of Industry 4.0 to them. This will enable at the same time improvements on performance of the processes and preparation for the integration with other production equipments. Hence, the vertical integration is stimulated within the organization which is one of the key aspects of Industry 4.0 (see Chapter 3.1). In fact, the Smart Retrofitting Approach prioritizes the vertical integration within an organization, since the biggest opportunities for cost saving and adding more value to their products relies on activities within their own value chain [SCHE13]. Such vertical integration process will occur by executing simultaneously several small, medium and large projects throughout a Bottom-up management approach (see Figure 4-4).

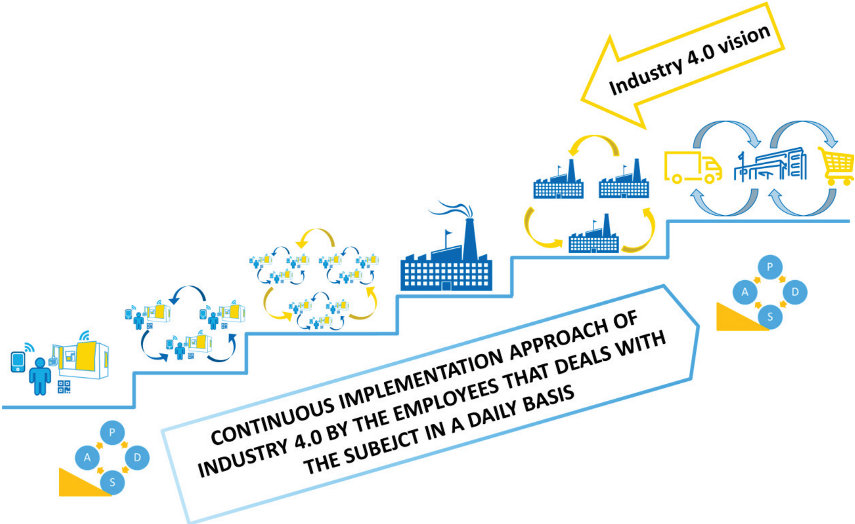


Figure 4-4 Top-down Bottom-up management approach to implement Industry 4.0 within the Smart Retrofitting Approach

Retrofitting component of the Smart Retrofitting Approach

According to the Cambridge dictionary retrofit is defined as [WAIT12]:

> *"To provide a machine with a part, or a place with equipment, that it did not originally have when it was built"*

Organizations commonly retrofit their production equipments by replacing for instance spindle motors, pumps or other components to achieve a higher performance. Nevertheless, Smart Retrofitting Approach will not limit itself to the traditional retrofitting Approach, in which the subject is to replace one component in a production equipment. Instead, any type of existing resource —production equipment, employees, IT-infrastructure and others— within an organization can be a subject for a retrofitting which will incorporate aspects of Industry 4.0 into it. Consequently, the use of embedded system is crucial for the application of the Smart Retrofitting Approach, since they empower the acquisition of real time operative data that can be used to feed the CPS of this particular production equipment or production line [SCHR16; GEIS14]. In addition, some analysis methods, for instance, Big Data, Data Mining, Machine Learning, Deep Learning techniques shall be performed with the collected data, which in turn opens the possibility for real-time adjustments on the process parameters increasing the performance and quality of that particular production step or the next ones [GOOD16; MOHR18; GEIS14; YIN15; KLÖT15; MÜLL13a; ROME16] (see Chapters 2.2 and 3.1).

Besides the embedded systems —sensors, actuators and software— the Smart Retrofitting Approach recommends and stimulates the use of Smart Devices and Wearables which will be the bridge for the employees between the physical and virtual world [BROY10]. Therefore, providing the employees with filtered and specific information concerning the equipments they are responsible for. Hence, this information supports the employees to make decisions concerning possible scenarios which could occur in his or her daily business activities. Additionally, Smart Glasses, tablets and other Smart Devices can support employees on the following activities [JESC16; HOLZ17; NIEM16; SIEP16; TERH18; SCHM18; GORE14; KRIS12]:

- Analysis of current production processes
- Visual quality inspection
- Remote assistance, inspection and maintenance
- Order pickup in the warehouse
- Set up of assembly procedure

Furthermore, the use of Smart Devices and Smart Wearables promotes a motivational effect on the employees acting like a tool they can count on and passing them the positive feeling and the confidence that they are part of the implementation of Industry 4.0. and such tool will support them to perform their activities in the most possible effective and safest way [SCHM18; GORE14]. Therefore, this motivational factor will support the reduction of possible resistance regarding the implementation of Industry 4.0 within an organization (see Chapter 4.2).

4.2 What is Smart Retrofitting Change-Management Modell

Nothing is as constant as change

Heraklit von Ephesus

The introduction of Industry 4.0 within an organization will cause primarily a huge impact on the execution of its daily manufacturing processes [GLAS16]. Unfortunately, the majority of organizations are focusing their efforts concerning the implementation of Industry 4.0 in isolated areas of their value chain or by launching huge initiatives in specific business units aiming to implement Industry 4.0 based on case studies from a different industrial sector. Such case studies normally are provided by big consulting companies and are unable to provide an organization with a tailor-made strategy without contracting them. Unfortunately, the big majority of organizations do not have the necessary financial resources to hire big consulting companies that could develop an organization-specific strategy to implement Industry 4.0 in a large scale within their business units and plants [GEIS16; ANDE15; KAGE13; HENN13; STAU16; SAMA17].

An additional factor to consider when hiring a big consulting company is that the development of their strategies normally involves very few employees from the high hierarchical levels of the organization. Such scenario strongly suggests that future resistance might occur during the roll out of the elaborated strategy. In addition, it also does not chase the need and challenges faced by the shop floor in a daily basis and the experience and knowledge from operative employees from the shop floor is not considered [DOPP11; HIAT06].

Reinforcing the coverage of the thesis with involvement of all levels of the organization, the Smart Retrofitting seeks to empower the management team to create a tailor-made strategy to implement Industry 4.0 within their organization with emphasis in the inclusion of the human resources from all hierarchical levels at such process. Additionally, the Smart Retrofitting covers the organizational changes that Industry 4.0 will be demanding within an organization.

The changes promoted by the implementation of Industry 4.0 can be characterized as episodic because the organization would not be able to modify their processes and especially their structures at the same pace as Industry 4.0 will demand [WEIC99]. It is important to take into consideration that the technical possibilities will be continuously evolving throughout time with possibly increasing with higher rates leading to technologies that can become obsolete much quicker than expected [BARR93].

Consequently, this thesis identifies the need to develop a change management model which aims the implementation of Industry 4.0 combined with the Smart Retrofitting Approach. Change management is not just about the concept development and it includes the success and the acceptance of an oriented implementation process [BÖNI97]. In addition, Schuh highlights that change management is highly indicated for change processes which mainly involves episodic changes [SCHU11]. With all these considerations in this thesis, the creation of a new change management model is proposed for the accomplishment of the implementation of Industry 4.0.

4.2.1 Inspiration for the Smart Retrofitting Change Management model

The development of the Smart Retrofitting Change Management Model is based on several existing models relatively widely known to the managers in general which reduces risks on its use and application. The phases of the Smart Retrofitting Change Management Model are strongly based on the 3-Phase Model of Change from Kurt Lewin (see Figure 4-5). In fact, Lewin's Approach has influenced almost all currently existing change management models and its structure is well known across organizations [SCHE99; MÜLL01].

Figure 4-5 Illustration of Lewin 3-Phase model

Lewin's model aims to surmount problems caused by social conflicts related to behavioural change, whether these conflicts happen inside organizations or in the wider society [BURN04a; LEWI51]. The aim of the Unfreezing phase in Lewin's model is to destabilize the current equilibrium before the new desired behaviour can be successfully adopted, substituting the old behaviour [BURN04a; LEWI51]. The trigger for the destabilization can be originated within as well as outside the organization like for instance, changes in the market or changes in the top leadership of the company. Independently of the source of the destabilization, the organization has to recognise that its business is not being conducted accordantly to meet the current or future requirements in order to keep or to expand its market position [MÜLL01]. The anchoring of new behaviour will be embraced through the motivation and involvement of employees at the design of the change process which will take place at their organization [SCHU11; MÜLL01]. Therefore, the Moving phase consists in putting the new behaviours into practice which had been planned at the previous phase [BURK17; LEWI51]. Consequently, the Refreezing phase consists on making the new behaviour to become a habit and, consequently, it will be embedded into the corporate culture of the organization [BURN04b; SCHU11].

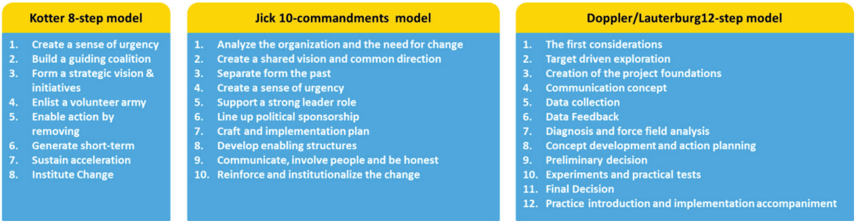


Figure 4-6 Illustration of the Kotter, Jick and Doppler/Lauterburg steps to achieve a change

Besides the Lewin model, Smart Retrofitting has been strongly influenced by the Kotter, Doppler/Lauterburg and Jick change models. This motivation arose from the fact that the Lewin model is strongly socio-psychologically oriented [SCHU11; GILL02; KOTT95] and to implement Industry 4.0 within an organization there should be a balance between a socio-psychological- and management-oriented Approach. Therefore, the 8-step model from Kotter was taken as a basis for the management-oriented component in the development of the Smart Retrofitting Change Management model since half of Kotter´s eight steps is related to management matters (see Figure 4-6) and it creates the sense of urgency for change [KOTT95; KOTT12; SCHU11].

Nevertheless, this thesis identified the need to have the Smart Retrofitting Change Management Model inspired in other socio-psychological models too and for this purpose the Doppler and Lauterburg 12-step change management model was selected, which engages the change process with strong concern on how to communicate to and on the involvement of the employees [DOPP08; DOPP96; SCHU11]. In addition, the 10-step from Jick's model [JICK93] has also contributed to the elaboration of the sequence of steps of the new designed Smart Retrofitting Change Management Model (see Chapter 4.3) because it also clearly considers the importance of communication and involvement of the people as well as the institutionalization of the change considering different elements and steps.

4.2.2 Smart Retrofitting Change Management Model

The three phases from Lewin´s model ―Unfreezing, Moving and Refreezing― are integrated and are the basis for the new developed Smart Retrofitting Change Management Model (see Figure 4-7). However, there are differences between the contents of the phases from Lewin's model and the model developed in this thesis as demonstrated in the following sub-Chapters. Furthermore, its content was enriched with two new phases for the accomplishment of the implementation of Industry 4.0 using available human and material resources within an organization (see Chapters 4.2.6 and 4.2.7). From this point on, when referring to Unfreezing, Moving and Refreezing phases these are going to be related to the developing Smart Retrofitting Change Management model of this thesis.

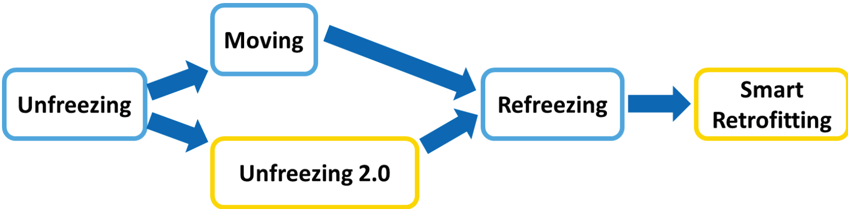


Figure 4-7 Illustration of the 5-phase Smart Retrofitting Change Management Model

The Smart Retrofitting Change Management Model follows a Top-down Bottom-up management approach. The Unfreezing and Unfreezing 2.0 phases have a Top-down management approach which is meant to empower the management board or top management team to guide their organization to implement Industry 4.0 following a tailor-made vision of it fulfilling the company´s needs (see Chapters 4.2.4 and 4.2.6). The difference between the two Unfreezing phases relies on the fact that the Unfreezing phase serves to create the sense of urgency in reaction to the Industry 4.0 while the Unfreezing 2.0 is meant for the management board and top management to establish the vision of Industry 4.0 for the organization. In addition, during the Unfreezing 2.0 phase, the management team will elaborate a general road map inserted in the vision which will guide their entire organization on the implementation of Industry 4.0 within their daily business activities (see Chapter 4.2.5). The Moving and the Smart Retrofitting phases will have a Bottom-up management approach since both of them will be empowering employees from lower hierarchical levels to elaborate concepts which will enable the implementation of Industry 4.0 within their daily business activities (see Chapters 4.2.5 and 4.2.6). Contrarily to all other phases, the Refreezing phase aims to communicate all employees regarding the Industry 4.0 vision and its respective road map that will be adopted to implement Industry 4.0 throughout the organization (see Chapter 4.2.7).

As mentioned earlier, the continuous improvement influenced the elaboration of the Smart Retrofitting Approach (see Chapter 4.1) and this is valid also for the Smart Retrofitting Change Management Model. Kiran suggests that ten requirements should be fulfilled to accomplish a continuous improvement process [KIRA16, S. 317]:

1. Accepting that the problem lies in the inadequacy of the present level in performance of the product or service
2. Right attitude to solve the problem
3. Proper organization to solve the problem
4. Adequate knowledge and practice in using problem solving tools and techniques
5. Structured method of problem-solving
6. Problem definition and analysis to be based in hard facts
7. Solutions to the cause, more than for the symptoms of the problem
8. Implementing and continuous monitoring until consistent result is obtained
9. Overcoming resistance to change
10. Control system for reversible changes.

All phases within the Smart Retrofitting Change Management Model will embed one or more of the requirements listed by Kiran.

- Unfreezing → requirements 1, 2, 3, 5 and 6 (see Chapter 4.2.4)
- Moving → requirements 5 and 8 (see Chapter 4.2.5)
- Unfreezing 2.0 → requirements 2, 3, 6 and 7 (see Chapter 4.2.6)
- Refreezing → requirements 9 (see Chapter 4.2.7)
- Smart Retrofitting → requirements 4, 7, 8, 9 and 10 (see Chapter 4.2.8)

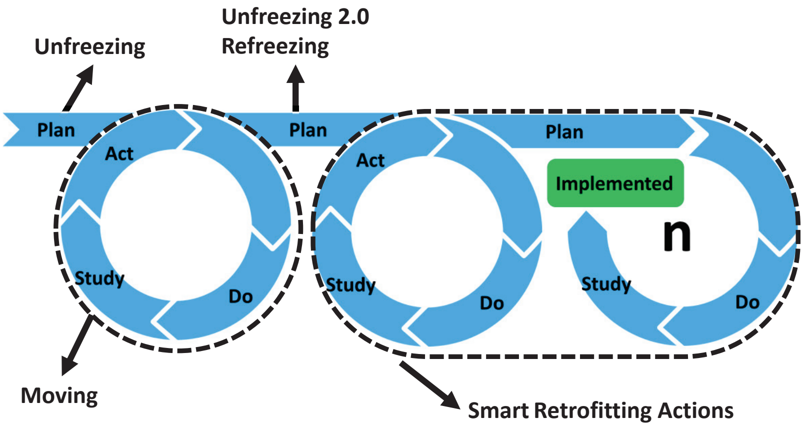


Figure 4-8 PDSA inserted in the Smart Retrofitting Change Management Model

As previously mentioned, multiple iterations of PDSA cycles will be applied throughout the phases of the Smart Retrofitting Change Management Model (see Chapter 4.1) (see Figure 4-8). Therefore, the first PDSA cycle occurs during Unfreezing and Moving phases (see Figure 4-8). The aim of the Unfreezing phase in the Smart Retrofitting Change Management model developed in this thesis is to initiate the planning process of the implementation of Industry 4.0 within an organization and to unleash the first wave of the sense of urgency (see Chapter 4.2.4). The first thoughts and experiences with the implementation of Industry 4.0 will occur in the Moving phase with the accomplishment of the Do, Study and Act steps of the PDSA (see Chapter 4.2.5). The second Plan step in the Unfreezing 2.0 and Refreezing phases will be performed in parallel (see Figure 4-8). This results from the fact that during these two phases the entire strategy on how to implement Industry 4.0 will be designed and also communicated to all employees of an organization (see Chapters 4.2.6 and 4.2.7) and, as mentioned before, the implementation of Industry 4.0 will be occurring in a learning and a steadily improving process (see Figure 4-8) which consists of executing numerous small, medium and large projects throughout the organization (see Chapter 4.2.8).

4.2.3 Smart Retrofitting Agent

Cummings and Christopher emphasize in their work the importance of having an employee —change agent— responsible to assist and support a change process [CUMM14]. Schreyögg also highlights the need of an agent ─normally an external person─ that will be trained to execute the tasks that will facilitate the expected changes [SCHR96]. Hence, to support the implementation of Industry 4.0, this thesis identifies the need to create several agents which will be called Smart Retrofitting Agent. Nevertheless, in contrary to Schreyögg´s proposal, the Smart Retrofitting Agent must be obligatorily an internal member of the organization since he or she will incorporate the corporate culture into the change process. Such integration of the corporate culture throughout the change process reduces internal resistance and consequently increases the probability of success of the desired change process [BERS08; WANG12; DOPP11].

Since the Smart Retrofitting Change Management Model can be applied in multinational conglomerates as well as in a single production plant, it is necessary to differentiate two types of Smart Retrofitting Agents which will be focused on different tasks and will be acting on different scopes (see Figure 4-9). Nevertheless, both will have common responsibilities to:

- motivate employees concerning the implementation of Industry 4.0 at their daily activities (see Chapter 4.2.7)
- create and lead training sections or workshops related to the rollout of the Industry 4.0 concept (see Chapter 4.2.8)
- manage Projects related to the implementation of Industry 4.0 (see Chapter 4.2.8)
- execute or at least participate on activities to review new Industry 4.0 technologies and standards (see Chapter 4.2.8)

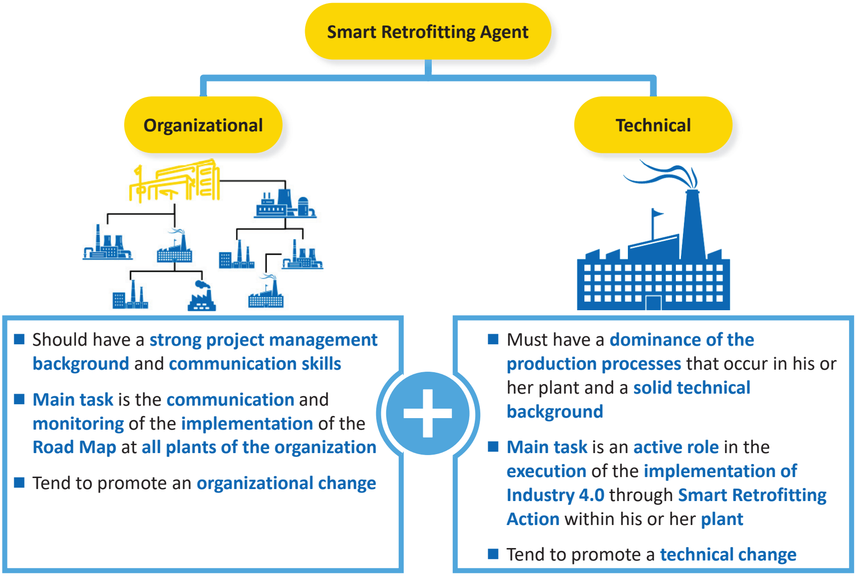


Figure 4-9 Illustration of the two types of Smart Retrofitting Agents

A plant Smart Retrofitting Agent will work to promote technical changes which support the retrofitting of existing production equipment in the plant to adapt and upgrade the equipment to the established Industry 4.0 concept. Such a technical change can be related to the increase in productivity, digitalization level, safety of the employees and stability of the process, as well as the enhancement of the sustainability within the supply chain of the plant. Furthermore, a technical change can be triggered by a plant manager, process owner or even shop floor worker and will reinforce the Bottom-up management approach in the Smart Retrofitting phase (see Chapter 4.2.8). Contrary to the technical change, the organizational one is initiated by the management board or top management team of an organization with impact throughout the entire organization. Therefore, they will spread best practices and standards fostering the rollout of Industry 4.0 in a large scale in the organization.

The adoption of the Smart Retrofitting Change Management Model by a multinational conglomerate will require so many Smart Retrofitting Agents that it is recommended to create a Network between them. Not necessarily all Smart Retrofitting Agents must have a direct contact to the top management (see Figure 4-10). Additionally, the group of employees designated as leadership coalition will be responsible for the entire Smart Retrofitting Network and their function within the Smart Retrofitting Change Management Model is not limited to administrate the Smart Retrofitting Network. Instead, they will be strongly involved in the activities from all phases of the Smart Retrofitting Change Management model.

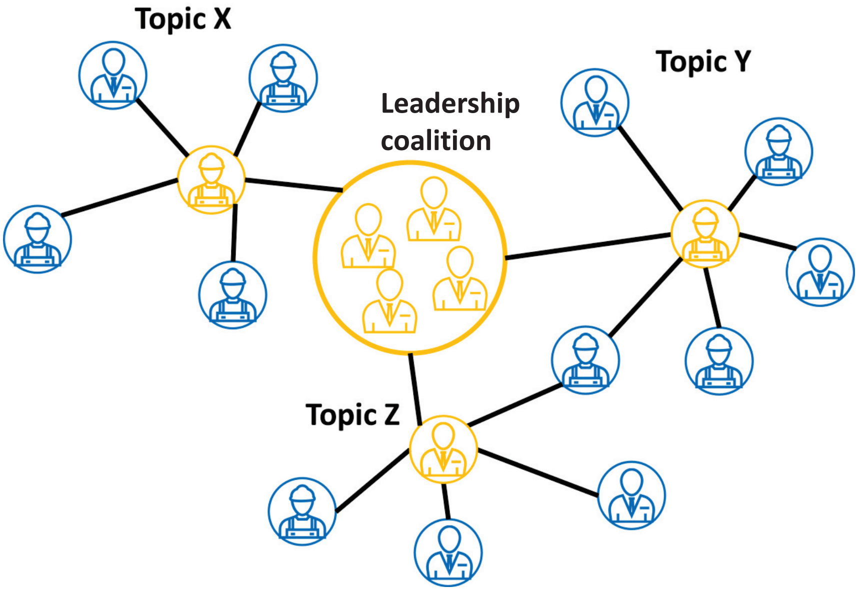


Figure 4-10 Illustration of the Smart Retrofitting Agent Network

The Smart Retrofitting Agent Network shall empower the employees from all different hierarchical levels of the organization to exchange knowledge and support each other in their activities concerning the implementation process of Industry 4.0. Therefore, the Smart Retrofitting Agents will be able to provide inputs to the small, medium and large size projects which will be part of the Smart Retrofitting phase (see Chapter 4.2.8). Consequently, such engagement of the employees will generate a motivational effect between them and will minimize possible resistances during the change process [HERZ68; DOPP11; KOTT14] caused by the implementation of Industry 4.0. The Smart Retrofitting Agent Network shall be organized following the topics established by the top management in the Unfreezing 2.0 phase (see Figure 4-10) (see Chapter 4.2.6). An additional highlight of the Smart Retrofitting Agent Network is that a topic leader can be any employee from the organization independent of his or her hierarchical level since he or she will be chosen concerning the knowledge and experience concerning the specific topic (see Figure 4-10).

4.2.4 Unfreezing phase

Kotter, Jick and Hiatt emphasize the importance of creating in the beginning of a change process a sense of urgency among certain members of the organization [KOTT95; KOTT14; JICK91; HIAT06]. Kotter reinforces that if the change process targets an entire organization such sense of urgency applies also to the management board or top management team [KOTT08]. Therefore, one of the main goals of the Unfreezing phase is to create the sense of urgency within the management board and the top management team of an organization regarding the importance of Industry 4.0 for the future of the organization in its market segment.

Differently to Kotter, who suggested that the first action for a change process is the creation of the sense of urgency, the Smart Retrofitting Change Management Model follows the Jick's model which recommends firstly to perform an analysis of the organization and the need for change followed by the creation of a shared vision and a common direction to follow [JICK91]. Consequently, the first step of the Unfreezing phase is dedicated on performing the status quo of an organization concerning its strengths and weaknesses (see Figure 4-11) (see Chapter 4.3.1). Such analysis will also guide the management board to elaborate a first draft of their Industry 4.0 vision (see Chapter 4.3.4).

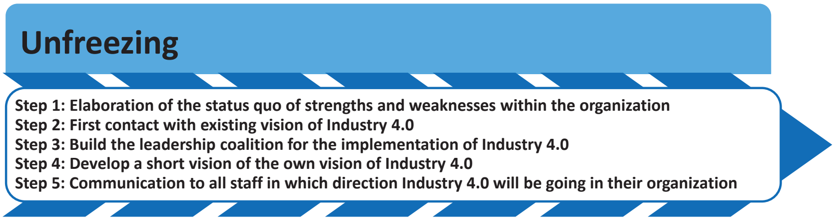


Figure 4-11 Unfreezing phase and its corresponding steps

The desired sense of urgency within the management board will be created by its members analysing and studying the current Industry 4.0 vision and several best practices available in the academic and industrial environment (see Chapter 4.3.2). Once these studies are accomplished, the management board assembles the leadership coalition which will be responsible for leading the Smart Retrofitting Agent Network and spreading the final Industry 4.0 vision of the company and its respective road map throughout the entire organization (see Chapter 4.3.3). The members of the leadership coalition must have a technical background and some experience with the processes which occur in a daily basis within their organization. Huselid, Jackson and Schuler indicate in their studies that a team which is composed primarily by members with technical background minimizes the risk of taking decisions based exclusively on financial aspects and therefore, increases the viability of the entire change process [HUSE97]. Nevertheless, one member of the leadership coalition has to represent the financial department of the organization. Ideally, all members of the leadership coalition should have a profound knowledge and identification concerning the corporate culture of the organization. Nevertheless, all activities related to the change process must be anchored in the corporate culture [DOPP11; MÜLL13b] which reduces the probability of future resistance [RAHI12] to the implementation of Industry 4.0.

The elaboration of the first draft of the Industry 4.0 vision of an organization will be the first activity which the leadership coalition and the management board will perform together (see Chapter 4.3.4) in order to conclude the activities of the Unfreezing phase and the communication made by the management board to all employees about the intention to implement Industry 4.0 across the organization (see Chapter 4.3.5). Having the communication right in the beginning of the whole change process is a motivational factor for the employees and the feeling of inclusion in the change process is transmitted [KIRA16; JICK91; KOTT12]. Consequently, the possibility of future resistance during the change process is minimized [MENT02a].

The Unfreezing phase has been designed to stimulate a continuous improvement process throughout the entire Smart Retrofitting Change Management Model and to support this, the first, second, third and sixth requirements listed by Kiran were incorporated to the Unfreezing phase (see Chapter 4.2.2).

4.2.5 Moving phase

Kotter's fifth step is dedicated to empowering employees to act by removing as many barriers as possible for the implementation of the vision over the change process [KOTT95; KOTT13]. Doppler and Lauterburg reinforce the necessity of experimenting and testing the planned changes in a controlled environment before starting to spread the change process throughout the organization [DOPP02]. Therefore, the entire Moving phase has been inspired on the recommendation of Kotter and Doppler and Lauterburg and pilot projects are to be performed in a controlled environment to gain knowledge to raise strengths and challenges expected when implementing Industry 4.0 within the organization which will foster motivation and consequently reduce any resistance to bigger projects for the implementation of Industry 4.0, once the pilot projects will generate some experience (Figure 4-12). Consequently, all pilot projects in this phase must be based on the first draft of the Industry 4.0 vision elaborated in the previous phase. Additionally, the Moving phase initiates the continuous implementation process of Industry 4.0 within the organization (see Figure 4-4) and therefore supports the eighth requirement of Kiran to fulfill the continuous improvement process.

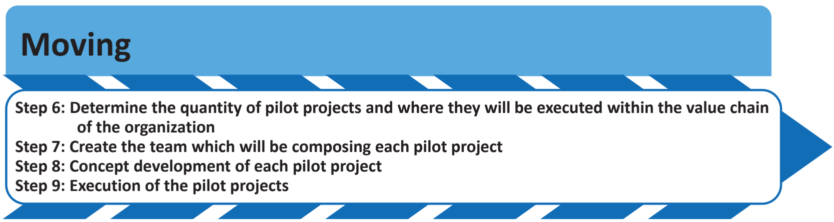


Figure 4-12 Moving phase and its corresponding steps

The Moving phase follows the Top-down Bottom-up management approach and the leadership coalition and the employees from lower hierarchical levels perform the activities related to the implementation of Industry 4.0. The first two steps to be performed are the determination of the number of projects by the leadership coalition (see Chapter 4.3.6) and of the location where the projects must be executed while assembling the team for each project (see Chapter 4.3.7).

The remaining two steps of the Moving phase will be completely performed through a Bottom-up management approach and the members of each pilot project team performs autonomously the implementation of Industry 4.0 in their daily business activities based on the first draft of the Industry 4.0 vision of the organization (see Chapters 4.3.8 and 4.3.9). Thereby, the leadership coalition will be able to evaluate challenges the employees are facing to implement aspects of the first draft of the Industry 4.0 vision. Such evaluation is of high importance for the Unfreezing 2.0 phase, providing the management board, the top management and the leadership coalition an idea about the complexity of implementing certain aspects of Industry 4.0 in their organization and supporting them to elaborate their road map for the implementation of Industry 4.0 in the entire organization (see Chapter 4.2.6).

4.2.6 Unfreezing 2.0 phase

Doppler and Lauterburg emphasize in their studies that within a change process no action should be taken without a systematic diagnosis of the status quo [DOPP96]. Additionally, they reinforce that such status quo must be realized based on data which was collected from employees that work on a daily basis at the desired subject of analysis [DOPP96; DOPP02]. Therefore, before the organization can elaborate its Industry 4.0 vision and its respective road map, the top management with the support of the leadership coalition has to perform an organizational footprint of the entire organization which has to highlight weaknesses and strengths which can bias the elaboration process of the Industry 4.0 vision and its respective road map (see Figure 4-13).

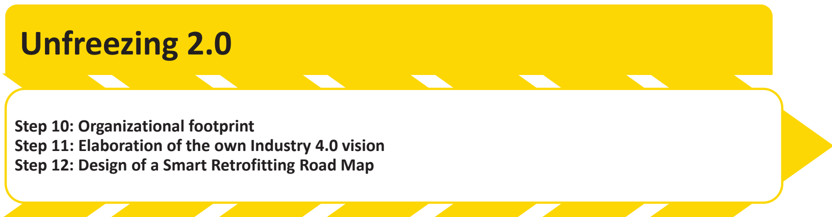


Figure 4-13 Unfreezing 2.0 phase with its corresponding steps

It is important to highlight that an organization can only start the elaboration of its own Industry 4.0 vision once the Moving phase is accomplished, because the Moving phase will serve as a reference regarding how challenging the implementation of Industry 4.0 can be for the organization.

4.2.6.1 The Organizational Footprint

The execution of the organizational footprint was inspired by the fifth, sixth and seventh steps of Doppler and Lauterburg Change Management Model as well as by the sixth requirement of Kiran to fulfil a continuous improvement process which is aimed in this thesis for the reasons previously mentioned (Chapter 4.3.10). The organizational footprint has to be executed via several survey campaigns intended to start the process of involving all employees in the implementation process of Industry 4.0 within their organization(see Figure 4-14). Such survey campaigns shall have a broader scope than the theme Industry 4.0 and must cover the following subjects, for instance:

- Industrial engineering
- Process engineering
- Lean Manufacturing
- Maintenance
- Quality
- Safety
- Sustainability and others

Such acquired knowledge from the surveys will be of high importance, since it can be used in the future to evaluate how effective the implementation of Industry 4.0 within certain areas of the supply chain of an organization has been and can even support on the search for the necessary technical solutions to be implemented. The organizational footprint surely provides an overview to the management board and to the top management where Industry 4.0 could be applied to solve current problems and to increase productivity (see Chapter 4.3.12).

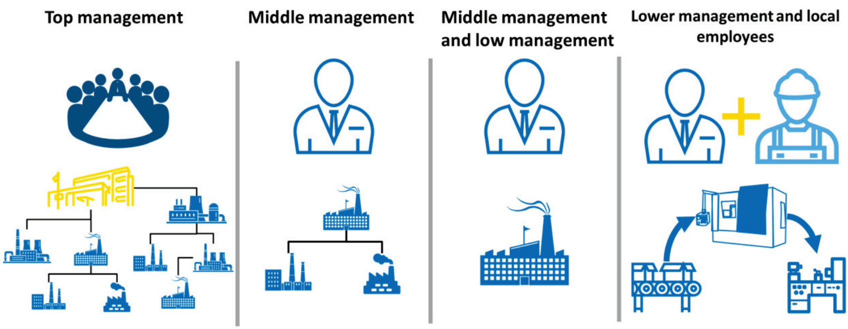


Figure 4-14 Groups reached by the survey and scope

Additionally, survey campaigns targeting the same subject shall be done for each hierarchical level of the different areas of the organization (see Figure 4-14), building a picture with different perspectives of the same subject which will influence the implementation of Industry 4.0. Furthermore, it is obligatory that the content of each survey campaign is elaborated with the participation of those employees which work on a daily basis in the activities directly related to the subjects being surveyed. This obligation relies on the statement proposed by Doppler and Lauterburg in one of their studies: *"The data basis for measuring the current situation in an organizational unit can only be supplied by those who work in that organizational unit. And often enough, only they know what should be changed more wisely."* [DOPP96, S. 155].

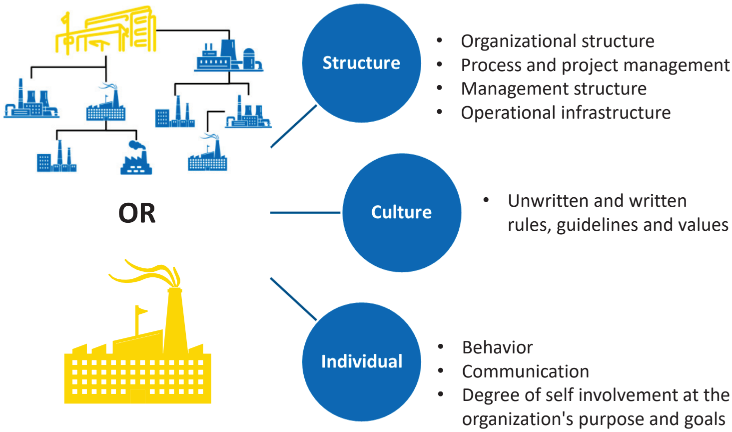


Figure 4-15 Three fundamental elements of a Change Management model

In case of very large organizations, it is necessary to cluster the survey campaigns by their individual business units. Since a huge organization tends to have an inhomogeneous culture across its different business units, distinguishing themselves subtly from each other, this can threaten the success of the change process-in the organization [WARR17; LEE16]. Therefore, it is recommended that such large organizations should perform survey campaigns which cover the three fundamental elements to consider in a change process [LAUE14; DOPP96] (see Figure 4-15).

4.2.6.2 The Own Vision of Industry 4.0

Previous studies from Kotter have emphasized that one of the most important actions within a change process is the elaboration of the vision which will guide all employees in the realization of the desired changes in their daily activities [KOTT12; KOTT14]. Furthermore, a well-elaborated and clear vision coupled to and reflecting the corporate culture has the power to achieve three fundamental outcomes with the potential to empower the success factor of the desired change process [KOTT12; ILJI15]:

- Clarifies the direction of the change
- Motivates employees to act
- Aligns the employees and actions concerning the changes

As Kotter also highlights in his studies, a good elaborated vision can end unnecessary and endless discussions or debates with the use of a simple question: “*Is this in line with the vision?”* [KOTT12, S. 71]. Additionally, a tailor-made vision supports the Smart Retrofitting Approach avoiding future resistance in the implementation process of Industry 4.0 within an organization (see Chapter 4.1). Considering the vision takes in consideration the corporate culture, it will prevent the occurrence of internal resistance and it will prevail [DOPP96]. Basically, there are two types of resistances that could occur during a change process in an organization, and these are from organizational and personal backgrounds. The organizational resistances are related to unwritten rules and guidelines which are for decades embedded in the daily procedures of an organization [MÜLL01; AMEL09; WATS75]. In addition, a vision also supports employees to overcome their negative feelings about getting out of the comfort zone. Therefore, suppressing the emergence of resistance that are classified as personal resistance [MÜLL01].

Given the fact that each organization is unique which is mainly attributed to its corporate culture [MART92; WARR17; ILJI15], the Industry 4.0 vision must mirror itself on the corporate culture. A vision that reflects the corporate culture will minimize the possibility that future resistance occurs during the implementation of changes [MÜLL01; ILJI15; MART92].

According to the Smart Retrofitting Change Management Model, the Industry 4.0 vision must be built by members of the management board since only they have a deep acquaintance about the challenges and demands the organization will be facing in the future [KOTT12; TJAH17]. In addition, the management board better holds the knowledge about available financial resources the organization possesses to invest in the implementation process of Industry 4.0. However, the leadership coalition can assist the management board on this since the leadership coalition members are the ones which possess the highest understanding concerning how to implement Industry 4.0 in the shop floor environment, once they gained theoretical and practical experience with the implementation of Industry 4.0 during the execution of the Moving phase (see Chapter 4.2.5).

4.2.6.3 The Smart Retrofitting Road Map

In order for an organization — independently of its size and field of operation — to implement Industry 4.0 in a structured process, the Smart Retrofitting Change Management Model proposes the elaboration of its own road map based on its organizational footprint, as explained earlier The Supply Chain Operations Reference (SCOR) Model is taken as an inspiration in this thesis to build the Smart Retrofitting Road Map due to the fact that it *links process elements, metrics, best practice, people and the features associated with the activities involved in a supply chain, promoting interaction between the different levels.* Additionally, all key aspects composing the Smart Retrofitting Approach and its respective Change Management model are merged into the Smart Retrofitting Road Map

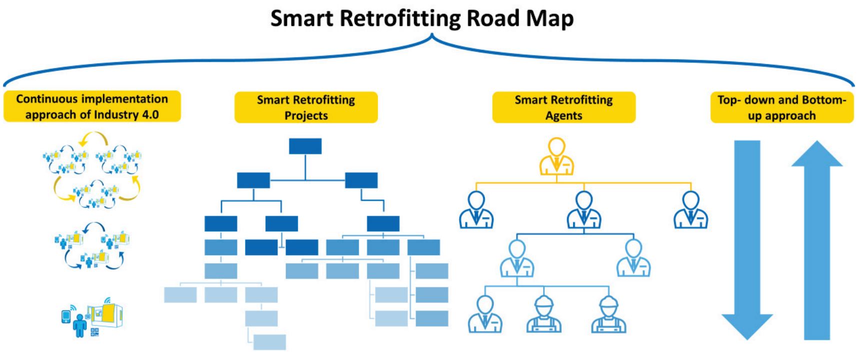


Figure 4-16 Merger of all aspects of the Smart Retrofitting Approach and its respective change management model into the Smart Retrofitting Road Map

The Smart Retrofitting Road Map effectively works in a Top-down Bottom-up management approach, which enables the high management to define the direction and timeline of the implementation process of Industry 4.0 empowering the low management and the employees to elaborate the concept to be implemented within their daily business activities. In addition, the Smart Retrofitting Agent Network will provide the necessary technical and specialist expertise within the several topics related or not to Industry 4.0. And finally, the process of implementing Industry 4.0 will occur throughout a continuous implementation process (see Figure 4-4) in which several Smart Retrofitting Projects will happen in parallel.

The below definition given by Huang, Sheoran and Keskar highlight the versatility and huge applicability of the SCOR model within an organization independently of its size and field of operation. Furthermore, it emphasizes why the Smart Retrofitting Road Map shall be based on it.

It is a model that links process elements, metrics, best practice and the features associated with the execution of a supply chain in a unique format. It provides a balanced horizontal (cross-process) and vertical (hierarchical) view as compared to the classical process decomposition models, which are developed to address one specific configuration of process elements. It is designed to be (re)/configurable and aggregates a series of hierarchical process models [HUAN05, S. 379].

The SCOR model is structured following the onion layer principle in which the first level is composed by the six primary management processes: Plan, Source, Make, Deliver, Return and Enable [APIC17] (see Figure 4-17). Therefore, empowering the SCOR model to be an excellent planning tool which allow the management board or top management of an organization to simplify and summarize their Intra and Inter supply chain activities [HUAN04; STEW97] (see Figure 4-17). Such characteristic supports the management board to acquire a better and clearer picture of where and how they shall implement Industry 4.0 in the supply chain.

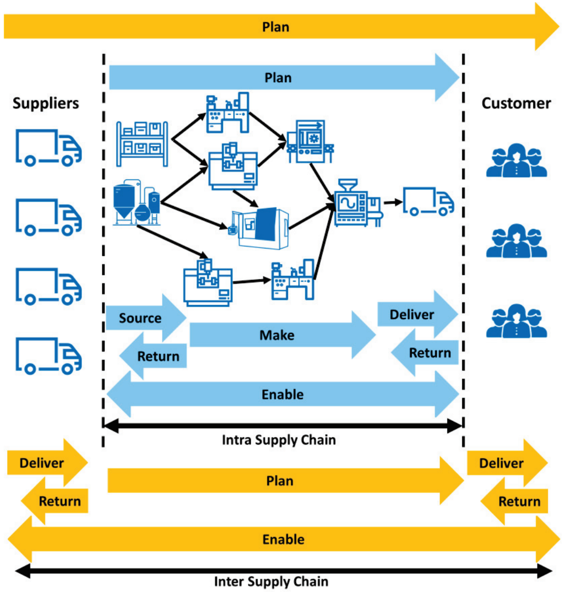
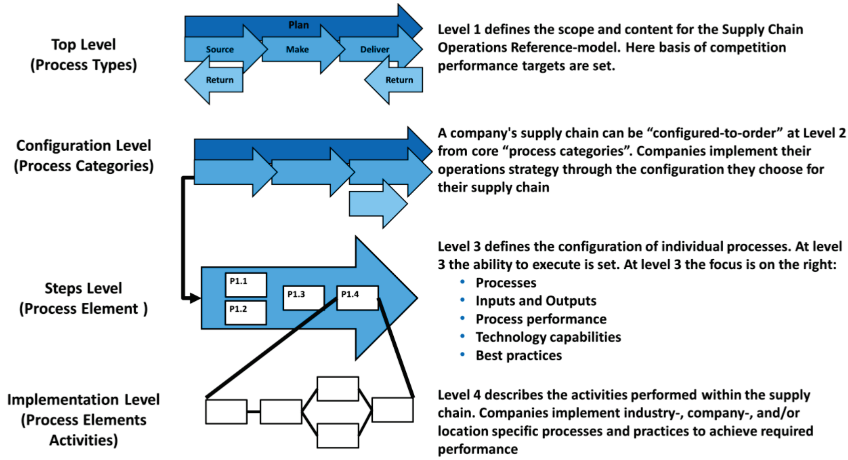


Figure 4-17 Illustration of the six management processes that compose the first level of the SCOR model

In addition, each of the six management processes are divided into three additional levels (see Figure 4-18) which primarily focuses on the description of how the processes interact between each other and which set of skills are required from the employees to perform their activities [APIC17; SUPP12].



Based on [SCHR12, S. 235; SUPP12, I.3]

Figure 4-18 Break down of the SCOR model into the four levels

In contrast to the SCOR model, the Smart Retrofitting Road Map keeps its aim and goals within the different levels. So, each of the six-management processes of the Smart Retrofitting Road Map aim to implement aspects of Industry 4.0 into its corresponding management process.

As mentioned earlier, within the Smart Retrofitting Approach the vertical integration in the implementation process of Industry 4.0, and so, the focus of the management board, shall be the elaboration of the Directive Smart Retrofitting Road Map concentrating effort to implement Industry 4.0 within the intra supply chain. This is given from the fact, that it is unproductive and a loss of resources to try to initiate an integration process with costumers and especially with suppliers without a certain degree of digitalization within the organization. Then, without such digitalization degree it will not be possible to transform the acquired information from the customers and suppliers in real-time corrective actions within the productions lines [JÄGE15; GAUS16; REIN17b; SAMA17]. The Directive Smart Retrofitting Road Map is the general overview and guideline and it will be extended with the elaboration of the different smaller road maps to be worked by the employees in their corresponding areas.

In addition, the Smart Retrofitting Approach recommends that the organization focuses its first efforts of implementing Industry 4.0 within its intra supply chain in the Make management process (see Figure 4-17). The Make management process is responsible to add value to the product and it also has one of the highest impacts regarding production costs. An issue in the Make management process could result in the worst-case scenario with complete waste of the product. Consequently, generating for the organization a huge waste of human and especially financial resources [HUMP04].

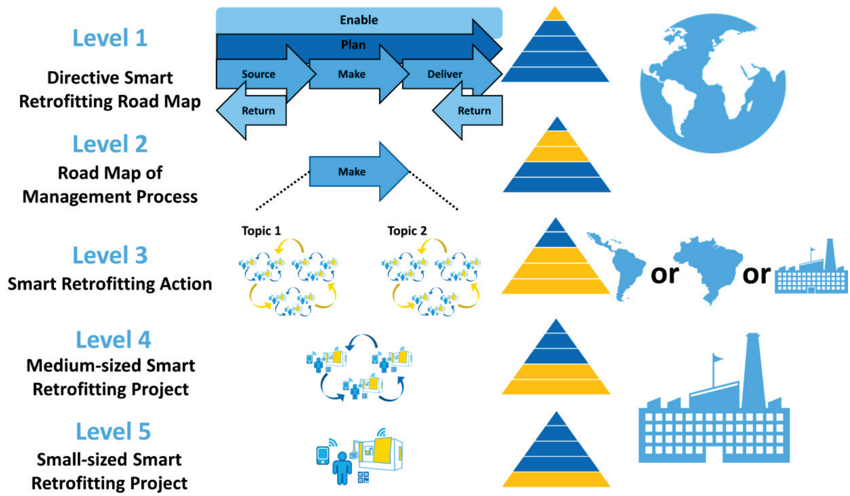


Figure 4-19 Framework of the Smart Retrofitting Road Map

Jick's Change Management model recognizes two fundamental groups of employees within an organizational that are directly involved with the change process: change strategists and receptors. The change strategists are those in charge of planning the organizational changes and consequently, the change receptors are those affected by the changes [JICK93]. In contrast to the Jick's model, the Smart Retrofitting Change Management Model adds to the change receptors also the capability to plan in a certain degree those changes that will be occurring in their daily activities. Therefore, within the first two levels of the Smart Retrofitting Road Map the management board and the top management play the role of the change strategist (see Figure 4-19 andFigure 4-20). However, the change receptors within the Smart Retrofitting Change Management Model will be the middle and lower management and employees which activities belong to the Smart Retrofitting Road Maps in the third, fourth and fifth levels (see Figure 4-19), and they will also plan, within a certain degree, the best way to implement Industry 4.0 within their corresponding daily activities considering that they will build their Road Maps based on and extending the Directive Smart Retrofitting Road Map. Consequently, such slightly different Approach to the one from Jick's model will empower the Top-down Bottom-up management approach which is pursued by the Smart Retrofitting Approach (see Chapter 4.1).

The execution of the five levels which compose the Smart Retrofitting Road Map is performed in the Unfreezing 2.0 and in the Smart Retrofitting phases (see Figure 4-20). Such, Approach enhances the involvement and empowerment of all employees during the implementation process of Industry 4.0 within an organization. Therefore, the Top-down management approach has been adopted for the first and second levels of the Smart Retrofitting Road Map (see Figure 4-20). As mentioned earlier, the management board and the top management primarily have important knowledge regarding where the organization shall be in the long term and the financial resources are available for the implementation of the Road Map.

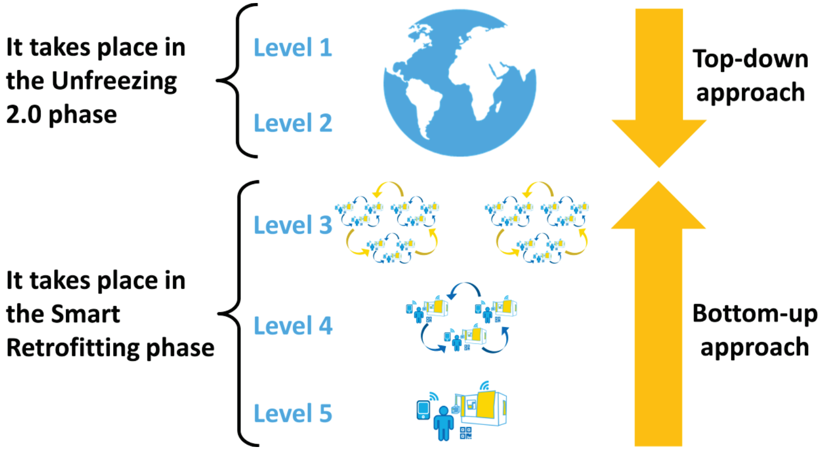


Figure 4-20 Illustration regarding the Top-down Bottom-up management approach in the Smart Retrofitting Road Map

As mentioned earlier, the Bottom-up management approach within the Smart Retrofitting Road Map has also the purpose to avoid resistance related to the implementation of Industry 4.0 within the organization and to empower employees from lower hierarchical levels to elaborate their respective Smart Retrofitting Projects belonging to the road maps extended in their corresponding areas. Doppler and Lauterburg reinforce in their work that only employees that work in a daily basis in certain activities have the full knowledge to judge what shall be improved and how shall it be done [DOPP98], this leads to realize that the active participation of the employees in the elaboration and proposals regarding projects in their corresponding areas is important not only for the motivation aspect but also for the quality of the projects and consequently the results. In addition, the Bottom-up management approach supports and enables the desired continuous implementation strategy of Industry 4.0 proposed with the Smart Retrofitting Approach (see Chapter 4.1). Additionally, the Smart Retrofitting Agent Network provides the support in the execution of all Smart Retrofitting Projects in the Smart Retrofitting activities.

Level 1

The management board elaborates the Directive Smart Retrofitting Road Map which covers the directions to follow in the entire organization and the business units. In addition, they shall define the available financial resources to implement Industry 4.0 within each business unit of the organization and they shall orient themselves on the results of the previously performed organizational footprint (see Chapter 4.3.10) and on the elaborated Industry 4.0 vision (see Chapter 4.3.11). Therefore, the Directive Smart Retrofitting Road Map is based on the needs and challenges that the organization is currently facing in its daily activities. Furthermore, the management board can also look for activities within the Directive Smart Retrofitting Road Map with potential to open new business opportunities which not previously possible for the organization. The Directive Smart Retrofitting Road Map must also follow the continuous improvement Approach concentrated on continuity as it is desired by the Smart Retrofitting Approach (see Chapter 4.1). The management board shall create the goals to be achieved in each business unit breaking them in short-, medium- and long term [JICK93] after the accomplishment of the Refreezing phase. This facilitates the management board to split the investments which minimizes the risk of investing in wrong initiatives; since the investment will be done according to the advancement and success of the improvements being implemented. Nevertheless, the management board members shall concentrate their efforts on the vertical integrations in the first year, since these can provide the organization immediately cost savings through increase of productivity and efficiency [BAUE14c; JESC16; KAUF15]. Such savings can be used to finance the Smart Retrofitting Actions aimed to accomplish the horizontal integration with the suppliers and vendor.

It is recommended for the management board to build a list of KPI’s, including OEE and OPE, to have an overview of the organization regarding Industry 4.0 activities. This KPI’s will guide the employees from all levels to build and execute their road maps and in the optimum scenario raising real time data for direct access up to the management board members, if desired.

Level 2

The top management and the middle management levels are responsible to elaborate the extension for the Directive Smart Retrofitting Road Map for each of the six-management processes in their respective business units (see Figure 4-19). Like the management board, the top management and middle management shall regard their road maps to the organizational footprint, the Industry 4.0 vision and the continuous improvement Approach concentrated on continuity. Consequently, the top management and middle management are also able to split the financial risk of implementing aspects of Industry 4.0 in each of the six-management processes, since the investment can as well be done according to the advancement and success of the improvements.

In parallel to the elaboration of the each of the six-management processes road maps, the leadership coalition creates the conditions and environment for the Smart Retrofitting Agent Network. The corporate culture influences directly on how this is elaborated. Thus, all singularities which Smart Retrofitting Approach carries with and its respective change management model defined to be elaborated through a Top-down management approach are fulfilled (see Chapters 4.3.10, 4.3.11 and 4.3.12):

- Creation of a tailor-made Industry 4.0 vision
- Elaboration of a Smart Retrofitting Road Map
- Allocation of financial resources
- Realization of the digital maturity degree of the organization
- KPI’s list that will be empowering the management board to have an overview of the organization in real-time
- Adoption of a continuous implementation approach of Industry 4.0 concentrated on continuity

Consequently, the level 2 marks the end of interaction between the management board and the top management with the rest of the employees through the Top-down management approach (see Figure 4-20).

Level 3

As previously pointed out, the Smart Retrofitting Action is elaborated in the third level of the Smart Retrofitting Road Map. The aim of the Smart Retrofitting Action is to implement aspects of Industry 4.0 following the road maps created in the previous levels (see Chapter 4.2.8). Therefore, it is highly recommended that the activities composing the Smart Retrofitting Action are divided within topics (see Figure 4-19) (see Chapter 4.2.8). Such, clustering of the topics shall be based on the elaborated KPI's list from the previously level. Additionally, it is up to the middle management to decide the clustering of criterions and it is highly recommended these to follow aspects of Industry 4.0, for instance:

- HMI
- Data collection
- Data analytics, Data Mining, Machine Learning
- Digital twin
- Track and trace
- Etc

Nevertheless, the middle management also can establish some topics concerning internal aspects of their organization, for example:

- Production equipment
- Production process
- Product
- Raw material
- Costumer
- Etc

This level marks the beginning of the empowerment of all employees in the implementation process of Industry 4.0 throughout the organization (see Figure 4-20), noting that all employees related to the topics shall be involved at the elaboration of the Smart Retrofitting Action since, the employees working in a daily basis at a certain activity can better judge what could be changed and if such change is realistic to be implemented [DOPP96] (see Chapter 4.2.8). In addition, the elaboration of the Smart Retrofitting Action marks the beginning of the continuous implementation process of Industry 4.0 in the shop floor level (see Figure 4-4).

Level 4 and 5

The two-last levels of the Smart Retrofitting Road Map are concentrated on the execution of several Smart Retrofitting Projects which compose the Smart Retrofitting Action (see Chapter 4.2.8). The core difference between both levels is the scope and size of their respective Smart Retrofitting Projects (see Figure 4-19). Therefore, for example, a small Smart Retrofitting Projects —level 5— limited itself to the implementation of Industry 4.0 into a single production equipment (see Chapter 4.2.8). Consequently, the effort to interconnect several production equipments which had already been worked on through small Smart Retrofitting Projects, can be considered medium sized Smart Retrofitting Project (see Chapter 4.2.8). However, more details regarding what difference a small to medium sized Smart Retrofitting Project will still be explained (see Chapter 4.2.8).

4.2.7 Refreezing phase

Jick highlights in his ninth commandments for implementing change that change leaders have an open communication which their employees concerning the upcoming changes. In addition, Jick reinforces the importance that the change leader seeks out the involvement and trust of all employees throughout the organization. Jick indicates that following such approach possible resistance can be avoided and employees would with a higher probability identify themselves with the upcoming changes [JICK93]. Inspired on Jick's commandments the Refreezing phase within Smart Retrofitting Change Management Model seeks to have an open communication with all the employees concerning the achievements of each pilot project executed in the Moving phase as well the upcoming changes that the management board and the top management had planned to implement Industry 4.0 throughout the organization.

Doppler and Lauterburg suggest that the team that worked in a particular change activity should also be the one to communicate the achievements to other employees within the organization [DOPP96]. Therefore, the achievements of all pilot projects which had been previously done in the Moving phase shall be presented by the employees who worked on them (see Figure 4-21). The attitude of enabling the employees of the Pilot Project team to communicate their achievements passes the message to the rest of the employees that: The management board, the top management and the leadership coalition recognizes the individual efforts of their employees to implement Industry 4.0 into their daily business activities. Such, recognition will most probably trigger motivation in the rest of the employees consequently facilitating their identification with the cause of implementing Industry 4.0 in their daily business activities [DOPP96; JICK93]. Consequently, it will be also preventing possible future resistances in the implementation process of Industry 4.0 throughout the organization [HIAT06; JICK93].

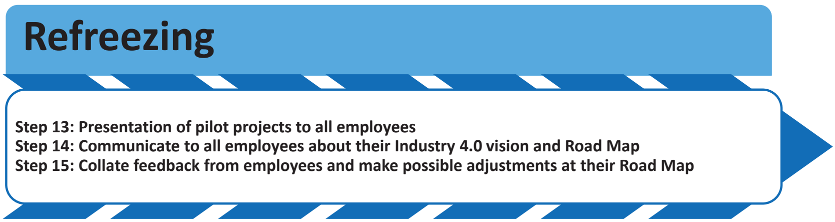


Figure 4-21 Refreezing phase and its corresponding step

As mentioned earlier the management board, the top management and the leadership coalition will communicate the Industry 4.0 vision to be adopted from now on in the organization (see

Chapter 4.3.14). Additionally, the Directive Smart Retrofitting Road Map shall be communicated throughout several campaigns throughout the different hierarchical levels of the organization (see Chapter 4.3.14). To stimulate the embedment of the Industry 4.0 vision in the corporate culture, it will be given to all employees the opportunity to give their feedback concerning the applicability of the section of the road map that concerns and affect their daily business activities (see Chapter 4.3.15).

4.2.8 Smart Retrofitting phase

The Smart Retrofitting phase is designed to enable the implementation of Industry 4.0 in a large scale throughout an organization through a retrofit of its existing resources. This will be occurring through the execution of several Smart Retrofitting Actions which merge the Smart and Retrofitting components of the Smart Retrofitting Approach in each of their actions and interventions. The change management models from Kotter, Jick, Doppler and Lauterburg [KOTT14; DOPP02; JICK93] had a deep influence on the Smart Retrofitting Approach and served as inspiration sources for the elaboration of the Smart Retrofitting Action and its respective Smart Retrofitting Projects to be worked on.

In addition, a safety trigger— Smart Retrofitting Revitalization Acts — is embedded within the Smart Retrofitting phase (see Figure 4-22) which aim is to ensure the organization is applying the newest technologies and trends concerning Industry 4.0 available in the academic and business community (see Chapter 4.3.19). This shall ensure to the organization that the investments dedicated to Industry 4.0 projects are not outdated in a near future and also do not miss any game changing technology. Further to this, it will reinforce that the organization shall keep or increase its compatibility and consequently, its strong market position. Consequently, the Smart Retrofitting Revitalization Acts will generate some adjustment to the second and third levels of the Smart Retrofitting Road Map of the organization (see Figure 4-19) (Chapter 4.2.6).

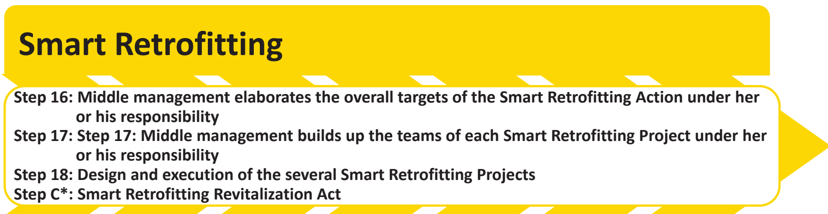


Figure 4-22 Smart Retrofitting phase and its corresponding steps

Smart Retrofitting Actions

A Smart Retrofitting Action consist of several projects (see Figure 4-23) each aiming to accomplish the implementation of one topic predicted within the third level of the Smart Retrofitting Road Map (see Figure 4 19) (Chapter 4.2.6). As mentioned earlier, the middle management members shall elaborate, plan and supervise the execution of the Smart Retrofitting Action which has been attributed to them by the top management. By the elaboration and design of a Smart Retrofitting Action the middle management shall follow three recommendation which was inspired by the three last steps of Kotter's change model and the last commandments of Jick's model [KOTT14; JICK93] (see Figure 4 6)

- Generate short-term wins
- Sustain acceleration
- Reinforce and institutionalize the change

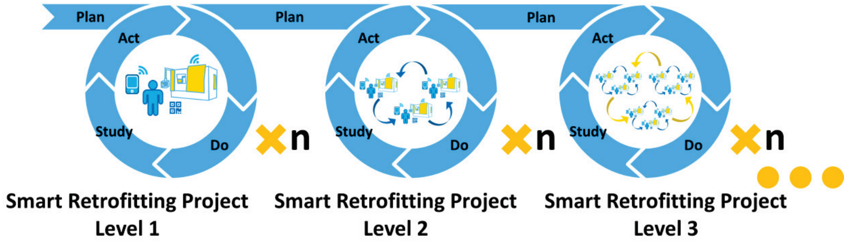


Figure 4-23 Structure of a Smart Retrofitting Action

As already mentioned before (see Chapter 4.1), the continuous implementation process and the continuous improvement process, the latter mainly concentrated on continuity, reflect on how the Smart Retrofitting Action has to be executed (see figure 4-23).

A Smart Retrofitting Action is composed by several Smart Retrofitting Projects which shall be clustered to different levels (see Figure 4-23). The number of levels that a Smart Retrofitting Action shall have depends on its scope and subject. For example, if an organization intends to create a digital twin of one existing production line, the first level of the Smart Retrofitting Action consists of collecting all relevant process parameters throughout a retrofit for each production equipment that compose the production line. Therefore, the interconnection among all relevant process parameters, from each single production equipment, occurs within the second level. Finally, the Smart Retrofitting Projects aiming the interconnection of all production equipments of that production line is performed within the third level (see Figure 4-23).

Nevertheless, all Smart Retrofitting Actions shall follow Kotter's recommendation of creating several small wins throughout its implementation process [KOTT14]. This will generate a motivational effect at the employees [HERZ68] and reinforce the institutionalization of the achieved change into the organizational daily business and corporate culture [KOTT14; LOCK96].

Smart Retrofitting Project

The sequence of action of a Smart Retrofitting Project shall follow the four stages of a PDSA cycle (see Figure 4-23). In addition, it is a must that the team leader of a Smart Retrofitting Project performs a DMAIC to assure that during the plan stage all possible necessaries and challenges are covered. Consequently, a high level DMAIC content is proposed by this work to guide the team leader of a Smart Retrofitting Project during the plan stage.

The questions for the DMAIC described below are focused for the Industry 4.0 vision worked in this thesis.

Define

- Why is the implementation of aspects of Industry 4.0 to this subject necessary?
- What is the scope of this project concerning Industry 4.0?
- How will this project add value by interconnecting it to another project within the organization?

Measure

- What are the key metrics of this subject?
- Can I measure these metrics by applying aspects of Industry 4.0 into the subject?
- How can I use these metrics in the future within others subjects that compose my organization?

Analyse

- What are the current gaps in the subject?
- What are the root causes for those gaps?
- What information can be generated by fulfilling those gaps?

Improve

- What are the key elements of Industry 4.0 which can generate an improvement within the subject?
- Are those improvements relevant to other subject within the organization?
- What are the key metrics of the subject that should be improved by the implementation of aspects of Industry 4.0?

Control

- Are the risks and costs covered to initiate the implementing process of aspects of Industry 4.0 within this subject?
- Has this project the potential to become a best practice in a near future?
- How to assure that each action within this project will be documented?

Nevertheless, the team leader can perform adaptations to his DMAIC concerning the particularity and challenges of his or her project and therefore, creating a continuous improvement process within the organization of how a Smart Retrofitting Project shall be structured.

Since, the Smart Retrofitting Project follows a PDSA cycle it empowers the project leader to study the achieved results and if they do not correspond with the hopes and expectations of the top management the PDSA cycle can be done again until all requirements are fulfilled. Such, recycling of the PDSA cycle will generate extreme value knowledge concerning what went wrong during the implementation of a certain aspect of Industry 4.0 and consequently, this can be exploited in future projects within the organization [DEMI18; DEMI86; LANG09; SPER04; TAYL14].

4.3 Steps of Smart Retrofitting Change-Management Modell

The most important factors for success are patience, a focus on long-term rather than short-term results, reinvestment in people, product and plant and an unforgiving commitment to quality

Robert B. McCurry,

Former executive V.P., Toyota Motor Sales

This sub-chapter provides further details of the nineteen steps of the Smart Retrofitting Change Management Model (see Figure 4-24). The author of this dissertation intends to provide organizations with a detailed guideline for the execution of each step of this new Model to be applied in the implementation of Industry 4.0.

The objectives of each step are listed in form of bullet points and, for some steps, the recommended methods and tools are also given. Nevertheless, the organization is motivated to apply other methods and tools which might be identified to be even more adequate or appropriate to the company.

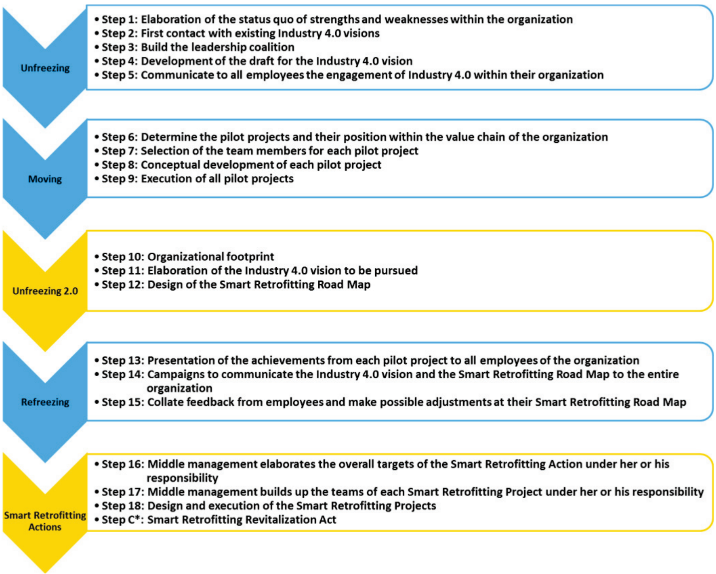


Figure 4-24 All steps of the Smart Retrofitting Change Management Modell

4.3.1 Step 1: Elaboration of the status quo of strengths and weaknesses within the organization

Within this step the management board, or top management team depending of the size of the organization, has to start mapping their status quo concerning their internal and external strengths and weaknesses within their organization resulting on the precise picture concerning the organization's needs. Consequently, this picture will guide the management board or top management team to create the tailor-made Industry 4.0 vision which will empower their organization to at least keep or even increase their market share (see Chapters 4.3.5 and 4.3.11).

The management board analyses the financial resources available for implementing Industry 4.0 in the organization. Such task shall be led by the Chief Financial Officer (CFO) of the organization. It is highly recommended to have a Chief Digital Officer (CDO) for a large organization [GART18; HORL16; SING17]. The CDO will be in charge of embedding the future Industry 4.0 vision (see Chapter 4.3.11) into the corporate culture. Nevertheless, if the organization is not a large one, the employee which could be responsible for the implementation of Industry 4.0 must have solid knowledge of the daily business activities and experience with the Industry 4.0 topic.

These are the main objectives in this step:

- Organizational footprint regarding current strengths and weaknesses concerning the execution of the company's daily business operation
- Definition of available budget to implement Industry 4.0 within their organization
- Definition of a leading employee for the implementation of Industry 4.0 throughout the organization

Methods and Tools

Brainstorming, Mind Mapping, Workshops, Team-Building activities, value stream mapping, and SWOT analysis

4.3.2 Step 2: First contact with existing Industry 4.0 visions

The management board and the top management team of the business units will be exploring the different concepts and visions concerning Industry 4.0 to have references (see Chapter 3.1). Therefore, researches regarding current works in the field of Industry 4.0 in the academic and business communities are important to provide them with a critical judgement concerning Industry 4.0 which can foster the discussion about how Industry 4.0 could be applied in their business. Once the management board and the top management have explored sufficiently about the current Industry 4.0 visions and projects, they can better interact with consulting companies which will provide them with a deeper and detailed understanding of Industry 4.0.

The sequence of these events is extremely important within the Smart Retrofitting Approach since it will empower the managers to create a critical understanding of Industry 4.0. Therefore, it is important to ensure the non-engagement in a certain direction of Industry 4.0 only because it is a trend in other industrial segments or is promoted by renowned references. The goal of the Smart Retrofitting Approach and its tailor-made change management model is to enable the management board and top management team to create a tailor-made Industry 4.0 vision driven by the needs and challenges of their specific organization (see Chapters 4.1 and 4.2.2).

These are the main objectives in this step:

- Exploring the different visions of Industry 4.0 in the academic and commercial community
- Contact consulting companies to provide them with a deeper knowledge concerning the possibilities of Industry 4.0

Methods and Tools

Brainstorming, Mind Mapping, Workshop with experts, Radar diagram and Benchmarking

4.3.3 Step 3: Build the leadership coalition

This step is particularly related to the involvement of the human resource (HR) department in a key task and element of the Smart Retrofitting Change Management Model. The management board together with the top management members and the HR employees shall assemble the leadership coalition team which will be the driving force to implement the Industry 4.0 across the entire organization (see Chapter4.2.3). Therefore, the HR department has to search within the organization for employees which possess some of the following characteristics and skills [BERS08; ILJI15; RHIN96]:

- Creative in problem-solving
- Team-oriented
- Motivated and inspiring motivation in co-workers
- Excellent communicator
- Truly identifies itself with the corporate culture of the organization
- Sees the Big Picture and acts through small and structured actions
- Extremely persevering and patient
- Works with employees of different cultural backgrounds
- Leads by example

Additionally, the management board and the top management should consider four key characteristics highlighted by Kotter necessary for an effective leadership coalition:

5. Position power: Are enough key players on board, especially the main line managers, so that those left out cannot easily block progress?
6. Expertise: Are the various points of view —in terms of discipline, work experience, nationality, etc.—relevant to the task at hand adequately represented so that informed, intelligent decisions will be made?
7. Credibility: Does the group have enough people with good reputations in the firm so that its pronouncements will be taken seriously by other employees?
8. Leadership: Does the group include enough proven leaders to be able to drive the change process?

[KOTT14, S. 59]

In addition, the leadership coalition should strongly avoid two types of individuals [KOTT14]:

- Individuals which have big egos that could fill up a room. Consequently, leaving no room for anybody else.
- Individuals which create mistrust to kill teamwork. Consequently, using their rolls in the leadership coalition as a trampoline for a higher ranked position within the organization.

These are the main objectives in this step:

- Find the employees with the proper characteristics and skills within the organization
- Build the leadership coalition team

4.3.4 Step 4: Development of the draft for the Industry 4.0 vision

The first draft of the Industry 4.0 vision of an organization is meant to fulfill the first of the three fundamental outcomes which a vision should generate clarifying the direction of the change (see Chapter 4.2.4) [KOTT12; ILJI15]. In contrast to Kotter and Jick's works that mention the first draft of the vision normally being done by one individual [KOTT12; JICK93], the elaboration of the draft for Industry 4.0 vision in the Smart Retrofitting Change Management Model has to be the result from the joint effort between the management board members to gather all the input directly from the different areas of the organization to avoid undesired impacts in one or another field.

The corporate culture must be embedded in the first draft of Industry 4.0 vision minimizing so possible resistance and lack of support to overcome the fear throughout its implementation [MÜLL01; AMEL09; WATS75].

Once the leadership coalition was formed after the management board and top management did the research about the different visions of Industry 4.0 (see Chapter 4.3.2), the leadership coalition has to learn and expand this knowledge. This prepares the leadership coalition members to actively participate in the next steps of the Smart Retrofitting Change Management Model.

These are the main objectives in this step:

- Definition of the direction that Industry 4.0 will take within the organization
- Leadership coalition acquires maximum knowledge concerning Industry 4.0

Methods and Tools

Ansoff-matrix, BCG-matrix, Five-Force-model, SWOT analysis, 5-Why-Methode,7-S model, Benchmarking, Workshop, Brainstorming sections, decision tree, mind mapping, Zwicky-Box and Six Thinking Hats

4.3.5 Step 5: Communicate to all employees the engagement of Industry 4.0 within their organization

The communication of the first draft of the Industry 4.0 vision shall be addressed directly to the employees. Therefore, it is not recommended the communication to be done primarily by means of [KOTT12; JOHA08]:

- Articles within the organizational newspaper
- Intranet website, videos and PowerPoints dedicated to change process
- Webcasts and continuous email updates
- Etc

Instead, the announcement of the first draft of the Industry 4.0 shall occur throughout communication channels in which the human contact is stimulated [HERZ68; JICK93; MCMA96]. This enhances the probability that the employees identify themselves with the resulting changes [JICK93]. Additionally, the employees will be stimulated to figure out how the changes can solve some challenges they are facing in their daily business activities, hence embedding the changes into the corporate culture [ILJI15; LEE16; WANG12; JICK93]. Therefore, it is recommended for the management board to make the announcement with an overall scope in the organization and the leadership coalition will be in charge to conduct the announcement with direct contact to small audiences with participation of the HR representative. Further to this, the announcement of the leadership coalition to the entire organization and the first draft of the Industry 4.0 vision must pass a clear message of who the members are, and which role they will assume on the whole process and what the vision represents to the organization.

These are the main objectives in this step:

- Present to all employees the leadership coalition team and their role
- Communicate the first draft of the Industry 4.0 vision primarily focusing on the communication of the strategies in direct contact to the audience

4.3.6 Step 6: Determine the pilot projects and their position within the value chain of the organization

The weakness analysis performed in the first step of the Smart Retrofitting Change Management Model (see Chapter 4.3.1) showing the current difficulties the organization is facing supports the work of the leadership coalition in this step. If the weakness analysis is not available, it is highly recommended that the leadership coalition performs a value stream mapping for the most challenging production plants within the organization. Hence, the outcomes from the value stream mapping of the production processes with the biggest return potentials with the implementation of Industry 4.0 can be to show the leadership coalition. Additionally, it provides to the leadership coalition an overview about the realistic number of pilot projects that could be executed within their value chain [RAHA12; ROTH03].

It is well known that shop floor collaborators hold important knowledge concerning weaknesses and challenges of the production processes [DOPP96]. This thesis takes this observation into consideration and the potential for these employees to cooperate with the leadership coalition in a two-way direction flow of information. In addition, the best scenario is to have at least one pilot project per region where the organization is present in order to keep momentum among the employees and have a steady grow in knowledge concerning the challenges of implementing Industry 4.0 within the organization. A scenario that considers all the regions covered with pilot projects might trigger a motivational effect across the regions and the respective staffs.

These are the main objectives in this step:

- Execution of analysis to determine in which business units, production plants and production processes the pilot projects shall be performed
- Determine the number of pilot projects that should be executed within their organization

Methods and Tools

Value stream mapping, Brainstorming, SWOT-Analyse, Ishikawa-Diagram and 5-Why-Methode

4.3.7 Step 7: Selection of the team members for each pilot project

Each member of the leadership coalition will be managing at least one pilot project and the team must include at least one employee from the following departments:

- Quality
- IT
- Engineering
- Safety

All shop floor employees of the selected processes belonging to the pilot projects must be team members. Among them, it is recommended to have one employee representing the labour union to convey the challenges the organization is seeking to overcome to keep its market position and the inclusion of the employees in the whole development process of Industry 4.0.

These are the main objectives in this step:

- Building the team that will work on the pilot project
- Define responsibilities among the team members

4.3.8 Step 8: Conceptual development of each pilot project

The leadership coalition has to transmit to all employees the first draft of the Industry 4.0 vision plus some valuable information from the academic and business community to reinforce the objectives of the organization avoiding doubts on how Industry 4.0 could be a solution provider (see Chapter 4.3.5).

The available budget must be informed in this step and the leadership coalition shall clarify that employees can receive assistance and that they are empowered to designing solutions to implement Industry 4.0 on the studied subject. Further to this, the leadership coalition shall give the final approval for the final concept developed by the pilot project team.

These are the main objectives in this step:

- Communication of the first draft of the Industry 4.0 vision of the organization and other available vision in the academic and business community
- Conceptual development of the Pilot Project for the approval of the leadership coalition

Methods and Tools

Brainstorming, Ishikawa-Diagram and 5-Why-Methode

4.3.9 Step 9: Execution of all pilot projects

The leadership coalition shall make sure that all the employees are involved in the execution of the pilot projects. Additionally, it will act as the project manager assuring the pilot projects will be successfully concluded within the committed budget. The documentation of the project is responsibility of the team members and in particular the leadership coalition must ensure this documentation can be shared with others inside the organization if it becomes a best practice.

These are the main objectives in this step:

- The participation of all team members
- Documentation of all activities and challenges faced during the execution of the pilot project
- Where applicable make the pilot project´s results best practice.

4.3.10 Step 10: Organizational footprint

Target of this step is to design and execute a systematic strategy to gain information about the internal status quo of the organization. How an organization should conduct their footprint is strongly linked to its size. Therefore, smaller organizations will be able to conduct organizational footprint throughout initiatives in which information collection happens through a direct interaction with the interviewed audience (see Figure 4-25). Nevertheless, larger organizations will be mainly conducting their information collection through surveys making use of digital tools. The selected digital tools shall be of common use inside the organization and preferred by the employees. Additionally, such digital tools must be the most user-friendly as possible for the interviewed person as well as for those who will be analysing the collected information. Nevertheless, this does not exclude the option to perform personal or group interviews or even diagnosis workshop within certain employees’ group in the organization.

Type of event	Personal interview	Group interview	Diagnosis workshops
Size of the group	1	5-7	20-25
Structure	The topics are pre-defined, within the framework of the individual topics an open dialogue takes place	Semi-structured conversation with pre-defined topics	Collection and Condensation of statements and knowledge through small group discussions and analyses of individual topics determined by the moderators
Duration	30-60 min	1-2 hours	Max 1 day
Advantage	• Highest degree of openness • High level of interactivity • Depth and detailed analysis	• Important points become very clear • Group activity promotes team culture	• High variety of results, wide range of displayed aspects covered • Flexible deepening of the analysis possible
Disadvantage	• High expenditure of time	• Individual openness is not that high	• Relatively high organizational effort • High time expenditure for the individual participants

Based on the content of [DOPP02; HIAT06]

Figure 4-25 Detailing of diagnosis workshops, personal and group interview

However, independently of the size of an organization two recommendations must be followed when performing the organizational footprint through direct interactions. First, the interviews, workshops and questionnaires shall be conducted by the employees from the organization which would drive to a vibrant communication culture about the upcoming changes [DOPP02].

Second, the involvement of shop floor people on this process is recommended because they hold the specific knowledge [DOPP02; DOPP96] and they are able to provide important inputs to the team developing the organizational footprint during the interviews, workshops or even digital surveys. These employees can also provide information and recommendations concerning how deeply the topics in discussion shall be Approached during the surveys, workshops or interviews [DOPP02]. This will surely stimulate the cultural exchange and will open new communication channels between the employees supporting the Smart Retrofitting Agent Network (see Chapter 4.2.3).

These are the main objectives in this step:

- Define which employees will be responsible to conduct the interviews and workshops within the business units, plants or production lines within the organization
- Define which digital tools or platforms will support the execution of the organizational footprint
- Design the organizational footprint throughout the interaction between the employees from different hierarchical levels
- Execute and evaluate the organizational footprint

4.3.11 Step 11: Elaboration of the Industry 4.0 vision to be pursued

The management board is now capable to build the final Industry 4.0 vision for the organization. Surely this vision can be revised after some time to be updated with the new technologies and trends on the market (see Chapter 4.3.19).

For this, they shall make use of the knowledge acquired in the second step of the Smart Retrofitting Change Management Model (see Chapters 4.2.4 and 4.3.2). Additionally, the organizational footprint will heavily support to elaborate the Industry 4.0 vision regarding the needs, challenges and strengths within the organization (see Chapter 4.3.10). Besides these two previously executed steps, it is highly recommended that the management board answers for themselves the following questions clustered in five categories. These will help them to shape their Industry 4.0 vision to better fit the company´s needs and to keep or even enhance its market position.

Business strategy

- What is our core business? How can we add more value to it through the use of Industry 4.0?
- Do we have the necessary access to the customer for our growth or through the appropriate distribution channels?
- What innovation and advantages could our main competitors offer with the use of Industry 4.0 in the future?
- What are the possible potential competitors that are not yet competing with us but could be in the future with the use of Industry 4.0? Which are the possible scenarios that Industry 4.0 will be generating in three to five years from today? And how do we have to be positioned in terms of knowledge concerning our product, business processes, organizational structures and qualifications of our employees?
- Do we have an USP (Unique Selling Proposition) compared to the competition?
- Where do we have the chance to significantly expand by applying aspects of Industry 4.0 with a reasonable effort within our organization?

Daily business activities

- What distinguishes us — positively and negatively—from our competitors? How can we increase the positive and decrease the negative element that distinguishes us from competitors throughout the use of aspects of Industry 4.0?
- What will encourage our customers to buy from us in three or five years from now?
- How could we reduce our waste by implementing aspects of Industry 4.0 within our organization?
- How could we reduce our stock by implementing aspects of Industry 4.0 within our organization?
- How could we reduce our takt time by implementing aspects of Industry 4.0 within our organization?
- How could we increase the quality of our products by implementing aspects of Industry 4.0 within our production lines?

- Which aspects of Industry 4.0 would better interconnect our Supply chain?
- What could make us more profitable by applying Industry 4.0 within our organization?

Customers

- What is the value-added which Industry 4.0 can offer to our current customers?
- Which are the products or services that Industry 4.0 will enablw us to offer to current and new customers?
- What are our customers' expectations regarding innovations that could be attributed to Industry 4.0?
- How can we distinguish ourselves from our competitors regarding the use of Industry 4.0?
- Do our competitors have an advantage concerning the implementation of Industry 4.0 within their organization; if so, what are they?
- How can we use our Industry 4.0 initiatives for marketing purposes and add value to our organization?
- Who will be our customers in the future?
- What are the current and future needs of our customers?
- How significant is Industry 4.0 for our market overall?
- Will be our customer willing to pay more money for products which had been produced with aspects of Industry 4.0? How to justify the added value which Industry 4.0 can provide to the costumers?
- How do we believe we can distinguish ourselves from the competition in the long term by implementing aspects of Industry 4.0 within our organization?

Skill sets among the employees

- Do we have enough knowledge from the developed projects aimed to implement aspects of Industry 4.0 throughout our organization?
- What type of employees do we need to hire to implement aspects of Industry 4.0 within our organization?

Existing resources within the organization

- Do we have the necessary IT infrastructure to implement Industry 4.0 within our organization? If not, what expenditure of time and resources would it take to build and maintain the appropriate IT Infrastructure within our organization?
- Which are the common production equipments within our organization?

As mentioned earlier it is of extreme importance that the Industry 4.0 vision is based on and reflects the corporate culture. This will massively contribute to avoid future resistance throughout the implementation of the vision [MÜLL13b; BURN04a; JICK91; KOTT12; LAUE14; DOPP02].

These are the main objectives in this step:

- Perform management board workshop to share their knowledge regarding Industry 4.0

- Define an overall Industry 4.0 vision for the entire organization
- Define distinct Industry 4.0 vision for each business unit within the organization

Methods and Tools

Ansoff-matrix, BCG-matrix, Five-Force-model, SWOT analysis, 5-Why-Methode,7-S model, Benchmarking, Workshop, Brainstorming sections, decision tree, mind mapping, Zwicky-Box and Six Thinking Hats

4.3.12 Step 12: Design of the Smart Retrofitting Road Map

As mentioned earlier, in this step only the first and second management levels will design and elaborated the first Smart Retrofitting Road Map (see Chapter 4.2.6). Therefore, this step will be conducted throughout a Top-down management approach in which only the management board —first level— and the top management team —second level— of the organization are involved (see Figure 4-20). Hence, the management board will create the general road map to implement Industry 4.0. This road map serves the top management to deploy and create the road map regarding the business units and plants they are responsible for. Both management groups should always design their road map in a form which will empower and motivate the employees under their responsibility to participate at the change process which will take place on their work environment. Additionally, their road maps must be profoundly linked to the corporate culture enhancing the success chance of the desired changes [KOTT12; ILJI15].

It is of great importance for the management board and for the top management team to guide themselves elaborating their own respective road map based on the results and acquired knowledge from the several survey campaigns performed earlier during the organizational footprint step (see Chapter 4.3.10). However, the acquired knowledge from the Moving phase is also an important source to judge the efforts of implementing aspects of Industry 4.0 (see Chapters 4.2.5 and 4.2.6) (see Figure 4-17). By following those recommendations, the management board and top management team will be able to create road maps that are tailor-made for the needs and status quo of their companies.

In the case of a small organization or even a single plant, it is recommended that the top management also creates road maps for each of their production's lines.

These are the main objectives in this step, valid also for a single production line:

- Creation of the overall road map for the organization based on the acquired knowledge from the Moving phase and the organizational footprint work
- Creation of road maps for each business unit of an organization based on the acquired knowledge from the Moving phase and the organizational footprint work.

Methods and Tools

Ansoff-matrix, BCG-matrix, Five-Force-model, SWOT analysis, 5-Why-Methode,7-S model, Benchmarking, Workshop, Brainstorming sections, decision tree, mind mapping, Zwicky-Box and Six Thinking Hats

4.3.13 Step 13: Presentation of the achievements from each pilot project to all employees of the organization

As it has been mentioned earlier, this step aims to spread achievement and knowledge gained by each pilot project executed during the Moving phase (see Chapters 4.2.5 and 4.2.6) to all employees within the organization. A motivational effect will be generated within the members of the pilot projects as well within the rest of the employees. This will be a sign to all employees that their efforts to implement Industry 4.0 have been recognized by their supervisors.

It is recommended that each pilot project team prepares its statement in two versions. The first version is to be published through traditional communication channels to the entire organization. Hence, offering a general overview related to how they implemented Industry 4.0. The second shall target groups of employees which perform similar activities as the pilot project team. Consequently, this second statement must carry more details and shall serve as reference for the audience to make their first thoughts on how to implement Industry 4.0 into their daily business activities based on the experiences from the pilot project team. Ideally, the second statement shall take use of workshops or group meetings. Nevertheless, the use of digital solution is also appropriate for the execution of those knowledge transfer sections.

In case the organization possesses several business units or plants, the leadership coalition should provide the support to enable the presentations on all of them.

These are the main objectives in this step:

- Pilot project teams present their achievements to the entire organization
- Pilot project teams perform several knowledge transfers sections to specific target groups within the organization.

Methods and Tools

The ones the organization is familiarised and already uses intensively

4.3.14 Step 14: Campaigns to communicate the Industry 4.0 vision and the Smart Retrofitting Road Map to the entire organization

The management board and the top management team, with the support of the leadership coalition, shall now promote campaigns using their communication channels to clarify the Industry 4.0 vision and its respective road map.

It is important that these campaigns cover the entire organization highlighting how Industry 4.0 matches and stimulates the corporate culture. The Smart Retrofitting Change Management Model offers the organization complete freedom to decide how campaigns shall be structured and executed once the interaction with the employees is deeply dependent to the corporate culture and it is productive to the managers to judge the best path to follow on this in order to stimulate the implementation of Industry 4.0 across the organization.

These are the main objectives in this step:

- Describe where the organization is now regarding Industry 4.0

- Describe where the organization needs to go regarding Industry 4.0 and its vision
- Describe how the organization will get to the desired Industry 4.0 vision using the Smart Retrofitting Road Map

Methods and Tools

The ones the organization is familiarised and already uses intensively

4.3.15 Step 15: Collate feedback from employees and make possible adjustments at their Smart Retrofitting Road Map

The management board and the top management team, with the support of the leadership coalition, shall encourage that all employees of their organization provide feedback concerning the feasibility of implementing Industry 4.0 through the proposed Smart Retrofitting Road Map at his or her daily activity. Such, necessity to provide all employees—specially the once from the lowest hierarchical levels of an organization— the opportunity to be listen is also recommended by Kotter in his works [KOTT14; KOTT12].

To facilitate the collection of all feedbacks provided by the employees it is highly recommended that the organization performed the feedback campaign throughout a digital tool which at least shall be excel or in the best scenario a web-based tool that was specially designed for the needs and requirements of the organization. In addition, it must be made very clear to the employees that their feedback had been analysed and taken into consideration. This will generate within the employees a motivational effect and reduce the probability of future resistance by the roll-out of the Smart Retrofitting Road Map.

These are the main objectives in this step:

- Create a tailor-made digital tool to collect the feedback of all employees
- Analyse all feedback and if necessary, perform some modification at the Smart Retrofitting Road Map
- Communicate to the employees that their feedback had been analysed and taken into consideration

4.3.16 Step 16: Middle management elaborates the overall targets of the Smart Retrofitting Action under her or his responsibility

The action sequence within a Smart Retrofitting Action follows the combination of a PDSA cycle (see Figure 4-23) and the eight elements of the business process reengineering methodology proposed by Kiran [KIRA16]. Nevertheless, some modification on the eight elements was done to fulfill the purpose of the Smart Retrofitting Project which is the implementation of aspects of Industry 4.0 within a certain area of the supply chain of an organization (see Figure 4-26).

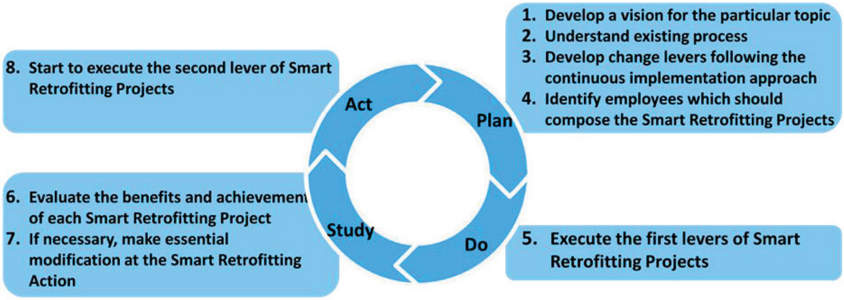


Figure 4-26 Eight elements to design a Smart Retrofitting Action

This sixteenth step will consist of the first four elements within the plan phase of the PDSA cycle (see Figure 4-26). It consists of elaborating the road map for each Smart Retrofitting Action and therefore initiating the activities of the third level of the Smart Retrofitting Road Map (see Figure 4-19) (see Chapter 4.2.6.3). Therefore, this step marks the beginning of the Bottom-up management approach at the implementation of Industry 4.0 within an organization which is desired by the Smart Retrofitting Approach and its respective change management model (see Figure 4-20) (see Chapters 4.1and 4.2.2). In addition, the middle management, with the support of the HR team, will be identifying possible employees that could compose the Smart Retrofitting Projects team

These are the main objectives in this step:

- Design the structure of each Smart Retrofitting Action (see Figure 4-23)
- List the number of layers that each Smart Retrofitting Action has and what objective shall be achieved at each layer (see Figure 4-23)
- List the number of Smart Retrofitting Projects that each layer has and what objective shall be achieved at each Smart Retrofitting Project (see Figure 4-23)
- Define the available budget for each Smart Retrofitting Action and its respective Smart Retrofitting Projects
- Identify possible employees that shall compose the team of each Smart Retrofitting Project

Methods and Tools

Ansoff-matrix, BCG-matrix, Five-Force-model, SWOT analysis, 5-Why-Methode,7-S model, Benchmarking, Workshop, Brainstorming sections, decision tree, mind mapping, Zwicky-Box and Six Thinking Hats

4.3.17 Step 17: Middle management build up the teams of each Smart Retrofitting Project under her or his responsibility

In this step, the middle management has to instruct and brief each Smart Retrofitting Project team concerning the responsibilities and achievements expected. It is highly advised the communication is done by a communication channel with all participants —middle management and Smart Retrofitting Project members— gathered together in the same room stimulating an open conversation among them. An announcement that is conducted through e-mail or another communication channel which does not stimulated the face-to-face conversation will not provide the synergy and engagement of the targeted employees as for example a workshop provides [PART10; GORR04].

These are the main objectives in this step:

- Middle management shall certify that the Smart Retrofitting Project team members understood the Industry 4.0 vision of the organization
- Middle Management shall explain to each Smart Retrofitting Project team the aim of the Smart Retrofitting Action he or she participates
- Middle management presents to the Smart Retrofitting Project team members the targets and timeline
- Middle management explains and clarifies to each Smart Retrofitting Project team the available financial resources they will have to perform the Smart Retrofitting Project

4.3.18 Step 18: Design and execution of the Smart Retrofitting Projects

The involvement and empowerment of the lower management, engineers, shop floor workers and other low hierarchical employees in the implementation of Industry 4.0 within an organization starts in the eighteenth step of the Smart Retrofitting Change Management Model. Therefore, this step follows a pure Bottom-up management approach desired by the Smart Retrofitting Approach and its respective change management model (see Figure 4-20) (see Chapters 4.2.1 and 4.2.2). As mentioned earlier, the elaboration and execution of the Smart Retrofitting Projects are under responsibility of the respective team members (see Chapter 4.2.8). Therefore, the Smart Retrofitting Project teams will perform the “Do and Act” elements of the Smart Retrofitting Action (see Figure 4-26) and will be accomplishing the fourth and fifth level of the Smart Retrofitting Road Map (see Figure 4-19) (see Chapter 4.2.6.3).

These are the main objectives in this step:

- Elaboration of high level DMAIC to establish the guidelines of the design of the Smart Retrofitting Project
- Elaboration of a Smart Retrofitting Project following a PDSA cycle
- Enable and empower the participation of all Smart Retrofitting Project team members during the elaboration of the DMAIC and the design of the Smart Retrofitting Project

Methods and Tools

Brainstorming, Ishikawa-Diagram and 5-Why-Methode

4.3.19 Step C*: Smart Retrofitting Revitalization Act

The execution of the nineteenth step of the Smart Retrofitting Change Management Model is under responsibility of the leadership coalition and it has to chase two main purposes. The leadership coalition is responsible for the execution of the Study element of the PDSA cycle of a Smart Retrofitting Action and therefore, it will evaluate the benefits and achievements of each Smart Retrofitting Project. The leadership coalition has to monitor if the Smart Retrofitting Project is following the agreed timeline. The leadership coalition has to interfere anytime an issue, or a concern is raised. If a specific Smart Retrofitting Project results in an outstanding benefit, yet unexpected one, it is the responsibility of the leadership coalition to coordinate adjustments to other Smart Retrofitting Actions within the Smart Retrofitting Road Map of the organization.

The second purpose of this phase is to ensure that the organization is applying the newest technologies and trends concerning Industry 4.0 available in the academic and business community (see Chapter 4.2.8). In case the leadership coalition finds a new technology or trend that matches with the challenges and needs of the organization, they shall inform the management board and the top management who shall decide if this new technology or trend should be included into their Industry 4.0 vision and in the Directive Smart Retrofitting Road Map. Such update concerning Industry 4.0 shall occur at least once a year. But it is up to the organization to decide whether to perform it more frequently.

These are the main objectives in this step:

- Monitoring each Smart Retrofitting Project
- Ensuring that the organization is using the newest technologies and trends concerning Industry 4.0 available in the academic and business community
- If necessary, adjust the Smart Retrofitting Action up to the Directive Smart Retrofitting Road Map

4.4 Conclusion

As previously mentioned, the third and fourth sub-research questions were answered in this chapter (see Chapter 2.2). In relation to the third sub-research question, the Smart Retrofitting approach was presented, and it was highlighted how it differentiates from the classic retrofitting because it does not limit itself to the upgrade of production equipment. Instead, it offers an approach that involves all employees at the implementation of Industry 4.0. Additionally, it proposes a continuous improvement and implementation strategy.

The fourth sub-research question in this dissertation is answered with a tailor-made change management model belonging to the Smart Retrofitting Approach which is based on its values and the specific challenges that Industry 4.0 demands from an organization. To support the involvement of all employees at the implementation of Industry 4.0 within an organization, the Smart Retrofitting Change Management Model follows a Top-down Bottom-up management approach in which employees will be providing their inputs conforming their activities within the organization. Additionally, to empower the employees change agent networks —Smart Retrofitting Agent Network— is proposed to spread and exchange knowledge regarding Industry 4.0.

5 Validation of Smart Retrofitting

Strategy is a commodity, execution is an art.

Peter Drucker

Considering that the developed Smart Retrofitting Approach, and its tailor-made change management model, supports the implementation of Industry 4.0 for all kinds and sizes of organizations, three case studies were performed with gradually increasing scopes of each consecutive one. The three validation case studies confirmed the versatility of the Smart Retrofitting Approach regarding its applicability for different cases and levels of complexity since each of the case studies was performed in a different industrial sector and a different size of organization.

The first case study targeted the execution of the Smart Retrofitting Approach on an over forty-year-old developed equipment which is exclusively used by the metallurgical industry sector to purify Aluminium. The implementation of Industry 4.0 was accomplished in only one production equipment which can also be the case for other industrial segments and did not demand the application of all features presented in the Smart Retrofitting Approach. Nevertheless, a road map dedicated to the one equipment in consideration was built and followed for the implementation of Industry 4.0 (see Chapter 5.1).

The second case study was accomplished at thyssenkrupp Brazil Ltda. – Division Rothe Erde and consisted in the implementation of Industry 4.0 in their large slewing bearing production line dedicated to the wind energy industry sector. In this case, a road map was established for the whole production line and included a broader application of the elements of the Smart Retrofitting Approach (see Chapter 5.2).

The third case study was accomplished on a global scale at Henkel AG & Company, KGaA at their Adhesives Technologies business unit. Prior to starting applying the Smart Retrofitting Approach, Henkel Adhesives Technologies business unit had its own Industry 4.0 vision and its respective road map. The Smart Retrofitting Approach was confronted with the existing vision and it was realized that a deeper involvement of the employees had to be explored and for that the Smart Retrofitting Approach was applied (see Chapter 5.3).

5.1 Case Study at a single production equipment

This case study is dedicated to applying the Smart Retrofitting Approach and its respective change management model on a single production equipment. The chosen production equipment is the fourty-year old zone melting equipment which belongs to the IME Process Metallurgy and Metal Recycling Institute at the RWTH Aachen University. Therefore, this case study was conducted in collaboration with two Ph.D. students from that institute. The zone melting process is derived from a family of methods that aims to control the impurities or the solute concentration in crystalline materials. In addition, it is one of the most efficient purification techniques currently available [EZHE17, S. 1; HO96, S. 227; PFAN64]. Other methods and processes—electrolysis, solvent extraction, precipitation, ion-exchange, vacuum distillation and crystallization—are also used, but they do not achieve as high efficiencies as the zone melting process [ZHAN18a, S. 34; SING68, S. 82; PFAN64]. Nevertheless, the zone melting process utilizes a high amount of electrical energy during its operation and consequently, its major cost relies on energy consumption.

The author of this dissertation was motivated to choose this production equipment given its age and the fact that this exact equipment model is utilized until now by several companies. An additional motivational factor is that future high-tech products will request large quantities of high purity metals within them or to enable their production. For example, the global high purity alumina market was valued around USD 1.7 Billion in 2014 and is expected to achieve around USD 5 Billion by 2025 [MARK16]. Consequently, the achievement of improvement in the production of high purity metals will became essential for countries as China, Norwegian, Canada, France, Belgium, Japan, Russia and the United States of America to maintain their market position and dominance [BLEI10, S. 5; KOND90; ZHAO08]. However, such achievement shall also be targeting the production of high purity metals that seek to be more sustainable and therefore not a burden our planet.

The following text will describe the subject of this case study in much more detail than the two other case studies will do with their subjects. This is done to facilitate the reader that is not familiarized with the zone melting process to understand the created Industry 4.0 vision for the chosen zone melting production equipment.

5.1.1 Highlights of ultra-pure metals and their application for this case study

As mentioned earlier with the advances in modern society and growth of technological influence in products, the requirements for ultra-purity metals is increasing significantly. The properties of the ultra-pure metals are what defines them as new functional materials. Depending on the required properties (electrical, optical, or mechanical) of the end-product, the sensitivity of a specific impurity concentration is what states the purity level requirement of the raw material used [ABIK00; KÉKE02].

The use of ultra-pure metals grows strongly and steadily in industries such as special electronics, integrate circuits, photovoltaic systems, optical elements, chemical applications, etc. [ZHAN18a]. The Table 1 below shows the purity requirement and main applications of some key metals used in industry. Besides general applications, high purity metals can also be used as additives to produce high purity alloys and provide the possibility to research on their intrinsic properties. Accordingly, the demand of high purity metals has been increasing with the steady development of technology and the investment in scientific research. [ZHAN18a, S. 33].

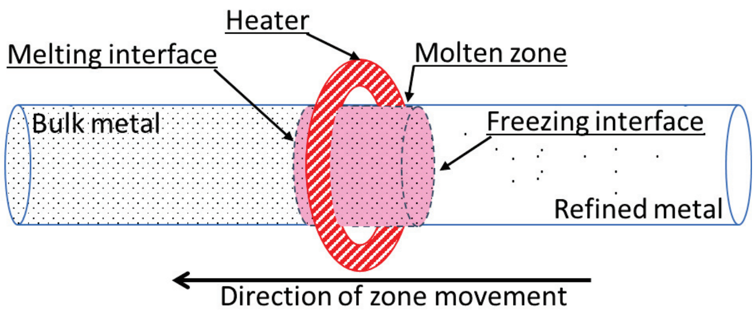
Because of the very low concentration of foreign elements in the base metal, the purity level of a material is defined as the number of “Nines” of purity. For example, a metal which has the sum of all the impurities as 10 ppm would have a purity of 99.999%, or 5N. As another example, a metal with 5 ppm of impurities (or 99.9995% purity) would be described as 5N5 [KÉKE02].

Table 1 Examples of ultra-pure metals and their applications [www.recylex.eu/de/ppm-pure-metals/]

Metal/ Compounds	Purity range	Application
Antimony	5N - 7N5	Hall sensors, infrared detectors, dopant for silicon single crystals and thin-film
Arsenic	5N5 - 7 N+	High frequency integrated circuits, LED´s and laser diodes
Cadmium	5N - 7N	Infrared optics, infrared and X-ray detectors, thin film and solar cells
Germanium	5N - 5N5	Infrared optics, GeO_2 is a catalyst in the production of polyester and PET, $GeCl_4$ for optical fibres
Indium	5N - 7N5	semiconductors, thin film and solar cell
Lead	4N - 5N	Production of solder alloys and radiation shields
Tellurium	5N - 7N	Peltier and thermoelements, optical storage material, solar cells and infrared and X-ray detectors
Tin	4N - 5N	Sputtering targets which are used in the production of thin layers
Copper	5N - 5N5	Sputtering targets, bonding wires, thin film, solar cells and copper oxide is used as component for ceramic superconductors
Gallium	4N - 8N	Semiconductors, thin film and solar cells

Zone melting

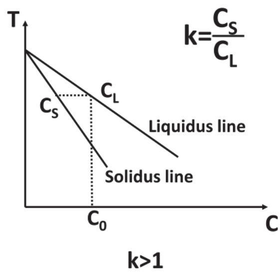
Since it was first develop by W.G. Pfann for the purification of germanium in the 1950s, the zone melting process became the standard industrial method to achieve high- and ultra-purification of diverse metallic systems [PFAN62]. This process works by slowly moving a molten zone through a metal bar, in a way that a freezing and a melting interface is formed in each side of the molten zone (see Figure 5-1). By moving the heater, the material located ahead of the melting interface is melted while at the same time the metal within the molten zone is slowly crystallized on the freezing interface.



Based on [ZHAN18, S. 35]

Figure 5-1: Sketch of a zone refining method. The dots represent the impurities.

When the solidification is sufficiently slow, the so-called fractional crystallization occurs. In the fractional crystallization, the impurity elements are only partially incorporated in the forming solid and it is dependent on each impurities' distribution coefficient (k). The k coefficient of each individual impurity diluted in a base metal is defined as the ratio of the impurity concentration in the solid phase (C_s) to its concentration in the liquid phase (C_L), and it can be obtained by the binary phase diagram of the base metal and each single impurity (see Figure 2).

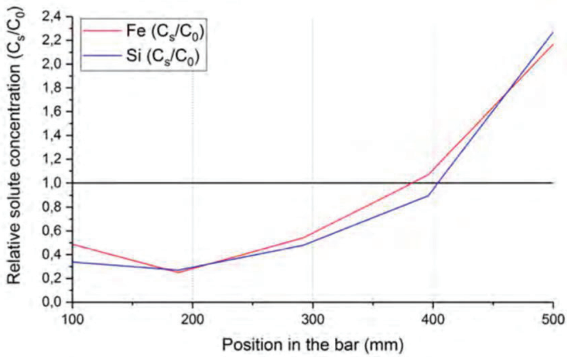


Based on [SING69, S. 84]

Figure 5-2: Representation of a generic binary phase diagram and the calculation of k coefficient

If the k coefficient is lower than one, the impurity tends to be segregated into the bulk melt upon solidification. In contrast, if the impurity has a k coefficient higher than one, it will tend to be incorporated into the crystallized phase during the solidification. In the rare cases that the k coefficient in close to one, the removal of the specific impurity via fractional crystallization is not possible.

With the moving of the molten zone throughout the bar, the impurities are constantly being segregated into the molten zone. This causes an increase in the impurity concentration of the molten zone and therefore generates an impurity concentration profile in the bar (see Figure 5-3).



[ZHAN18a, S. 37]

Figure 5-3: Practical example of impurity (Fe and Si) in a 500 mm long aluminum bar [ZHAN18a, S. 37].

In the figure above (see Figure 5-3), the blue and red lines indicate the relative impurity concentration (C_S) of silicon and iron along an aluminum bar after one pass of zone melting. The black line indicates the relative initial concentration (C_0) of the impurities. As clearly shown, the section of the bar that lies below the black line is the purified section, and the one above contains the segregated impurities. By choosing the correct yield, one can obtain several categories of end-purity, e.g. the first section (from 150 to 250 mm length) contains the purest fraction of metal, while the section ahead (250 up to max. 400 mm length) would contain an intermediate level of purity. The shape of the purification profile is greatly influenced by the key zone melting process parameters, such as [SPIM00; RODW89]:

- Zone movement velocity;
- The temperature gradient at the molten zone;
- The number of passes;
- Molten zone length.

Main process parameters

The velocity of the freezing interface (V) has a direct influence on the rate of solute segregation, as stated by the effective distribution coefficient (k_{eff}) in the Eq. 1 below.

$$k_{eff} \frac{k_0}{k_0 + (1 - k_0) * e^{\frac{-V\delta}{D}}} \qquad \text{Eq. 1}$$

Where, k_0 = C_s/C_0, δ is the thickness of the diffusion layer and D is the diffusion coefficient of the impurity in the base metal.

The velocity of the freezing interface is a direct result of the molten zone movement velocity, which is controlled by two main aspects: the mechanical movement of the heater V_{heater} ,and the relative movement of the freezing interface $V_{Freezing\ interface}$ caused by the expansion/contraction of the molten zone length (see Eq. 2).

$$V = V_{heater} + V_{Freezing\ interface} \qquad \text{Eq. 2}$$

The $V_{Freezing\ interface}$ is influenced by the temperature gradient imposed to the molten zone as well as thermophysical properties of the metal and the crucible employed. Ideally, the lower the employed velocity the better is the purification achieved. However, one should also consider the economic aspects of the process and a velocity between 0.8 up to 1.2 mm/min are considered as an ideal interval for most metallic systems.

Additionally, the temperature gradient is an indirect process parameter that greatly influences the zone length and, as a result, the purification efficiency. The gradient is most related to the type of heater used (resistance or induction), the material properties of the crucible and metal processed, and of course the power used by the heater. When subjected to an induction heating, the magnetic fields also promote an intense mixing of the melt within the molten zone, and therefore increases the heat distribution. As a result, the temperature gradient inside the molten zone is not as pronounced as when a resistance heater is used.

Since the growth of the solidification front is dependent on the temperature gradient (see Eq. 3), the proper control of the heating condition within the molten zone becomes a key process parameter.

$$V \leq \frac{D.k.\Delta T}{m.C_0.(1-k)} \qquad \text{Eq. 3}$$

Where, V is the freezing velocity, ΔT is the temperature gradient, m is the slope of the solidus line in a binary phase diagram.

Moreover, the thermal conductivity of the material from the crucible and the metal itself is of paramount importance in the heat transfer along the system. When the heat generated by the heaters cannot be fully distributed along the bar, an increase in temperature is observed within the molten zone and the process (mainly heater power) needs to be adjusted.

Usually, a typical zone melting purification campaign consists of several zone passes, each of them taking several hours to be completed. The number of passes is determined by the desired end purification as well as the distribution coefficient (k) of the main impurities present in the system. The farther the k coefficient is from one, the lower the number of passes is needed to achieve a given purity. Furthermore, each pass can be individually designed for an optimized process.

One of the most important process parameters is the length of the molten zone as it affects the ultimate distribution of impurities as well as the rate in which it is achieved. The length of the molten zone is also the most difficult parameter to be controlled, as it is directly influenced by all the other parameters (temperature gradient, velocity, material properties) as well as the distribution coefficient of each impurity present in the system. As an effect of that, the current industrial standard of the zone melting parameters are a function of empirical evaluations coupled with a few theoretical models.

Many of the theoretical investigations behind zone length aim at suggesting the best combination of zone length for several metallic systems, but due to the difficulty in controlling (and measuring) the zone length, most of the studies remained within the theoretical field with few practical evaluations.

Variation in zone length

As stated before, the length of the molten zone is a function of the following process parameters within the zone melting: power, type of heater used, crucible and charge material, and velocity. Due to the difficulty in measuring and controlling the zone length, the standard process conditions used in industrial applications considers a constant zone length for all the zone passes [HASH95].

However, many researchers have pointed out that the variation of the zone length between each zone pass as effective optimization of the zone melting process, ultimately leading to a reduction in the number of passes needed to achieve the desired purification of the material [PRAS06; CHEU11; BURR55; PFAN58]. Furthermore, the variation in the zone length along the bar length is also reported to greatly increase the purification achieved by each single pass [HO99; RODW89; ZHAN18a].

Through the continuous adjustment of the zone length, the solute concentration in the liquid becomes equal to the concentration in the solid ahead of the melting interface. This minimizes the accumulation of solute within the molten zone and therefore decreases the k_0 value within the interface. The result is that the center of gravity of the impurity profile is moved to the far end of the bar, increasing so the obtained yield.

While the models and theoretical investigations clearly support the advantages in changing and varying the zone length during the zone melting process, to achieve it under practical conditions is a very challenging work. Since the zone length is a function of several controllable and incontrollable parameters, the optimization of the zone length remains to date an empirical process with trial and error.

5.1.2 Application of the Smart Retrofitting Approach and its respective change management model at a zone melting production equipment

The entire Smart Retrofitting Change Management Model will not be used in this case study since the subject is a single production equipment and therefore does not require all characteristics and components of the model. Nevertheless, three —Unfreezing, Moving and Unfreezing 2.0— of the five phases of the Smart Retrofitting Change Management Model were applied in this case study (see Chapters 5.1.2.1, 5.1.2.2 and 5.1.2.3). As previously mentioned, this case study was executed in collaboration with two Ph.D. students from the IME Process Metallurgy and Metal Recycling Institute at the RWTH Aachen University and therefore, these three Ph.D. students formed the leadership coalition (see Chapters 5.1.2.1 and 5.1.2.3) and at the same time the team which worked on the pilot project in the Moving phase (see Chapter 5.1.2.2).

5.1.2.1 Unfreezing phase

The important action of creating a sense of urgency desired within the Unfreezing phase was not necessary in this case study since the team involved in this case study was from the beginning on aware of the importance and impact that Industry 4.0 will have in a near future on the zone melting process.

As recommended in the first step of the Smart Retrofitting Change Management Model, a deep analysis concerning the status quo of the strengths and weaknesses of the studied subject was realized (see Chapter 4.3.1) which in this case study was a zone melting production equipment. This equipment is used for more than fourty years in its industrial segment and it is an extremely reliable and stable production process. Nevertheless, its main weakness relies on the fact that the process parameters cannot be altered during the process since there is no possibility to measure the zone length, which is the most critical parameter (see Chapter 5.1.1), and therefore it is not possible to making analyses if the process could be optimized in real-time.

Following the sequence of steps from the Smart Retrofitting Change Management Model, the team explored several existing visions concerning Industry 4.0 in the academic and commercial community. The main focus was concentrated at on Industry vision and perspectives from the metal processing industry sector.

Given the fact that this case study was applied at one single production equipment, the execution of the third and fifth steps of the Smart Retrofitting Change Management Model was not done. Nevertheless, the fourth step which is fundamental for the entire further execution of the Smart Retrofitting Change Management Model was executed and consisted of the elaboration of a short Industry 4.0 vision (see Chapter 4.3.4) for the chosen zone melting production equipment. Such vision aimed in creating a Digital Twin (see Chapters 2 and 3.1) which shall be based on the zone length since it is the parameter with the largest influence over the zone melting process (see Chapter 5.1.1) and has a huge economical and sustainable impact of this production equipment. To accomplish such desire, the team chose to perform a retrofit using embedded systems (see Chapter 3.1) which are in a large scale available in the commercial market. This was motivated from the fact that organizations working with the same zone melting production equipment of this case study can replicate the created solution in this dissertation. This particularity was only possible within this case study since it was not funded by a private organization and instead by public research funds.

5.1.2.2 Moving phase

As mentioned earlier, the members of the leadership coalition also compose the pilot project team since the scope of this case study is limited to one single production equipment and therefore the seventh step of the Smart Retrofitting Change Management Model (see Chapter

4.3.7) was not necessary to be executed in this case study. The pilot project team decided that only one pilot project was needed to highlight the possibility of implementing aspects of Industry 4.0 in the zone melting production equipment (see Chapter 4.3.6).

As the literature review concerning the zone melting process highlighted that the key parameter to control the entire process is the zone length and currently it is not possible to measure it during the process (see Chapter 5.1.1), the team decided that the pilot project shall target on its measurement. Following the Smart Retrofitting Approach such measurement shall be achieved through a retrofit (see Chapter 4.1) which could be easily replicated by other organizations.

As foreseen in the eighth step of the Smart Retrofitting Change Management Model (see Chapter 4.3.8), the pilot project team initiated the development of the concept of the project. By analyzing the zone melting production equipment the team immediately identified the potential of measuring the zone length through a camera system. Such a system shall consist of an infrared (IR) camera that is capable of capturing the radiation of the ingot through the quartz cylinder (see Figure 5-4). The chosen IR camera used a wide-angle lens configuration with a horizontal field of vision of 72.5° and pixel resolution of 1280x1024 which was more than enough for this pilot project. In addition, to assure a precise measurement of the zone length, a conventional DSLR camera has been mounted on the frame of the heating coil. Consequently, both cameras and the zone length moved with the same velocity of the heating coil (see Figure 5-4).

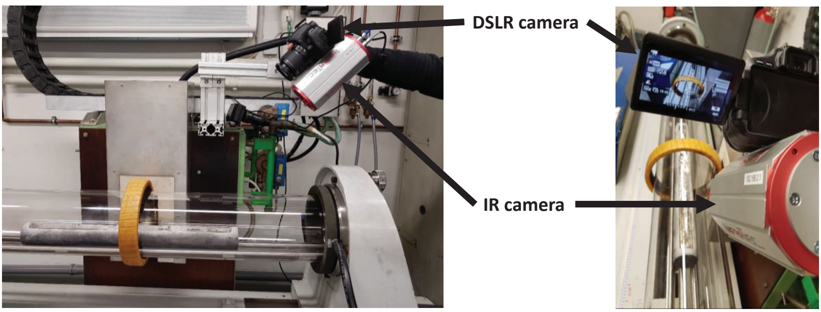
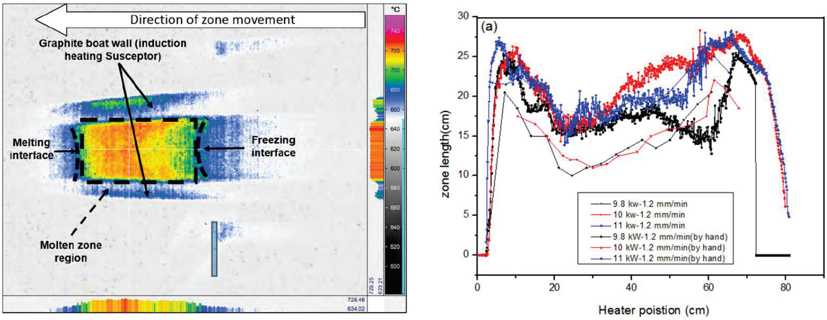


Figure 5-4 Picture illustrating the positioning of the camera relative to the ingot

Before the pilot project could be executed, several calibrations were done based on the characteristics of each camera, like view angle, pixel resolution, sensor dimensions, etc. In addition, a Matlab code was written to evaluate the captured data and enable the measurement of the zone length by the camera set-up.

The concept developed for this pilot project aimed in determining the ingot's final degree of purity with the smaller number of passes possible in comparison to current techniques. Therefore, the pilot project team decided to correlate the velocity and power of the heating element with the zone melting length. These two parameters were chosen as the literature review highlighted that they are crucial to decrease the number of passes within the zone melting process since the distribution coefficient k influences the freezing velocity of the melted zone and the heat distribution along the ingot (see Eq. 3) (see Chapter 5.1.1).



(a) **(b)**

Figure 5-5 (a) A random infrared thermographic picture showing the zone length [CURT18, S. 5]. (b) Measured zone length throughout all trials of the pilot project

Once the entire concept for this pilot project was completed, the ninth step —execution of the pilot project— of the Smart Retrofitting Change Management Model was initiated by the pilot project team (see Chapter 4.3.9). Its execution was accomplished in four months and for industrial standards can be classified as a relative short time period and a successful project. The pilot project proved that the measurement and the adjustment of the zone melting can occur during the production process (see Figure 5-5 (a)). In addition, the several experiments conducted provided the first database for an AI-program which shall be developed in a near future (see Figure 5-5 (b)). The detailed results were published in two following scientific publications: [ZHAN18b] [CURT18]

Since the focus of this dissertation relies on the execution of the Smart Retrofitting Approach and its respective change management model, further details concerning the pilot project will not be discussed. However, the retrofitting cost to execute this pilot project was under 20,000 euros and for the possible gains that it can generate in the future, it can be considered a relative low-cost investment.

5.1.2.3 Unfreezing 2.0 phase

To execute the Unfreezing phase in this case study, the leadership coalition included the customer as a fundamental factor to their considerations during the elaboration of their Industry 4.0 vision for the zone melting production equipment. It was not necessary to include the suppliers on the elaboration process of their Industry 4.0 vision since their raw materials — mainly aluminium with a purity of 2N and a noble gas— do not show variation in their quality and are commonly used in the industrial environment.

The created Industry 4.0 vision for the zone melting production equipment resulted in two research proposals to be submitted to the DFG (German Research Foundation). Consequently, a detailed description of the created Industry 4.0 vision of the chosen zone melting production equipment shall be treated with confidentiality in this case study. Nevertheless, some details regarding the elaboration process and the final Industry 4.0 vision are highlighted below. In addition, the respective road map to implement the created Industry 4.0 vision for the zone melting production equipment will be explained to a certain level.

Elaboration of the Industry 4.0 vision for the zone melting production equipment

Although this case study was executed in a research environment, the leadership coalition imagined all possible needs, challenges and strengths that their zone melting production equipment could face within an organization. Such proactive process was motivated by assessing the recommendations made in the eleventh step of the Smart Retrofitting Change Management Model (see Chapter 4.3.11).

The leadership coalition worked on several questions suggested by the Smart Retrofitting Change Management Model (see Chapter 4.3.11) which supported them in creating a clear overview of how Industry 4.0 shall be applied on the zone melting production equipment in order to provide the best optimization scenario for its production process and its customers. The leadership coalition did not use all questions suggested within the eleventh step of the Smart Retrofitting Change Management Model and concentrated on the following ones:

- Business strategy
    - What is our core business? How can we add more value to it through the use of Industry 4.0?
    - What innovation and advantages could our main competitors offer with the use of Industry 4.0 in the future?
    - Where do we have the chance to significantly expand by applying aspects of Industry 4.0 with a reasonable effort within our organization?
- Daily business activities
    - What distinguishes us — positively and negatively—from our competitors?
    - What will encourage our customers to buy from us in three or five years from now?
    - How could we reduce our waste by implementing aspects of Industry 4.0 within our organization?
    - How could we reduce our takt time by implementing aspects of Industry 4.0 within our organization?
    - How could we increase the quality of our products by implementing aspects of Industry 4.0 within our production lines?
    - What could make us more profitable by applying Industry 4.0 within our organization?
- Customers
    - What is the value-added Industry 4.0 can offer to our current customers?

- Which are the products or services that Industry 4.0 will enable us to offer to current and new customers?
- How can we distinguish ourselves from our competitors regarding the use of Industry 4.0?
- Will be our customers willing to pay more money for products which will be produced with aspects of Industry 4.0? How to justify the added value which Industry 4.0 can provide to the costumers?

By answering the above questions, the leadership coalition concluded that the Industry 4.0 vision shall enable them to monitor and adjust the zone length in real-time during the production process since it was proven in the pilot project that by altering the velocity and the power of the heating element, an improvement in the numbers of the pass number can be achieved. Consequently, a reduction in the number of passes necessary to achieve the desired metal purity will reduce the energy consumption of the production process which represents the main production cost of this zone melting process. In addition, it will also transform the production process of high purity aluminium into a more sustainable and greener process by supporting the reduction of the CO_2 footprint of this production process.

Additionally, the leadership coalition identified the need to create a digital footprint (see Chapter 3.1) of their zone melting production equipment since, it will be empowering their customers to integrated the generated data of the zone melting production equipment into their analyses. Such integration will enhance the horizontal integration which is aimed within Industry 4.0 (see Chapter 3.1) and the Smart Retrofitting Approach Model (see Chapter 4.1).

Consequently, their Industry 4.0 vision aimed at the creation of a Digital Twin of the zone melting production equipment which became part of the road map descried below.

Design of the Road Map for the zone melting production equipment

Due to the fact that the two research projects were submitted for funding's of the DFG, the road map described here will be refrained of all details (see Figure 5-6).

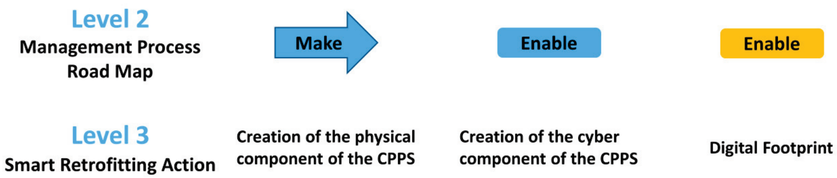


Figure 5-6 Illustration of the second and third levels of the created Smart Retrofitting Road Map for the zone melting production equipment of this case study

The two Management Processes highlighted in blue in the above figure are related to the vertical integration of the components from the zone melting production equipment (see Figure 5-6). Therefore, the combination of their Smart Retrofitting Action shall result on the creation of a CPPS for the zone melting production equipment in this study. Consequently, the Make

Management Process has two following sub-topics aimed to create the physical component of the CPPS:

- Spindle of the heating element
- Power supply of the heating element

Additionally, the Enable Management Process highlighted in blue consists of the two following sub-topics to create the virtual component of the CPPS:

- AI program to evaluate and optimized the zone melting process
- Integration interface of all collected data within the CPPS

To ensure the desired horizontal integration, the leadership coalition designed the Enable Management Process highlighted in dark yellow in the above figure and deals with the creation of the Digital Footprint (see Figure 5-6).

The leadership coalition created each of the three Smart Retrofitting Actions following the recommendation of the sixteenth step of the Smart Retrofitting Change Management Model (see Chapter 4.3.16). In addition, the execution of the three actions occurred in parallel as suggested in the Smart Retrofitting phase (see Chapter 4.2.8). Further details regarding the full content of each Smart Retrofitting Action cannot be described in this case study since such information is to be used in the research proposals for the DFG and therefore, shall be treated with confidentially.

5.2 Case study at a production plant

This case study was realized in one of the fifteen plants from thyssenkrupp Rothe Erde which is a business unit within the thyssenkrupp AG. The plant —Robrasa Rolamentos Especiais Rothe Erde Ltda.— is situated in Brazil and has a market presence of over forty years in the region. Robrasa Rolamentos Especiais Rothe Erde Ltda. is specialized in the production of slewing bearings with diameters in the range of 300 mm up to 4000 mm, used, for instance, in the following segments and sectors:

- Construction Machinery
- Conveyor Technology
- Crane Technique
- Wind Energy
- Mechanical Equipment

In 2005, Robrasa Rolamentos Especiais Rothe Erde Ltda. has started to supply serial slewing bearings to the starting wind energy market in Brazil. Given their success within this market and the high demand for their slewing bearings, the company has grown from fifty employees in 2005 to around three hundred employees in 2014. The wind energy market represents the majority of its production and has reached more than fifty percent of the local market demand.

Robrasa Rolamentos Especiais Rothe Erde Ltda. planned to implement the Industry 4.0 vision within the company, but it was facing some difficulties regarding keeping all its production equipments that were not originally designed to fulfill the vision of Industry 4.0 while introducing the Industry 4.0 vision in the company. Therefore, Robrasa Rolamentos Especiais Rothe Erde Ltda. started seeking for a model which would enable them to implement Industry 4.0 without replacing their relative old production equipments otherwise it would be impossible to keep the commitments with customers' demands in terms of delivery time, cost and quality. In addition, the management board formulated a possible future scenario for the global wind energy market in which the OEMs could challenge the slewing bearings suppliers worldwide to supply a single design for the slewing bearing to be installed in all wind turbines of a certain power range independently of the OEM, increasing dramatically the competition among the slewing bearings suppliers once everyone would have to deliver the same design for all OEMs. If that comes to reality in the future, the design itself will not be a competitiveness differential and quality and manufacturing costs will be the major decision factors for the OEMs to place orders. This scenario would demand an extremely highly efficient manufacturing plant to achieve customer's demand.

To face this scenario, Robrasa Rolamentos Especiais Rothe Erde Ltda. decided to combine the Industry 4.0 vision with their technological know-how acquired along the last fourty years to empower them to maintain or even increase their market position in the Brazilian wind energy market. The Smart Retrofitting Approach and its respective change management model were identified as the right methodology for implementing aspects of Industry 4.0 in the production equipment which were originally not designed for it targeting to promote the continuous development and upgrade the company was looking for.

5.2.1 Description of the manufacturing process of slewing bearings used in the wind turbines

Before describing the manufacturing process of a slewing bearing it is important to highlight some details concerning it. A slewing bearing is composed of five key elements (DIN 625-1 2011-04):

- Inner ring
- Cage
- Sealing washer
- Rolling elements
- Outer ring

The slewing bearing used in this case study has a final weight of 3.2 tons with an outer diameter of 2.7 m and was a pitch bearing. The outer ring has 90 fixing holes and the inner ring has 64 fixing holes. Each wind turbine has three blades, three pitch bearings and one yaw bearing. Each blade is fixed in the inner diameter of the so-called pitch bearing; and as the name suggests the pitch bearing adjusts the pitch of the blade according to the wind. The three pitch bearings are fixed in the hub on their outer diameters. The rolling elements for this specific blade bearing are balls of 60 mm in diameter. In this case study, it was not considered the manufacturing of the yaw bearing even though it is manufactured in the same production line as the blade bearing. This pitch bearing is not featured with gearing in the inner ring while in the case of the yaw bearings the gearing is always in the outer ring. The gearing is applied on bearings driven by electric motors but with the increasingly power capacity of the wind turbines and consequently the size and weight of the blades, the pitch adjustment of the blades is mostly made by hydraulic units.

Below, the manufacturing process of the slewing bearing in study that does not have gearing is briefly presented. The production steps for an inner and outer ring are practically the same.

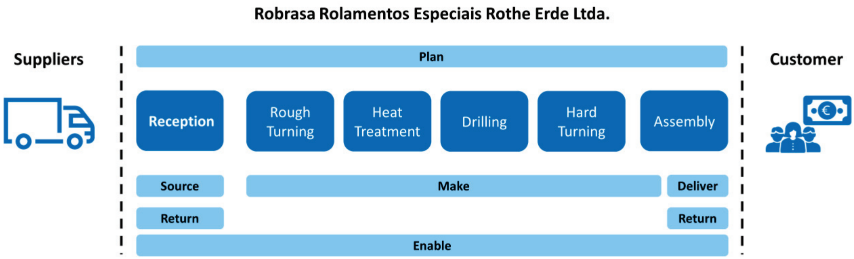


Figure 5-7 Sequence of the internal production steps for the slewing bearings

The first production step for the slewing bearing is the reception of the rings which are manufactured by rolling process. As soon as the rings are in the production facility, they are ultrasonic tested concerning the existence of possible micro cracks or internal wrinkles. Additionally, a test is realized to determine the chemical composition and the dimensions of each ring. All the collected information during the reception of the rings is manually written down in a standardized template (see Figure 5-7).

The first machining operation is the rough turning which will machine all four surfaces of a ring to remove the stock material bringing it to the desired dimension for the next production step (see Figure 5-7). The next manufacturing step is the induction hardening and it is extremely critical since it assures the designed lifetime of the slewing bearing with the hardness and hardness depth as well as the profile of the hardened layer of the raceways of both inner and outer rings (see Figure 5-7). If necessary, the rings can be stress relieved in an oven.

Once the heat treatment of the rings is completed, the fixing holes have to be drilled (see Figure 5-7). Such drilling process is highly time-consuming since the number of holes and size —90 for the outer ring and 64 for the inner ring with depth around 300 mm and a diameter of 40 mm— produces a huge amount of material to be removed.

The final machining operation consists of hard turning the raceways (see Figure 5-7). Consequently, once all machining operations of the rings are completed, the assembly process of the slewing bearing is initiated. Firstly, a so-called pre-assembly is done to evaluate the torque necessary to turn the slewing bearing. Once this is accomplished, the bearing can be completely filled with the balls in the dimension required to fulfil the torque specification. The torque is measured again after the completion of the assembly prior to the Zinc coating deposited by Thermal Plasma Spraying.

5.2.2 Unfreezing Phase

As emphasized in the Smart Retrofitting Change Management Model the most critical action that must be done in the Unfreezing phase is to generate the sense of urgency at the management board and top management to embrace the implementation of Industry 4.0 (see Chapters 4.2.2 and 4.2.4). Therefore, the first initiative within this case study was to combine the sense of urgency of implementing Industry 4.0 to overcome the future challenges that Robrasa Rolamentos Especiais Rothe Erde Ltda. would face with a possible common design from the costumer to all slewing bearing suppliers which would drive the competition among suppliers to practically exclusively the production costs. This urgency process was realized by the author of this dissertation with the CEO and Industrial manager —second highest employee and partially with financial responsibilities— of Robrasa Rolamentos Especiais Rothe Erde Ltda. throughout a workshop that also aimed to transmit the necessity of embracing the following five requirements listed by Kirian [KIRA16, S. 317] in a continuous improvement process which are also incorporated into the Unfreezing phase (see Chapter 4.2.2):

- Accepting that the problem lies in the inadequacy of the present level in performance of the product or service
- Right attitude to solve the problem
- Proper organization to solve the problem
- Structured method of problem-solving
- Problem definition and analysis to be based on hard facts

Only after the author of this dissertation was confident that both key members of the management understood and truly incorporated the five requirements listed above and the sense of urgency, the first step of the Smart Retrofitting Change Management Model was initiated.

As recommended in the first step of the Unfreezing phase, the CEO and the Industrial manager initiated a campaign to map the strengths and weaknesses of the company to support them in the upcoming Unfreezing 2.0 phase, with the elaboration of their Industry 4.0 vision to be oriented by their challenges and strengths. Therefore, the two managers decided to perform a value stream mapping and a questioning campaign within the quality, engineering and financial departments of the company. In accordance to the corporate compliance policy of Robrasa Rolamentos Especiais Rothe Erde Ltda., the results and details of these two actions to determine their status quo concerning their strengths and weaknesses will not be described within this case study. Nevertheless, it can be highlighted that their main strengths rely on the manufacturing capability and delivered quality, both well-recognized by all customers.

The second step of the Smart Retrofitting Change Management Model was performed with all top and middle managers and the CEO of the company and occurred through a workshop section which highlighted the key aspects of Industry 4.0 (see Chapter 3.1) and several use cases in the academic and business environment (see Chapters 4.2.4 and 4.3.2).

After the responsibilities and roles of the leadership coalition had been explained to the CEO, it was highlighted to him that at least one member of the leadership coalition shall be a representative of the financial department (see Chapter 4.2.4) and in addition the chosen employees shall own specific characteristics and skills listed in the third step of Smart Retrofitting Change Management Model (see Chapter 4.3.3). The CEO also followed the recommendation of the third step to include the HR team in the effort to assemble the leadership coalition. Consequently, the leadership coalition was composed with the following employees plus the author of this dissertation:

- Industrial manager
- Process engineer
- Production manager
- Head of maintenance

The participating employees had a profound identification with the corporate culture. In addition, all of them had proven in the recent past to be team-oriented, excellent communicators and most important lead by example. As emphasized in the Unfreezing phase, at least one member of the leadership coalition shall have the autonomy to perform financial decisions and therefore represent the financial department (see Chapter 4.2.4). The member in the case of the leadership coalition of this case study was the industrial manager who, as mentioned earlier, is the second highest in the hierarchy of the company.

As predicated in the fourth step of the Smart Retrofitting Change Management Model, the leadership coalition shall elaborate a short vision of their own vision concerning Industry 4.0 (see Chapter 4.2.4). Since all members of the leadership coalition participated on the workshop section regarding Industry 4.0, it was not necessary to perform another workshop section to highlight Industry 4.0 as it is predicated in the fourth step (see Chapter 4.3.4). Therefore, the leadership coalition with the support of the author of this dissertation immediately initiated the elaboration of the first Industry 4.0 vision. After a review of the company's strengths and challenges, the team concluded in their first draft that two steps, from different difficult levels in the vision of Industry 4.0, must be followed. First, the implementation of Industry 4.0 shall enable to make real-time adjustments during the machining operation and heat treatment since they have been facing some challenges with tool breaking during machining operation (see Chapter 3.1). The second and most difficult step consists of making adjustments to the process parameters of an upcoming manufacturing step regarding the information collected at the current process or even correct parameters from a prior manufacturing step (see Chapter 3.1).

Finally, the CEO and the leadership coalition communicated to all their employees that the company will be imitating the process of implementing Industry 4.0 within Robrasa Rolamentos Especiais Rothe Erde Ltda. As specified in the fifth step of the Smart Retrofitting Change Management Model, this communication was done using several communication channels the employees are familiarized with. Important to highlight is that several small meeting sessions were conducted to assure that all employees were well-informed and aware about the future changes the company was going to pass. These meeting sessions reflect the high importance in the upcoming Refreezing phase related to avoiding future resistance throughout the change process of Industry 4.0 (see Chapter 4.2.7).

5.2.3 Moving Phase

As recommended, the two first steps —sixth and seventh steps— of this phase were performed by the leadership coalition following the desired Top-down management approach highlighted in the Moving phase (see Chapter 4.2.5). The leadership coalition decided that one pilot project had to be performed (see Chapter 4.3.6) and the author of this dissertation is not allowed, due to the corporate compliance policy of Robrasa Rolamentos Especiais Rothe Erde Ltda., to give details about the motivation of this decision because manufacturing know-how would have to be exposed.

The leadership coalition decided that the pilot project shall be executed at the most time-consuming production step —drilling— targeting the avoidance of tool breakage once in the host case scenario results in a relatively large waste. The activities predicated in the sixth step of the Smart Retrofitting Change Management Model were so completed (see Chapter 4.3.6).

The leadership coalition decided that the following employees had to participate on the pilot project including four members of the leadership coalition:

- Process Engineer
- Head of maintenance
- Production Manager
- Author of this dissertation
- Production System Engineer
- Quality assurance Engineer
- All six shop floor employees from the drilling process

An extreme important recommendation from the seventh step, is to include employees from a vast hierarchical levels to the pilot project since this empowers the team to observe the implementation process of Industry 4.0 from different points of view and, in addition, this surely prevents future resistance that may occur over the change process inside the company (see Chapters 4.1, 4.2.5 and 4.3.7). The inclusion of all six shop floor employees from the drilling process had achieved the desired avoidance of resistance and it will be discussed in the Refreezing phase (see Chapter 5.2.5).

Once the pilot project team was elaborated, they immediately initiated the development of a concept to implement Industry 4.0 throughout a retrofit (see Chapters 4.1, 4.2.5 and 4.3.8) at the drilling process which at the end solved the issues with a certain tool breaking. Nevertheless, the CEO made some requirements the pilot project had to take into consideration:

- Production schedule could not be affected by the implementation process of the pilot project
- The pilot project had to follow the continuous implementation approach predicated by the Smart Retrofitting Approach
- The developed concept had to be built and validated in an external environment and then lately be integrated to the machine
- Quality gates must be applied throughout the execution of the pilot project

- If possible, the concept of the pilot project should be transferable to other machines following the retrofit principle
- Budget of the pilot project should be under 50,000 €

Oriented by the requirements of the CEO and by the Smart Retrofitting Approach, the leadership coalition team decided that the pilot project had to have two sub-projects. These sub-projects were executed simultaneously and followed the continuous improvement approach (see Chapter 4.1) since both projects aimed to implement different aspects of Industry 4.0 to the drilling process.

The first sub-pilot project consisted in monitoring the wear or breakage of the drill through a real-time analysis of the cutting power measured on the main spindle during the drilling process. Therefore, fulfilling the first difficult level of the first draft of the Industry 4.0 vision would enable the desired real-time adjustment of the process parameters achieving higher performance and productivity of the drilling process. As predicated in the Smart Retrofitting Approach and the Moving phase, the created solution shall make use of the existing material resources and follow a retrofit. It was necessary to acquire supportive software to complement the hardware identified and installed during the execution of the project. This special software enhanced the retrofitting characteristic of the solution providing further increase in performance.

The execution of the supportive software was a total success since its installation did not affect the schedule of the company, solved the biggest issue concerning tool and tool holder breakage and generated the following benefits to the drilling process:

- A reduction of 41% in the consumption of inserts in the drilling process
- A reduction of 36% of the tool cost per manufactured ring
- ROI of one year
- Significant improvement on the OEE of the process

The second sub-project had an in-house developed solution with the support of a Brazilian Professor from the Federal University of ABC and a post-doc student of the Fraunhofer Institute for Production Technology IPT (see Figure 5-8). This concept was elaborated following completely the retrofit principles and this sub-project will be implemented in other CNC machines that perform the rough and hard turning.

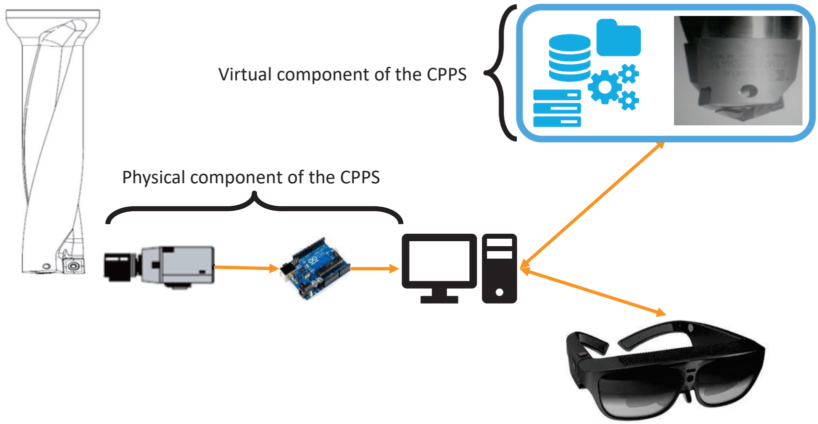


Figure 5-8 Retrofit solution based on a camera system to measure the insert wear during the drilling process

The camera system measures the wear of the insert after five drilling operations and after each measurement a report is generated and transmitted to the machine operator who wears Smart Glasses. Therefore, the machine operator based on his or her long-standing experience and results from the report decides whether the drilling process has to be interrupted for tool change.

By combining the data bank acquired in a machine learning model, it is possible to adjust in real-time the process parameters of an upcoming production process considering the characteristics of each individual ring or to adjust the manufacturing parameters of a prior manufacturing step. The machine learning model is going to be developed within a Smart Retrofitting Action still to be defined and developed inside the company (see Chapter 5.2.6).

In accordance to the corporate compliance policy of Robrasa Rolamentos Especiais Rothe Erde Ltda., further details concerning both sub-projects cannot be disclosed in this case study. Nevertheless, some details regarding the elaborated retrofit solution can be found in the scientific publications resulted from the work performed in this case study [SCHM17a], [SCHM17b], [LINS19].

5.2.4 Unfreezing 2.0 Phase

As suggested in the Unfreezing 2.0 phase, the organizational footprint was realized in the company involving employees from all hierarchical levels (see Chapter 4.2.6.1) (see Figure 4-14). Instead of performing an individual survey campaign, as suggested in the Unfreezing 2.0 phase (see Chapter 4.2.6.1), the leadership coalition decided to perform group interviews with the shop floor workers (see Chapter 4.3.10) (see Figure 4-25). However, in the different departments of the company several diagnostic workshops were performed with the respective engineers and the lower and the middle management (see Chapter 4.3.10) (see Figure 4-25). Additionally, the top management and management board realized a diagnostic workshop.

Since the corporate culture is well embedded within the company, it was not necessary to perform any type of campaign concerning the three elements of a change management model as suggested in the Unfreezing 2.0 phase (see Chapter 4.3.10) (see Figure 4-15).

As the Unfreezing phase predicates, the tailor-made Industry 4.0 vision of Robrasa Rolamentos Especiais Rothe Erde Ltda. was elaborated by the management board since the members of the board are the ones who have a full knowledge of the future challenges and demands that the company will be facing and shall be satisfied by the implementation of Industry 4.0 (see Chapter 4.2.6.2). During the elaboration process of their Industry 4.0 vision, the management board, with the support of the author of this dissertation, made wide use of the suggested questions proposed in the eleventh step of the Smart Retrofitting Change Management Model and added some questions specific to the challenges and demands identified for the company's future. Such elaboration process was well-documented since it is possible that it could be repeated in the following years during the planned realization of the Smart Retrofitting Revitalization Act.

During the presentation of the Smart Retrofitting Road Map structure (see Figure 4-19), the management board quickly understood the proposals in it since they and the others managers within the company were already familiarized with the SCOR model. As suggested in the Smart Retrofitting Approach and its respective change management model, the management board prioritized the elaboration of the Directive Smart Retrofitting Road Map concerning the Make management process of their intra supply chain (see Figure 4-19) (see Chapters 4.2.6.3 and 4.3.12). The management board was exclusively responsible for the elaboration of the Directive Smart Retrofitting Road Map —first level of the Smart Retrofitting Road Map— as it is predicated in the Smart Retrofitting Road Map (see Figure 4-19) (see Chapters 4.2.6.3 and 4.3.13). Additionally, the management board classified as the change receptors all the employees below the process owner and therefore, they will be responsible for the elaboration and execution of the future Smart Retrofitting Actions (see Chapters 4.2.6.3 and 5.2.6). As proposed in the Smart Retrofitting Road Map, the management board completely oriented themselves taking into consideration the elaborated organizational footprint which highlighted the challenges and demands of the entire company (see Chapters 4.2.6.3 and 4.3.13). In addition, the management board created KPIs to give guidance to the other employees on their participation in the Smart Retrofitting Road Map (see Chapters 4.2.6.3 and 4.3.13). The management board also created short-, medium-, and long-term goals for each of the production steps (see Chapters 4.2.2 and 4.2.6.3).

The top and middle management team elaborated each of the six-management process Road Maps which belong to the second level of the Smart Retrofitting Road Map (see Chapters 4.2.6.3 and 4.3.13), and the leadership coalition created the conditions and environment for the Smart Retrofitting Agent Network.

5.2.5 Refreezing Phase

As stated in the thirteenth step of the Smart Retrofitting Change Management Model, the pilot project team presented to all the employees the achievements and benefits of the implementation of Industry 4.0 within the pilot project that occurred during the Moving phase (see Chapters 5.2.3, 4.2.7 and 4.3.9). This presentation occurred through several workshops and also through the common internal communication channels of the company. As proposed by the Smart Retrofitting Change Management Model, the active participation of the employees, fulfilling responsibilities and respecting timelines, on the pilot project combined with the fact that the shop floor employees were involved early on in the elaboration process of the pilot project, with the same authority as engineers and middle- and lower management, has generated a huge motivational effect within all the employees (see Chapters 4.1, 4.2.7 and 4.3.9). The effect was so vast that the level of involvement and motivation on the structured innovative work proposed to them took the management board and the author of this dissertation by surprise since several shop floor workers elaborated numerous proposals to optimize their daily activities with the implementation of Industry 4.0. They even researched by themselves what Industry 4.0 is.

The management board quickly reacted to the fascination among the shop floor workers and performed several announcements of the Industry 4.0 vision created for the company (see Chapters 4.2.7 and 4.3.14). In addition, it was explained to the shop floor workers and the rest of the employees that in a near future they will be also performing projects —Smart Retrofitting Projects— concerning the implementation of Industry 4.0 in their daily activities. As suggested in the Refreezing phase, the opportunity to provide feedback concerning the elaborated Road Map was offered to all employees (see Chapters 4.2.7 and 4.3.15).

5.2.6 Smart Retrofitting Phase

Herewith, it will be highlighted that four Smart Retrofitting Actions —paper less production, real-time adjustments of individual production steps, interaction between production steps, HMI— were planned and performed with a total of 26 Smart Retrofitting Projects. These projects ranged from productive improvement up to HMI aiming the improvement of the safety factor of the workers. All four Smart Retrofitting Actions followed a continuous implementation process suggested in the Smart Retrofitting phase (see Chapter 4.2.8). The company followed the recommendation of elaborating a DMAIC during the design of a Smart Retrofitting Project (see Chapter 4.2.8). Additionally, the leadership coalition decided to create a standard DMAIC for all of their Smart Retrofitting Projects since its use showed to be an excellent guideline for the two first Smart Retrofitting Project teams.

As recommended in the Smart Retrofitting phase, the leadership coalition realized two Smart Retrofitting Revitalization Acts to ensure that the company is applying the newest technologies and trends regarding Industry 4.0 available in the academic and business community. Further to this and as part of the development of this case study directed to the implementation of Industry 4.0, it was conducted a Smart Retrofitting Revitalization Act by the leadership coalition and the author of this dissertation aiming a new market segment which is not part of the portfolio of the company today and this is one of the possibilities that the Smart Retrofitting Approach offers to companies to explore different markets with the support of Industry 4.0. The success of the application of the Smart Retrofitting Approach and its respective change management model could also be noticed directly by the shop floor workers who identified the work realized as a solution provider instead of a problem for them. For instance, the solution developed in the drilling machine provided not only a cost reduction for that operation, but it also reduced dramatically the work load for the machine operator who frequently had inspections as well as tool changes which became unnecessary after the completion of the project and its use will be expanded to the production equipments of the rough and hard turning.

5.3 Case study at a multinational conglomerate

The two previous detailed cases dealt with the implementation of aspects of Industry 4.0 within existing production equipments within an organization (see Chapters 5.1 and 5.2) and therefore, satisfied some of the subject— existing material resources— within the Smart Retrofitting Approach (see Chapter 4.1). Therefore, a retrofit in an organization concerning the human resources in a larger scale as it was considered in the two previous case studies was performed. Consequently, one of the focuses of the application of Smart Retrofitting Approach in the chosen organization was to empower and assist all its employees throughout the implementation process of Industry 4.0 within all their production plants (see Chapter 5.3.5.1). Additionally, a Smart Retrofitting Action had been designed and executed to accomplish an HMI within a chosen production step which occurs in all their production plants (see Chapter 5.3.5.2). In addition, another Smart Retrofitting Action was dedicated to increase the safety of all the employees within any production facility of the organization (see Chapter 5.3.5.3).

5.3.1 Highlights of the chosen organization for this case study

Henkel AG & Company, KGaA., is a German chemical and consumer goods producer company which was founded in Aachen and it is headquartered in Düsseldorf [HENK16]. Henkel is organized in three globally operating business units —Adhesive Technologies, Beauty Care and Laundry & Home Care— and it is known for brands such as Loctite, Pritt, Persil and Schwarzkopf amongst others [HENK18].

The case study of this work was done at the Adhesive Technologies business unit of Henkel. It is Henkel's biggest business unit employing 49% of the 53,000 employees that Henkel has world-wide. Additionally, it was responsible for almost 9 billion euros in sales in 2017 representing half of the sales that Henkel AG & Company, KGaA. made that year.

Fascinating for this case study was not only the number of employees and the financial achievements of Henkel Adhesive Technologies business unit. The diversity of the product range and applications were considered for the implementation of the Smart Retrofitting Approach since the work would not be restricted to a single product within the organization. Henkel Adhesives Technologies produce over 70,000 adhesives, sealants and functional coatings using around 20,000 raw materials across more than 140 plants around the world. Therefore, Henkel Adhesive Technologies business unit has a total of 11 sub-business units listed below:

- Automotive OEMs
- Automotive Components
- Metals

- Packaging
- Consumer Goods
- Lifestyle
- Industrials
- Electronics
- Consumers & Craftsmen
- Construction
- Manufacturing & Maintenance

The products of this Henkel business unit ranges from the traditional Pritt stick up to adhesives used to glue the wings of commercial airplanes.

Furthermore, Henkel Adhesive Technologies has a high cultural background diversity within their organization world-wide. Consequently, this business unit served very well to validate the Smart Retrofitting in an organization which has a huge variety of products, processes and employees with different cultural background.

5.3.2 Status quo and challenges of the Henkel Adhesive Technologies business unit concerning Industry 4.0

Prior to this work within the Henkel Adhesives Technologies, Henkel AG & Company, KGaA. had already elaborated a road map concerning the implementation of Industry 4.0 within its different business supply chains. All three business units of Henkel have very specific targets to be implemented in their respective plants considering their individual characteristics related to their product line, productions facilities and costumers' requirements. In accordance to the corporate compliance police of Henkel AG & Company, KGaA. the aspects and details of the road map cannot be presented in this work. Nevertheless, for Henkel Adhesives Technologies it can be highlighted that the implementation of Industry 4.0 relies mainly on the planning, execution and sourcing of its supply chain.

Beside Henkel's road map mentioned above, Henkel Adhesive Technologies business unit identified the need to elaborate a separate initiative —Smart Factory— to implement Industry 4.0 regarding the particular needs and challenges that the plants bellow to this business unit face in their daily businesses. This Smart Factory initiative is designed modularly which enables the Global Digital team to elaborate a Smart Factory tailor-made solution for each plant. Additionally, the Smart Factory initiative includes a web-based Manufacturing Execution System which has been designed and developed in collaboration with the company Vegam Solutions. The Smart Factory initiative is supported by over 150 digital capabilities and most of them was developed in-house considering the specific needs highlighted by some plants to the Global Digital Team.

5.3.3 Smart Retrofitting in Henkel Adhesive Technologies

Given the fact that Henkel Adhesives Technologies already had a strategy and road map, the activities concerning Smart Retrofitting and its respective change management model within

Henkel Adhesive Technologies mainly focused on the first step —Organizational footprint— of the Unfreezing 2.0 phase (see Chapter 5.3.4) and the creation of three Smart Retrofitting Actions (see Chapters 5.3.5.1, 5.3.5.2 and 5.3.5.3) within the Enable management process of the Smart Retrofitting Road Map (see Chapter 4.2.6) (see Figure 4-19).

The comparison between the Industry 4.0 implementation strategy elaborated by Henkel Adhesive Technologies and the Smart Retrofitting Approach followed the continuous improvement process which is part of the Smart Retrofitting Approach for the implementation process of Industry 4.0 (see Chapter 4.1). Therefore, the author of this work firstly made by himself a comparison between the existing Industry 4.0 implementation strategy of Henkel Adhesive Technologies and the Smart Retrofitting Approach and its respective change management model. Once this first evaluation had been concluded a second comparison round has initiated, in which several Henkel employees at different hierarchical levels were now included in the evaluation process and theses employees continued participating actively in the subsequent comparisons.

In the first comparison mentioned above, the lack of involvement and empowerment employees throughout the entire implementation process of Industry 4.0 within their organization was perceived by the author of this work. Therefore, this scenario, if not changed, could lead to future resistances for the implementation process of Industry 4.0 within Henkel as highlighted in pervious Chapters (see Chapters 4.1, 4.2 and 4.2.8). Such observation was also done by several authors who dealt themselves with the implementation of changes within an organization [JICK91; KOTT14; DOPP08; RAHI12; MÜLL13b]. Consequently, the Smart Retrofitting Approach and its respective change management model was applied to enable the involvement and empowerment of all Henkel employees during the implementation process of Industry 4.0 and therefore, a Smart Retrofitting Action was designed and executed which included aspects of the Smart Retrofitting Approach (see Chapter 5.3.5.1).

Therefore, following the recommendation of the Smart Retrofitting Approach, the involvement of several employees of different hierarchical levels was proposed to ensure the avoidance of future resistance during the implementation process of Industry 4.0 (see Figure 5-9). In addition, this also enabled to get more precisely inside the current situation from those who are in a daily basis involved with topics that shall influence the roll-out of Industry 4.0 within Henkel Adhesives Technologies (see Chapter 4.1).

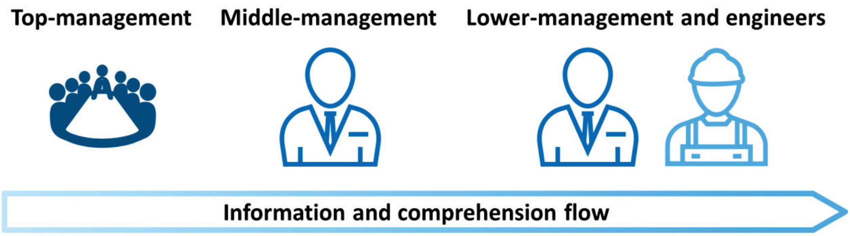


Figure 5-9 Sequence of discussions and comprehension for the comparison process within Henkel Adhesives Technologies

In order to increase the diversity of insight, the involvement of employees from different departments of Henkel Adhesives technologies were included, as listed below:

- Investment
- Digital
- Lean
- Engineering
- Strategy
- IT

The conclusion of such comparison section was that three of the four singularities of the Smart Retrofitting Change Management Model (see Chapter 4.2.6) needed to be incorporated in future activities related to Industry 4.0 within Henkel Adhesives Technologies. These are:

- Smart Retrofitting Agents network
- Continuous implementation approach
- Bottom-up management approach

It is important to highlight that Henkel Adhesives Technologies had, prior to the comparison activity done in this work and mentioned above, already performed some initiatives concerning a network of experts limited exclusively to matters related to some technologies applied in its production processes. Therefore, within the scope of this work, their network of experts has been expanded and followed the characteristics of the Smart Retrofitting Agents Network (see Chapter 5.3.5.1).

Respecting the compliance polices from Henkel Adhesives Technologies, it will be not possible to discuss within this case study how the organization intensified the Industry 4.0 implementation process throughout the continuous implementation approach belonging to the Smart Retrofitting Approach (see Chapter 4.1). Nevertheless, the effort of promoting a Bottom-up management approach in a controlled environment to design and elaborate the implementation of aspects of Industry 4.0 within Henkel Adhesives Technologies was part of this work (see Chapters 5.3.5.2 and 5.3.5.3).

In addition, a leadership coalition was created inside Henkel Adhesives Technologies as suggested in the Smart Retrofitting Change Management Model which was composed by a member of the Top- and Middle management and the author of this work (see Chapter 4.2.4) (see 4.3.3). Differently to the two previous case studies, the author of this work fulfilled the role of an Organizational Smart Retrofitting Agent (see Chapter 4.2.3) for the whole implementation process at Henkel Adhesives Technologies (see Chapters 5.3.4 and 5.3.5).

5.3.4 Unfreezing 2.0 in Henkel Adhesives

Given the fact that Henkel Adhesives Technologies had previously worked on its vision concerning Industry 4.0 which is their Smart Factory initiative, it was unnecessary to execute the eleventh step of the Smart Retrofitting Change Management Model dedicated to the elaboration of an Industry 4.0 vision (see Chapter 4.2.6 and 4.3.11).

Nevertheless, during the explanation of the Smart Retrofitting Approach to the top and middle management they identified the need to perform an organizational footprint of Henkel Adhesives Technologies which is proposed in the tenth step of the Smart Retrofitting Change Management Model (see Chapters 4.2.6 and 4.3.10). In addition, the author of this work identified that such organizational footprint had to be performed using a digital solution such like a web-based platform; consequently, the generated data could be linked to their Smart Factory initiative (see Chapter 5.3.2).

To accomplish the incorporation of the three singularities of the Smart Retrofitting Change Management Model highlighted in the comparison section, the author of this work together with the top manager identified the need to elaborate a Road Map concerning the Enable management process in which a middle manager, with the guidance of this author, designed two Smart Retrofitting Actions to implement aspects of Industry 4.0 directed to solve current challenges, like, for instance, shop floor production related challenges (see Chapters 5.3.5.2 and 5.3.5.3). Further to this, a central platform was designed, and all Henkel Adhesives Technologies employees could then have access to all ongoing activities related to the implementation of Industry 4.0 within the organization (see Chapter 5.3.5.1).

Organizational footprint within Henkel Adhesives Technologies

The organizational footprint within Henkel Adhesives Technologies followed strictly the recommendations of the tenth step of the Smart Retrofitting Change Management Model and incorporated the continuous improvement Approach suggested in the Smart Retrofitting Approach (see Chapters 4.2.6 and 4.3.10). The effort to identify the organizational footprint occurred by means of a survey campaign conducted with the specifically designed web-based tool which was improved over the process from one survey to the next eventually achieving a very satisfactory and user-friendly method and platform well accepted by the participants.

The tenth step of the Unfreezing 2.0 phase contemplates a survey campaign that started focusing on digital and Industry 4.0 relevant topics (see Chapter 4.3.10). Therefore, this survey campaign within Henkel Adhesives Technologies started with the Digital Survey (see Figure 5-10) aiming to map the digital maturity level and gathering information concerning the roll out of the Smart Factory initiative previously established inside the company. In addition, after collecting some inputs and acquiring some experience with the first round of digital survey, a second one was started (see Figure 5-6) which empowered the creation of a similar Smart Retrofitting Agent Network (see Chapter 4.2.3) within Henkel Adhesives Technologies, reaching the desire of the top management of incorporating an expert network within their organization (see Chapter 5.3.3).

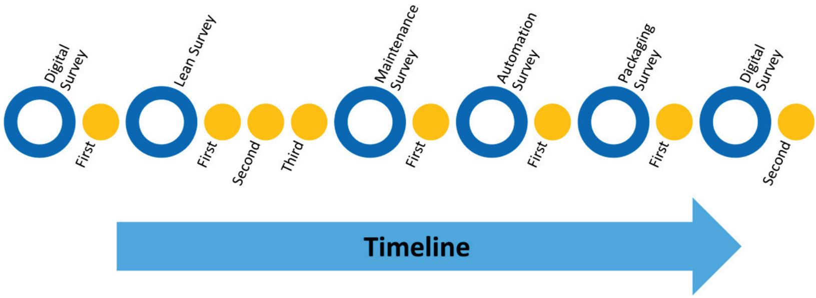


Figure 5-10 Timeline of survey campaign steps within Henkel Adhesives Technologies

The chosen sequence of surveys within Henkel Adhesives Technologies (see Figure 5-10) was structured to enable a continuous implementation approach suggested by the Smart Retrofitting Approach (see Chapter 4.2.6) and with increasing complexity degree from survey-to-survey. Such Approach contributed to elaborate a survey template that reflects the corporate culture of Henkel Adhesives Technologies and, therefore, being extremely user-friendly for any employee within the organization. Additionally, it reduces possible organizational and personal resistance (see Chapters 4.1 and 4.3.10) during the execution of a particular survey.

As suggested in the tenth step of the Smart Retrofitting Change Management Model, the surveys shall be answered by those who work in a daily basis with the Approached topic by each particular survey and, therefore, providing an accurate database of the status quo of that particular topic (see Chapter 4.2.4). Such suggestion was incorporated since the first survey and adopted as mandatory for all future surveys which will occur within Henkel Adhesives Technologies concerning the elaboration of their organizational footprint.

The suggested survey Approach offered by the Smart Retrofitting Change Management Model was so greatly welcomed and showed great acceptance within Henkel Adhesives Technologies that the second lean survey included all three business units of Henkel: Adhesive Technologies, Beauty Care and Laundry & Home Care. Therefore, mapping the *status quo* concerning lean within over 210 plants worldwide was accomplished. Such challenge was successfully accomplished, and Henkel decided to adopt the developed lean survey within this case study as their standard for all future lean surveys as well.

Enable Road Maps

An Enable Road Map was elaborated by the author of this work and a member of the middle management as it is specified in the Smart Retrofitting Road Map (see Chapters 4.2.6 and

4.3.13) which purpose was to satisfy the demands listed by the top-, middle, and lower- management in the comparison process between Smart Retrofitting Approach and its respective change management Model and the existing Henkel Adhesives Technologies strategy concerning the implementation of Industry 4.0 within its organization (see Chapter 5.3.5.1).

The full description of the Enable Road Map shall be treated with confidentiality and this case study concentrates its analysis within three Smart Retrofitting Action which have been implemented within Henkel Adhesives Technologies (see Figure 5-11) (see Chapters 5.3.5.1, 5.3.5.2 and 5.3.5.3). It is important to highlight that one of the Smart Retrofitting Action embedded several aspects of the Smart Retrofitting Approach and its respective change management Model and heavily supported that all employees are involved within Henkel's Smart Factory initiative (see Chapter 5.3.5.1).

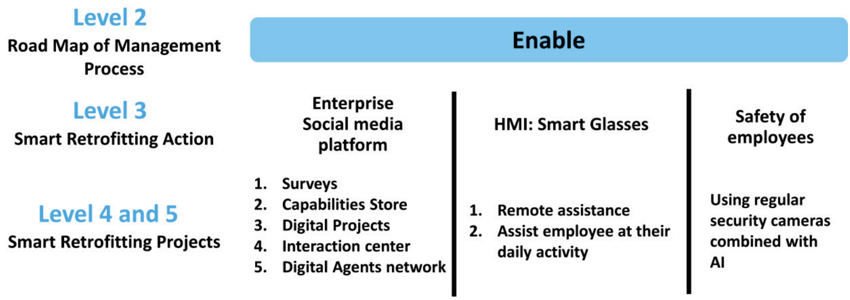


Figure 5-11 Illustration of the Enable Road Map with its respective Smart Retrofitting Action and Projects

From all three Smart Retrofitting Actions (see Figure 5-11), the one concerning the creation of an Enterprise Social Media Platform was the one that mostly used the aspects and the singularity of the entire Smart Retrofitting Action structure proposed in the Smart Retrofitting Road Map (see Figure 4-23) (see Chapter 4.2.8). In addition, it made use of several small and middle Smart Retrofitting Projects to be accomplished and it followed a continuous implementation process as proposed in the Smart Retrofitting Approach and its respective change management Model (see Figure 4-23) (see Chapter 4.1, 4.2.8 and 5.3.5.1). Another particularity of this Smart Retrofitting Action is that once it was concluded, its application and implementation range covered immediately the entire Henkel Adhesives Technologies plant (see Chapter 5.3.5.1).

Unlike the Smart Retrofitting Action related to the creation of an Enterprise Social Media Platform, the two remaining Smart Retrofitting Actions—HMI: Smart Glasses and Safety of employees— covered firstly only a specific area within the organization (see Chapters 5.3.5.2 and 5.3.5.3). This is given from the fact that the activities concerning these two Smart Retrofitting Actions executed in this work were the first stage within its continuous implementation process. Additionally, to prevent future resistance in the roll-out of both Smart Retrofitting Actions, the central IT department of Henkel AG & Company, KGaA was since the beginning involved on its elaboration and some other departments were also included in the execution of both Smart Retrofitting Actions (see Chapters 5.3.5.2 and 5.3.5.3).

5.3.5 Smart Retrofitting Action in Henkel

The three Smart Retrofitting Actions elaborated within Henkel were motivated by the current challenges that some of their plants were facing and suggested by members of the top-management. As recommended within the Smart Retrofitting Change Management Model, all three Smart Retrofitting Actions were designed by middle managers which work on a daily basis with subjects' Approach by each Smart Retrofitting Action that they had been involved in. Furthermore, a strong involvement of employees from lower hierarchical levels had been respected and, therefore, following the Top-down Bottom-up management approach of the Smart Retrofitting Approach. Respecting the corporate compliance police of Henkel AG & Company, KGaA., each Smart Retrofitting Action will be exposed until a certain level of detail. Nevertheless, it will be highlighted how the Smart Retrofitting Approach and its respective change management model were integrated in each of the Smart Retrofitting Action within this case study.

5.3.5.1 Enterprise Social Media Platform

In contrast to the two previous case studies (see Chapters 5.1 and 5.2) and the two upcoming sections regarding Smart Retrofitting Action (see Chapters 5.3.5.2 and 5.3.5.3), which were primarily focused on the retrofit of existing material resources as foreseen in the Smart Retrofitting Approach (see Chapter 4.1), this Smart Retrofitting Action is dedicated to the use of existing human resources within an organisation as it is also highlighted in the definition of Smart Retrofitting Approach (see Chapter 4.1 page 111). In addition, several aspects of the Smart Retrofitting Approach and its change management model are merged in this Smart Retrofitting Action which engineered an Enterprise Social Media Platform for Henkel Adhesives Technologies.

The motivation to create such Enterprise Social Media Platform —Smart Operation Platform— came from the author of this dissertation and was based on his analysis regarding Henkel Adhesives Technologies Industry 4.0 vision and its respective road map. In these two initiatives it was identified lack of involvement and empowerment in a large scale among Henkel's employees in the roll-out of their Smart Factory initiative and other Industry 4.0 relevant topics.

To make it possible that each and every Henkel Adhesives Technologies employee is involved and empowered to contribute in the roll-out of Industry 4.0 within his or her organization, the following aspects of the Smart Retrofitting Approach and its respective change management model was integrated into the Smart Operation Platform (see Figure 4-1)(see Figure 4-9)

- Use of existing human resources
- Continuous implementation and improvement process at the design and implementation of the Smart Operation Platform
- Creation of a Network of Experts based on the proposed Smart Retrofitting Agent Network
- Top-down Bottom-up strategy

- Involvement of all Henkel contributors
- Vertical and horizontal integration

The Smart Operation Platform was built following the continuous improvement process suggested by the Smart Retrofitting Approach (see Figure 4-3) (see Chapter 4.1). Consequently, to achieve the desired Smart Operation Platform and to be able to adapt it to possible scenarios that could be highlighted by the execution of a Smart Retrofitting Revitalization Act, the Smart Operation Platform was planned to be executed in three versions. The first version was built during the writing of this dissertation and comprises a total of five applications (see Figure 5-12). In addition, to enable the use by any Henkel Adhesives Technologies employee, the Smart Operation Platform considers a total of four types of users. Respecting the compliance policies from Henkel Adhesives Technologies, details concerning each user type will not be explained within this dissertation.

Figure 5-12 Illustration of the Adhesive Smart Operation Platform

In accordance to the corporate compliance policy of Henkel AG & Company, KGaA. further details of the other two version cannot be revealed within this dissertation. Nevertheless, it can be highlighted that the second version shall initiate a horizontal integration with suppliers and customers.

The design of this first version of the Smart Operation Platform took into consideration how a Smart Retrofitting Action shall be structed through PDSA cycles (see Chapter 4.2.8) (see Figure 4-23). Therefore, the first application to be elaborated and tested was the Digital Surveys. Once this process was almost completed the remaining applications were simultaneously built. All five applications are interconnected with each other and therefore exchanging relevant information with support of the roll-out of Industry 4.0 through Henkel Adhesives Technologies. In accordance to the corporate compliance policy of Henkel AG & Company, KGaA. such exchanging process and the proposals of each application will be explained in the following text until a certain level.

Digital Surveys

As previously mentioned, members of Henkel's top-and middle-management identified the need to perform an organizational footprint within their organization which occurred throughout several Digital Surveys across Henkel Adhesives Technologies business unit and the entire organization in the case of the Lean Surveys (see Chapter 5.3.4). These Digital Surveys were performed within the Smart Operation Platform since the generated outcomes are vital to a structured roll-out of Henkel´s Smart Factory initiative. Consequently, the knowledge acquired by each Digital Survey supported the following applications of the Smart Operation Platform:

- Network of Experts
- Smart Operation Projects
- Smart Factory Capabilities Store

The Digital, Lean, Maintenance, Automation and Packaging surveys enabled the Global Digital team from Henkel Adhesives Technologies to identify experts within each of their plants and, consequently, provided the information to the Network of Experts within the Smart Operation Platform. Such achievement was of great value to the Global Digital team since the vast majority of the identified experts were classified by the Smart Retrofitting Change Management Model as technical. This is justified because it would be almost impossible in a reasonable time frame to identify all these experts through the traditional method—plant visits— that Henkel Adhesives Technologies used. In addition, both the identification and evaluation processes occurred in a very short period of time. Furthermore, each survey had a one-time cost under 5,500 euros which covered the elaboration of the survey and to run it as many times as desired by Henkel Adhesives Technologies.

The Digital Survey also provided essential knowledge regarding the areas the top-management should focus on planning to elaborate projects to accelerate the implementation of Industry 4.0 in a large scale within all their plants. Such knowledge combined with the Smart Operation Projects application provided the top- and middle-management an immediate overview where in their organization a project related to Industry 4.0 could be most effectively executed.

The Digital Surveys add an enormous value to the Smart Factory Capabilities Store application since all surveys provided information whether a plant fulfils the requirements to purchase or request a certain capability. Such functionality empowered the Global Digital team to spread the Smart Factory initiative in a shorter time period and with less efforts. More details regarding this topic will be provided in the text concerning the Smart Factory Capabilities Store application.

Smart Operation Projects

This application incorporates the Top-down Bottom-up strategy desired by the Smart Retrofitting Approach (see Chapter 4.1). In addition, it is one of the applications of the Smart Operation

Platform which empowered the involvement of all employees to implement Industry 4.0 throughout their organization (see Chapter 4.1) (see Figure 4-1). To enable those desired characteristics of the Smart Retrofitting Approach, this application displays Henkel's Industry 4.0 vision and its corresponding road map to all Henkel plants around the world. The displayed Industry 4.0 road map is linked to all current projects aimed to achieve targets of the road map and therefore fostering an open communication between plants in which the plant managers, lower managers and engineers can identify by themselves possible synergies between current Industry 4.0 projects and their own needs. Consequently, such interaction between these employees intensified the process of incorporating Industry 4.0 into the corporate culture of Henkel. Further details and achievement of this application cannot be explored in this case study given the corporate compliance policy of Henkel AG & Company, KGaA.

Digital First Aid Center

The main purpose of the Digital First Aid Center is to offer to all Henkel Adhesives Technologies employees a communication channel in which they can raise questions concerning topics related to Industry 4.0 or other subjects. Such questions can be answered by any employee within the organization and will be analysed. If the provided answer led to the solution of the raised challenge it will be stored in form of a ticket and in the future any employee can have access to the proposed solution. Therefore, within the Henkel Adhesives Technologies community a database is generated to the most common challenges which occurs in the daily business activities and furthermore, anchoring Industry 4.0 within the corporate culture while stimulating the interaction between employees around the world which increases their identification to the organization. This interaction is more than welcome and stimulated by the Smart Retrofitting Approach (see Chapter 4.1) (see Figure 4-1).

Network of Experts

Inspired by the Smart Retrofitting Agent Network (see Chapter 4.2.3), Henkel Adhesives Technologies decided to build a Network of Experts concerning topics related to Industry 4.0. However, after all five applications had been designed and tested the author of this dissertation suggested to a top-manager that its Network of Expert shall go beyond of digital topics within the Smart Operation Platform and therefore be extended to any topic or subject which could support the implementation of Industry 4.0 in the organization and also increase their productivity and efficiency.

To find the possible employees which could be classified as experts in a certain topic, Henkel Adhesives Technologies adopted one of the key elements of the Smart Retrofitting Approach: Top-down Bottom-up strategy. The Top-down management approach to enlist experts within Henkel Adhesives Technologies occurs in two forms which were implemented in the organization following the proposed continuous implementation process by the Smart Retrofitting Approach (see Chapter 4.1). Firstly, the middle and lower management listed experts based on the knowledge acquired through the several conducted digital surveys and based on their longstanding interaction with employees from lower hierarchical levels. Once this process was completed, Henkel Adhesives Technologies shall acquire an external service provider which empowers them to find experts within their organization based on all kinds of data that they have concerning their organization. In addition, each employee of Henkel Adhesives Technologies can register herself or himself in the Network of Expert application and therefore enabling the earlier mentioned Bottom-up strategy. Nevertheless, a middle or lower manager shall confirm and approve whether that specific employee is an expert in the topic that she or he claims to be. Respecting the corporate compliance policy of Henkel AG & Company, KGaA further details on how their Network of Expert is built and operates will be not revealed in this case study.

Smart Factory Capabilities Store

From all five applications elaborated for this case study, the Smart Factory Capabilities Store is the one which incorporates almost all characteristics of the Smart Retrofitting Approach (see Chapter 4.1) (see Figure 4-1). The Smart Factory Capabilities Store was designed in such a way that empowers all employees to see by themselves which Industry 4.0 solutions are pre-approved and available within Henkel Adhesives Technologies. Therefore, if someone identifies something that could be of interest, she or he can order it with the Global Digital team or even directly with the vendor since suppliers and vendors of Industry 4.0 solutions can display their products within the Smart Factory Capabilities Store. Such Approach was inspired by the following characteristics of the Smart Retrofitting Approach (see Chapter 4.1) (see Figure 4-1):

- Vertical and horizontal integration
- Involvement of all contributors inside the organization at the Change Process and its Implementation Involvement
- Use of existing human resources
- Integration of the employee in the implementation process

In addition, the Smart Factory Capabilities Store was designed regarding to be the most user-friendly as possible which is proposed by the Smart Retrofitting Change Management Model once it emphasizes the creation of solutions that prevent possible future resistance at its implementation. Consequently, the Smart Factory Capabilities Store has a very lean and self-explanatory layout (see Figure 5-13) which is divided into areas of the organization.

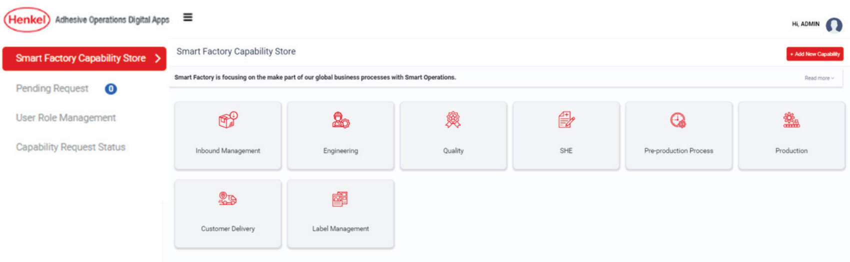


Figure 5-13 Overview of the Smart Factory Capabilities Store from the point of view of an administrator of the Smart Operation Platform

The desire to implement a Capability in a particular plant can occur through two methods inspired by the Top-down Bottom-up strategy proposed by the Smart Retrofitting Approach (see

Chapter 4.1). The Top-down management approach occurs when a member of the top or middle management suggests that a specific Capability shall be implemented in one or several Henkel Adhesives Technologies plants. Therefore, the plant manager is informed —through the Smart Operation Platform— that she or her shall be implementing the chosen Capability.

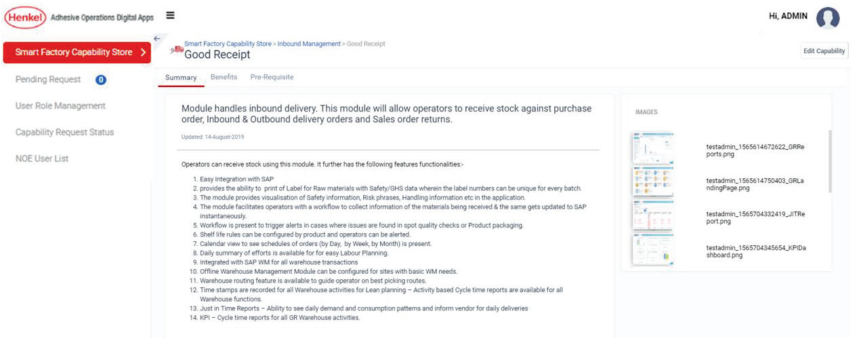


Figure 5-14 Illustration of how information of the Digital Survey´s, Smart Operation Projects, Digital First Aid Center and Network of Experts merge within one digital capability within the Smart Factory Capabilities Store

The Bottom-up management approach consists of enabling and empowering any Henkel Adhesive Technologies employee to request a particular Capability. Such request is analysed by the plant manager of this employee and by members of the middle management and, depending on the Capability, also by members of the top management. To facilitate and simplify the request process, each Capability has a summary of the benefits, implementation complexity and costs. In addition, each Capability is linked to the Digital Surveys and therefore, highlights in advance to the employee if her or his plant fulfill all pre-requirements to request the chosen Capability. In accordance to the corporate compliance policy of Henkel AG & Company, KGaA, more details concerning the Smart Factory Capabilities Store will not be discussed within this case study.

5.3.5.2 HMI using Smart Glasses

As recommended in the Smart Retrofitting Road Map, topics related to Industry 4.0 shall be implemented by means of Smart Retrofitting Actions (see Chapter 4.2.6) (see Figure 4-19). As mentioned earlier, this Smart Retrofitting Action has two topics related to the use of Smart Glasses (see Figure 5-7):

- Remote assistance
- Smart Glasses within the production environment

Nevertheless, the topic concerning remote assistance targeted its implementation within the entire Henkel AG & Company, KGaA organization and the topic concerning Smart Glasses was limited to the Henkel Adhesives Technologies business unit. However, both topics followed the continuous implementation process and the continuous improvement process designed in the Smart Retrofitting Action structure (see Figure 4-23) (see Chapter 4.2.8).

In accordance to the corporate compliance police of Henkel AG & Company, KGaA each topic will be explored in this dissertation until a certain level of details and therefore, the topic concerning the remote assistance will limit itself to the description of the outcomes. In contrast, the topic that deals with Smart Glasses within the production environment will be described in more detail.

Topic: Remote assistance

As mentioned above, details of these two topics and their respective Smart Retrofitting Projects cannot be given nor discussed in this case study. However, the benefits these topics generated by following the Smart Retrofitting Approach (see Chapter 4.1) and the recommended structure of a Smart Retrofitting Action proposed at the Smart Retrofitting phase will be highlighted (see Chapter 4.2.8) (see Figure 4-23).

One of the highlights generated within these topics was the creation of a group of employees which eventually became experts regarding Smart Glasses. Such expertise is related to the current available operation systems for Smart Glasses. This expertise can also be applied in an office environment that is mainly focused on the use of virtual reality technology. The analysis of the safety standards in the shop floor of Henkel AG & Company, KGaA. production plants regarding the use of such Smart Glasses has contributed to extend the expertise thanks to those involved on the selection process of which type is most adequate for the particularities found in these production plants.

The safety standards are mainly related to possible explosion hazards to be considered within a Henkel AG & Company, KGaA production plant. All this broad expertise developed within some Smart Retrofitting Projects enabled to fulfil a suggestion of the Smart Retrofitting Change Management Model which is the creation of experts inside the company on specific topics related to Industry 4.0 (see Chapter 4.2.3). In addition, such experts have to be integrated within the Enterprise Social Media Platform (see Chapter 5.3.5.1).

Another proposal from the Smart Retrofitting Change Management Model is to explore the possibility of interactions between different topics (see Chapter 4.2.8). Such interaction occurred in a certain moment of this Smart Retrofitting Action with the topic concerning the use of Smart Glasses within the production environment. Team members of both topics joined forces to define which Smart Glasses shall be utilized within the process step that drives to the preparation of the glue recipe. This interaction ranged from the middle management until the shop floor worker, as it will be highlighted below. Ultimately, this interaction process triggered an embedment of Smart Glasses to the corporate culture of Henkel AG & Company, KGaA. This is given from the fact that after the conclusion of this topic, more projects within Henkel AG & Company, KGaA included the possible use of Smart Glasses without the stimulation of the author of this work.

Topic: Smart Glasses within the production environment

After the Smart Retrofitting Approach and its respective road map was presented to a member of the top-management, he confronted the author of this work with several issues occurring within more than a few of Henkel´s Adhesives Technologies production plants. The issues described could be classified into categories, but their occurrences happened to be found in several sub-business units around the world. The scenario was not favourable to elaborate a project with the acquision of a new production equipment for each plant to satisfy their needs since the efforts to accomplish this would be extremely high and time consuming. The top-manager decided that a Smart Retrofitting Action had to be elaborated by the author of this work to solve those issues throughout a retrofitting of the existing human and material resources.

Therefore, the topic concerning the use of Smart Glasses within the production environment was created which considers a total of four application areas: Audits, recipe preparation, inbound/dispatch and process monitoring (see Figure 5-15). Accordingly to the Smart Retrofitting Change Management Model, members of the middle management elaborated with the support of the author of this work the overall targets attributed to each of the Smart Retrofitting Projects that composed this Smart Retrofitting Action (see Chapter 4.2.8).

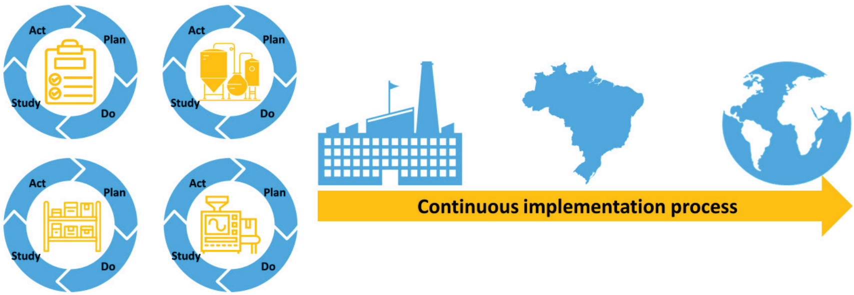


Figure 5-15 Smart Retrofitting Action for the use of Smart Glasses within the production environment of Henkel Adhesives Technologies

Each of the four identified application areas was structured following the proposed continuous implementation process within the Smart Retrofitting phase (see Chapter 4.2.8) and the eight Smart Retrofitting Action elements (see Chapter 4.3.16) (see Figure 4-26). In accordance with the corporate compliance policy of Henkel AG & Company, KGaA the full content of this Smart Retrofitting Action will not be exposed in this case study. However, the first Smart Retrofitting Project which occurred within the area of the preparation of the chemical recipe will be, until a certain level of detail, explained in this case study.

As recommended within the Smart Retrofitting phase, the middle management created a vision of how the recipe preparation shall be done in the future (see Chapter 4.3.16). Additionally, the middle manager searched for other existing processes within Henkel Adhesives Technologies plants that are related to the recipe preparation (see Chapter 4.3.16) aiming to create a knowledge base for future activities of the Smart Retrofitting Project team on the search of a retrofit solution that covers almost all scenarios within Henkel Adhesives Technologies plants.

Further details regarding the Plan steps of the PDSA cycle of this Smart Retrofitting Action cannot be explored due to the corporate compliance policy of Henkel AG & Company, KGaA.

As recommended for the Smart Retrofitting phase, the teams of a Smart Retrofitting Project shall be composed of employees of numerous hierarchical levels and from different departments (see Chapter 4.3.17). Therefore, the team working with the Smart Retrofitting Project for the utilization of Smart Glasses within the production environment was composed of:

- The author of this work representing the Global Digital department
- Two members of the IT department responsible for the topic related to Industry 4.0
- One plant engineer
- Several shop floor workers working at the subject area
- The works council of the plant in which the Smart Retrofitting Project was executed

As mentioned earlier, the challenge that this first Smart Retrofitting Project dealt with was related to the glue recipe preparation within a European plant. Such challenge is given from the fact that a glue recipe consisted of several raw materials which are received in containers that are almost identical in appearance and therefore might induce to human errors. This scenario is the case in the majority of Henkel Adhesives Technologies plants.

Following the recommendation of the Smart Retrofitting Approach and its respective change management model, employees involved in the daily basis operation on this subject shall have a strong participation in the elaboration of solution (see Chapters 4.1 and 4.2). As already explained earlier, this will minimize future resistance [RAHI12; MÜLL13b; MENT02b; MART92; ILJI15] and it will also enhance the motivation of the employees [KIRA16; JICK91; KOTT12] throughout the change process that will take place at their work environment. Consequently, the solution arising from the Smart Retrofitting Project can primarily be proposed by those from the plant's shop floor and the respective plant engineer (see Figure 5-16). The recipe is in the SAP system of the plant and the shop floor workers must follow a precise checklist to accomplish their activity and the Smart Glasses showed to be very supportive to them on this task.

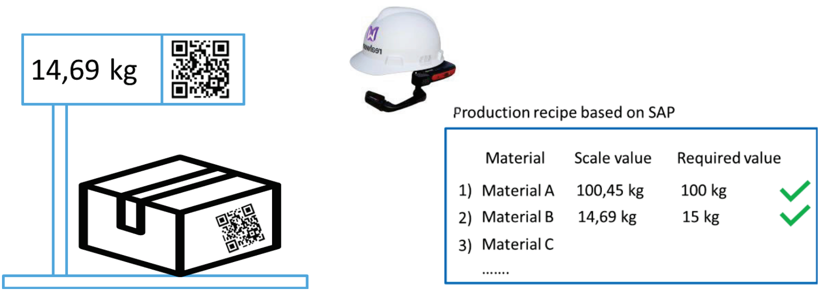


Figure 5-16 Demonstration of the use of Smart Glasses within the production step concerning the preparation of the glue recipe

Following the recommendation to have interaction between different Smart Retrofitting Actions and projects, this Smart Retrofitting Project which dealt with the use of Smart Glasses within the production step regarding the preparation of the glue recipe had very proactive interaction with other projects related to remote assistance within Henkel AG & Company, KGaA. This interaction targeted the validation of which Smart Glass better applies to the production environment in study. Therefore, the team members of both Smart Retrofitting Projects joined efforts defining which Smart Glasses satisfies the IT requirements and specially the requirements from the shop floor workers.

The IT and some Digital team members elaborated a decision matrix with requirements that in their view were relevant to choose a Smart Glasses which could be utilized in almost all Henkel AG & Company, KGaA production environments (see Figure 5-17).

Requirements		Microsoft HoloLens	Realwear hmt-1Z1	Realwear hmt-1	ODG 8	Vunix M300
Software	Operation System	Windows 10	Android 8+WearHF™ hands-free interface	Android 8+WearHF™ hands-free interface	Android Nougat Framework	Android 6 OS
	Microphone noise cancellation software	No	Yes	Yes	No	Yes
Usability	Weight in grams	579g	430g	380g	<141g	not provide by the manufacturer
	Adjustable Display	with certain restrictions	In X,Y and Z	In X,Y and Z	The Smart Glass do it automatically	Only in Y and Z
	Smart Glass need cable to function	No	No	No	No	Yes
	Possibility to use with an eyeglasses	Yes depending on the eyeglasses	Yes	Yes	Yes depending on the eyeglasses	Yes
Safety related topics	Can be used with Safety Glasses	No	Yes	Yes	No	Yes
	Designed to work with standard hard helmets	No	Yes	Yes	Yes	Yes
	Intrinsically safe ATEX Zone 1 and CSA C1/D1 certified fully rugged head-mounted device	No	Yes	Yes	Yes	Yes
	IP66 Waterproof	No	Yes	Yes	Yes	Yes
Other technical specification	Camera	2MP photo / HD video camera	16 MP 4-image stabilized, PDAF with LED flashlight	16 MP 4-axis optical image stabilization, PDAF with LED flashlight	5MP Cameras for Stereo Capture and Depth Tracking, Fisheye Camera for Visual Odometer	Up to 10 MP stills, Up to 1080p video, auto-focus, optical image stabilization, flash/scene illumination
	Battery life	Not known	8-10 hours with typical use	9-10 hours with typical use	Not known	2 – 12 hours of operation based
	Removable battery	No	NO	Yes	No	on external battery choice
	Bluetooth®	Bluetooth 4.1 LE	Bluetooth 4.1 LE	Bluetooth 4.1 LE	Bluetooth® 5.0	BT 4.1/2.1+EDR
	WI-FI	Wi-Fi 802.11ac	802.11 a/b/g/n/ac – 2.4GHz and 5GHz	802.11 a/b/g/n/ac – 2.4GHz and 5GHz	WiFi® 802.11ac	Wi-Fi b/g/n/ac – Dual-B 2.4/5 GHz
	Microphones	4 microphones	4 digital microphones with active noise cancellation Accurate voice recognition even in 95 dBA of typical industrial noise	4 digital microphones with active noise cancellation Accurate voice recognition even in 95 dBA of typical industrial noise	Two Digital Microphones	Ear speaker
	Speaker	2 speakers	Internal 91 dB loudspeaker	Internal 91 dB loudspeaker	Built-In Stereo Speakers	Noise cancelling microphones

Figure 5-17 Smart Glasses decision matrix

However, the final decision about which Smart Glasses were most suitable for the shop floor was done in agreement with the shop floor workers and the union representatives of the plant where the Smart Retrofitting Project was executed. The Realwear Smart Glasses were chosen because these fulfil the hygiene requirement specified by the workers' council who want to avoid contact between Glasses and the face of the users. Such scenario was not considered by the middle manager, the plant engineer nor the author this work who were focused on the technical features of the five available Smart Glasses (see Figure 5-17). Would this scenario not be considered, which in this case study was not part of the issue, most probably a huge resistance would be encountered in the shop floor to embrace the use of Smart Glasses.

This achievement has only been realized due to the application of the Smart Retrofitting Approach which considers the know-how of employees from lower hierarchical level with view in a daily basis of the studied subject resulted from the Top-down Bottom-up management approach.

5.3.5.3 HMI to ensure the safety of employees

The Smart Retrofitting Action used to enhance the safety of Henkel Adhesives employees in the shop floor environment was a request made by the worldwide top-manager responsible for safety, health and environment (SHE) and by the middle-manager responsible for the Digital department. Both managers identified a huge potential for the Smart Retrofitting Approach and its respective change management model to be an excellent complement to the company's safety programs. Therefore, a series of current challenges had been presented to the author of this dissertation and in a joint effort with the two top-managers from the SHE and Digital departments a Smart Retrofitting Action was designed. the corporate compliance policy of Henkel AG & Company, KGaA the full content of this Smart Retrofitting Action will not be detailed in this case study.

Nevertheless, a sub-topic of the case study is presented below which intends to ensure and increase the safety of the employees through the use of existing closed-circuit television (CCTV) cameras —also known as security cameras— within the production plant. Such retrofit was executed respecting the following recommendations of the Smart Retrofitting Approach (see Chapter 4.1) (see Figure 4-1):

- Use of existing human and material resources,
- Incorporation of Sensors and actuators to collect useful process data,
- Enabling and interconnection between Machine-Machine,
- Continuous implementation process through Short-, medium- and long-term projects,
- Top-down Bottom-up management approach and,
- Involvement of employees from several hierarchical levels.

The vision created by the two middle-managers combining the CCTV cameras with an AI video recognition software shall enable them to automatically identify behaviours of employees that could expose them to a risk and so mitigate the occurrence of an incident. Therefore, a middle quality manager with the support of his team and the author of this dissertation— who was a member of the team of this sub-topic— listed the most common scenarios within Henkel Adhesives Technologies that expose the shop floor worker to a risky situation:

- Not using the personal protective equipment for each area within the facility of the plant,
- Moving around in non-authorized area,
- Forklift operation,
- Manual Handling without adequate equipment for a certain production equipment,
- Use of mobile phone in non-authorized areas of the plant,
- Fallen and unstable objects,
- Obstructed passageways,
- Etc.

Following the recommendation of the Smart Retrofitting phase, a continuous implementation process was elaborated to deploy the created vision into all Henkel Adhesives Technologies plants (see Figure 4-23 and Figure 5-18) (see Chapter 4.2.8). Such, implementation process was based on the three recommendations proposed for a Smart Retrofitting Action (see Chapter 4.2.8):

- Generate short-term wins,
- Sustain acceleration and,
- Reinforce and institutionalize the change.

To ensure the accomplishment of short-term wins, a solution was elaborated which could be implemented within a short period of time. In fact, the team of this sub-topic came with a solution for each possible scenario that could expose an employee to a risky situation which could take under 10 working days to be tested and be operational. Once the technology is validated, its global roll out can be done simultaneously in all production plants and completed within under two months. Such a quick global deployment will institutionalize the change throughout an extreme accelerated process.

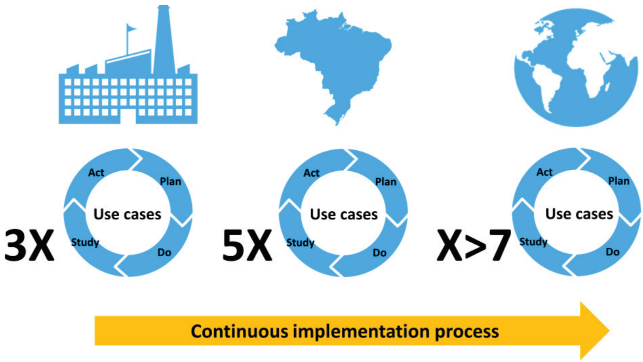


Figure 5-18 Sub-Smart Retrofitting Action concerning the use of CCTV cameras combined with an AI video recognition software

In accordance to the corporate compliance policy of Henkel AG & Company, KGaA, the full description of the proposed solution will not be subject of this dissertation. Nevertheless, the author of this dissertation is allowed to inform that organisational as well personal resistance has been avoided and these are a crucial component of the Smart Retrofitting Approach and its respective Change Management Model.

The validation of the technology occurred in a production plant in Brazil and covered three of the possible risk scenarios listed by the team (see Figure 5-18). The roll out of the solution will start in all Henkel Adhesives Technologies plants in Brazil (see Figure 5-18). Consequently, after all Brazilian plants have completed all five additionally scenarios, the roll-out of the solution will occur on global scale. To avoid possible organizational and personal resistance, the AI video recognition software shows blurry images of the faces of the employees and therefore fulfils the regulation of several countries and meets the expectations of the trade union. Additionally, the images generated cannot be saved and also will not be used as a punishment tool.

The solution cost is relatively low —under 2,000 euros a month for each use case— since the cost is not strongly influenced by the complexity of the use case and the number of CCTV cameras utilized.

6 Summary and Outlook

Smart Retrofitting Approach distinguishes itself from the classical retrofit model since it is not limited to providing new components to or upgrading a machine or an equipment. Instead, it offers the possibility to implement Industry 4.0 across the entire organization by using all available human and material resources in a continuous implementation process. Additionally, it calls for the commitment and involvement of the employees from all different hierarchical levels within the organization for the implementation process of Industry 4.0.

A change management model was developed based on the Smart Retrofitting Approach aiming to fulfill its values and purposes. This change management model pursues the involvement of all employees within an organization. Therefore, it is composed of a Top-down Bottom-up management approach in which the organization's own created vision and the direction to be followed is given by the highest hierarchical employees. The Industry 4.0 vision is based on current and upcoming challenges and needs that the organization faces. In order to implement the created vision, the Smart Retrofitting Change Management Model promotes a roadmap —Smart Retrofitting Roadmap— assembled in a Top-down Bottom-up strategy.

The implementation of the own Industry 4.0 vision occurs through a wave of medium- and small-sized projects following a continuous implementation and improvement process that are designed and executed by those employees directly affected by the changes that Industry 4.0 will promote in their daily business activities. Additionally, to empower employees from lower hierarchical levels the Smart Retrofitting Change Management Model has its own change agent network in which the employees support themselves with their various expertise.

Therefore, taking all the elements described previously, a succinct definition of Smart Retrofitting Approach can be exposed as:

"Smart Retrofitting Approach is a management approach and practice that aims to harness the existing human and material resources of an organization in the most effective way to spread the implementation of Industry 4.0 throughout the entire organization according to the local environment and needs of each single business unit or plant that composes the organization and it takes into consideration a tailor-made change management model to assure empowerment and involvement of all employees over the entire implementation process of Industry 4.0."

Three case studies were conducted and answered the main research question the two hypotheses regarding the two first sub-research question once the Smart Retrofitting Approach was able to implement aspects of Industry 4.0 in outdated machine park, as well as in single equipment, from different industrial segments and organization sizes.

The first case study dealt with the first steps to create a CPS for an over fourty-year-old zone melting equipment that was not designed for Industry 4.0. Following the Smart Retrofitting Approach, the available resources of the equipment were used and two sensors in form of cameras were added to optimize the process in real-time adjustment of a parameter which before the retrofitting was not possible to be measured and all adjustments had to be done based on the knowledge acquired over time. After the application of the Smart Retrofitting

Approach, the process became faster and most importantly much more precise. The Smart Retrofitting Change Management Model was decisive for the actions taken by the specialists on the zone melting process and the author of this dissertation who did not have previous experience with it.

The second case study made use of the whole Smart Retrofitting Change Management Model since the target was to implement Industry 4.0 in an entire production plant. The most significant output for the company was the convincement of the employees, especially the shop floor workers, about the need and urgency to implement Industry 4.0 in their daily business activities. Furthermore, Industry 4.0 became naturally and deeply embedded into the corporate culture of the company justified by the fact that the shop floor employees who were not involved in the pilot project demanded the implementation of Industry 4.0 within their daily business activities. Hence, the aim of the Refreezing phase was almost completely anticipated. The convincement of the need and urgency to implement Industry 4.0 within the company, and therefore embedding Industry 4.0 within the corporate culture of that particular company, was successfully achieved. Besides all that, the pilot project strictly followed the Smart Retrofitting Approach and the second sub-project will be replicated integrally in two other production steps saving time and efforts in the whole development of the company on its way to Industry 4.0. The fast and immediate replication of the second sub-project became possible because the Smart Retrofitting Change Management Model and the Smart Retrofitting Action were designed following the PDSA cycle, which resulted in acquired knowledge that allowed upscaling the results faster by those project participants in the second sub-project and in the following considered Smart Retrofitting Projects.

The third and last case study was conducted in a multinational conglomerate which had previously an Industry 4.0 vision with a huge potential for improvements regarding the use of the existing human resources in the whole implementation process of Industry 4.0. The main outcome of this case study was the creation of an Enterprise Social Media Platform based on the characteristics of the Smart Retrofitting Approach and its respective Change Management Model. This platform enabled the Bottom-up management approach throughout the implementation of Industry 4.0 across the whole organization. Additionally, this platform empowered the mid- and low-hierarchical levels of employees in various manners. An overview of all activities with potential for synergies between the different plants worldwide was generated. Further to this, the managers as well as the employees are now able to search and request existing capabilities related to Industry 4.0. To promote the exchange of expertise among the employees, a Smart Retrofitting Agent Network —Network of Experts— was consolidated. One of the Smart Retrofitting Actions resulted in the homologation of the best Smart Glasses for the organization’s specific health and safety regulations.

The Smart Retrofitting Approach and its tailor-made change management model have proved to be successful in the implementation of Industry 4.0 in applications ranging from single production equipment up to a multinational conglomerate. Nevertheless, there is potential for further studies to compare the approach of the last phase of the Smart Retrofitting Change Management Model —Smart Retrofitting— against the Scrum Methodology which is a project management methodology in the development of software that is gaining popularity in the execution of Industry 4.0 projects in the industrial environment.

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Student Thesis

The present results are partially built on findings obtained within the research team led by the author. The following student thesis has contributed to the second case study and was elaborated under the guidance of the author:

Gao, M.: Remote decision making of machine tools using smart glasses. Master Thesis, Faculty of Mechanical Engineering, RWTH Aachen University, Aachen 2017