UNIVERSITATEA TEHNICĂ DIN CLUJ-NAPOCA

Ștefan BODI

VIRTUAL QUALITY MANAGEMENT IN THE ERA OF INDUSTRY 4.0

UTPRESS
Cluj-Napoca, 2020
ISBN 978-606-737-438-4

PROIECT COFINANŢAT DIN FONDUL SOCIAL EUROPEAN PRIN PROGRAMUL OPERAŢIONAL SECTORIAL DEZVOLTAREA RESURSELOR UMANE 2007 – 2013

INVESTEŞTE ÎN OAMENI !

UNIUNEA EUROPEANĂ

Fondul Social European POSDRU 2007-2013

Instrumente Structurale 2007-2013

MINISTERUL EDUCAȚIEI ȘI CERCETĂRII ȘTIINȚIFICE

OIPOSDRU

Universitatea Politehnica Timişoara

Priority axis: 1 “Education and professional formation in support of economic growth and development of the knowledge based society”
Major domain of intervention: 1.5 “Doctoral and postdoctoral programs in support of research”
Project title: “Increasing the attractiveness and performance of doctoral and postdoctoral training programs for researchers in engineering sciences – ATRACTING”
Contract code: POSDRU/159/1.5/S/137070
Beneficiary: Politehnica University of Timișoara

Ștefan BODI

VIRTUAL QUALITY MANAGEMENT IN THE ERA OF INDUSTRY 4.0

Scientific advisor:

Prof. Dr.-Ing. Prof. h.c. Dr.-Ing. E.h. Dr. h.c. mult. Albert WECKENMANN

TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

FACULTY OF MACHINE BUILDING

UTPRESS

Cluj-Napoca, 2020

ISBN 978-606-737-438-4

MINISTRY OF EDUCATION

TECHNICAL UNIVERSITY
OF CLUJ-NAPOCA, ROMANIA

FACULTY OF MACHINE BUILDING

Ștefan BODI

VIRTUAL QUALITY MANAGEMENT IN THE ERA OF INDUSTRY 4.0

Scientific advisor:

Prof. Dr.-Ing. Prof. h.c. Dr.-Ing. E.h. Dr. h.c. mult. Albert WECKENMANN

str. Memorandumului nr.28, 400114 Cluj-Napoca, România
tel. +40-264-401200, fax +40-264-592055, secretariat tel. +40+264-202209, fax +40-264-202280
http://www.utcluj.ro/

__Motto:__ "If you would not be forgotten as soon as you are dead, either write something worth reading or do something worth writing."

Benjamin Franklin

Foreword

The following work represents the Ph.D. thesis of the author, refined with the valuable coordination of **Prof. Dr.-Ing. Prof. h.c. Dr.-Ing. E.h. Dr. h.c. mult. Albert WECKENMANN**, alongside **Prof. Dr. Ing. Sorin POPESCU** as co-tutor. The public defense of the thesis took place September 8th, 2017 in Cluj-Napoca, at the Technical University of Cluj-Napoca. The evaluation committee of the Ph.D. thesis is presented in the following table:

CHAIRMAN:	- Prof. Dr. Ing. **Silviu-Dan, MÂNDRU** – Technical University of Cluj-Napoca;
TUTOR:	- Prof. Dr.-Ing. Prof. h.c. Dr.-Ing. E.h. Dr. h.c.mult. **Albert, WECKENMANN** – Technical University of Cluj-Napoca;
CO-TUTOR:	- Prof. Dr. Ing. **Sorin Gabriel, POPESCU** – Technical University of Cluj-Napoca
MEMBERS:	- Prof. Dr. Ing. **Anca, DRĂGHICI** – Reviewer, Politehnica University of Timișoara;
	- Prof. Dr. Ing. **Claudiu, KIFOR** – Reviewer, "Lucian Blaga" University of Sibiu;
	- Prof. Dr. Ing. **Claudiu, RAȚIU** – Reviewer, Technical University of Cluj-Napoca;

Acknowledgements

First and foremost, I would like to address my collective thanks to everyone that supported me throughout my doctoral study period and to those that contributed to the research endeavors presented within this thesis.

My concern with this thesis' topic started during my master's degree, when, being an intern at the "Interuniversity Research Centre for Quality Management and Engineering", I came into contact with the virtual related aspects of QM. These were the focus of my dissertation paper in which I demonstrated and underlined the benefits of using process simulations for increasing the quality level of manufactured products.

I was very fortunate to have the opportunity to continue studying the virtual aspects of QM during my Ph.D. period, working under the coordination of **Prof. Dr.-Ing. Prof. h.c. Dr.-Ing. E.h. Dr. h.c. mult. Albert WECKENMANN**, to whom I express my outspoken thanks and appreciation and I am grateful and honored to be the student of such a prestigious advisor with great scientific accomplishments. I am also thankful for the valuable advice, input and guidance of prof. WECKENMANN and I acknowledge all the help I received that facilitated the advancement and completion of this thesis.

Secondly, I would like to thank the committee chairman and members, **Prof. Dr. Ing. Silviu-Dan MÂNDRU**, **Prof. Dr. Ing. Anca DRĂGHICI** and **Prof. Dr. Ing. Claudiu KIFOR** for accepting the invitation of being a part of the evaluation of the current scientific contributions.

Special thanks go out also to **Prof. Dr. Ing. Sorin POPESCU** for his support and advice as co-tutor, throughout all the years of the doctoral study and for his constant availability and openness towards finding solutions to problems I encountered during my research activities.

I couldn't have succeeded without the support of key members from the Design Engineering and Robotics department within the Technical University of Cluj-Napoca. Here I would like to nominate and offer my sincere thanks to **Prof. Dr. Ing. Daniela POPESCU**, **Conf. Dr. Ing. Călin NEAMȚU**, **Conf. Dr. Ing. Mihai DRAGOMIR** and **Assist. Lect. Dr. Ing. Diana DRAGOMIR**. Their help, opinions, judgement and recommendations left their mark not only on my professional, but personal development as well. I am looking forward in continuing our good collaboration.

I would like to offer my thanks also to **Assist. Lect. Dr. Ing. Radu COMES** for his valued friendship, help and moral support that motivated me throughout my doctoral study period.

Finally, I express my recognition and provide my warmest thanks to my parents, to my sister and to all my family and friends who encouraged me, supported me and helped me believe in myself. *As a sign of gratitude, I dedicate this work to my family, residing both locally and abroad.*

Cluj-Napoca,
July 12th, 2017

Sincerely,
Ștefan Bodi

Table of contents

List of figures

List of tables

List of annexes

List of abbreviations

2D – Two dimensional;
3D – Three dimensional;
3PL – Third party logistics
AHP – Analytical Hierarchy Process;
AQL – Acceptable Quality Level;
AR – Augmented Reality;
B2B – Business to Business;
CAD – Computer Aided Design
CAM – Computer Aided Manufacturing;
CAPP – Computer Aided Process Planning;
CNC – Computer numerical control;
CPS – Cyber-Physical Systems;
CRM – Customer Relationship Management;
CTQ – Critical to Quality;
DoE – Design of Experiments;
DovE – Design of virtual Experiments;
FMEA – Failure Modes and Effects Analysis;
GT – Group Technology
ICT – Information Communication Technology;
IoS – Internet of Services;
IoT – Internet of Things;
IPv6 – Internet Protocol version 6;
ISO – International Organization for Standardization;
IT – Information Technology;
KPI – Key Process Inputs;
KPO – Key Process Outputs;
LSA – Latent Semantic Analysis;
NACE – Nomenclature des Activités Économiques dans la Communauté Européenne;
NNMI – National Network for Manufacturing Innovation;
OF – Objective Function
PLC – Product Life Cycle

QFD – Quality Function Deployment;

QM – Quality Management;

QMS – Quality Management System;

R&D – Research and Development;

RPN – Risk Priority Number;

SCM – Supply Chain Management;

SME(s) – Small and medium-sized enterprises;

SPC – Statistical Process Control;

VCI – Virtual Customer Integration;

VoCT – Voice of the Customer Table;

vQM – virtual Quality Management;

INTRODUCTION

1. Context and motivation for selecting the research topic

The meaning of quality, as we know it today, cannot be determined just by one single definition that is universally applicable and valid. It is such a vast concept, that it includes many points of view and can't be characterized just by a single perspective. Some refer to quality as an instrument through which it is ensured that the needs of the customer are incorporated into the product. Some see in quality the monitoring and improvement of processes, but the end goal is still reaching the customer expectations by the corrections made or preventions applied to the manufacturing process. Others may refer to quality only from the standardization point of view: an organization that implemented a quality management system, based on a quality management standard, it is presumed that its manufactured or created products are of a high degree of quality.

However, the general perception and consensus about quality is that it is a positive concept: no one is opposed to it (Boljevic, 2007), namely because it drives for improvement and betterment. This is the reason why organizations are continuously looking for ways to increase the quality of their products enabling them to evolve in the market segment in which they operate.

Quality Management (QM) is known to be one of the most important research topics in the field of operations management and it is a "widely accepted organizational goal" for most companies that operate in the economy sectors such as: manufacturing, health care, construction engineering, education, food processing industry and other services (Nair, 2006).

One of the state of the art QM methods is Six Sigma, which, according to (Linderman, Schroeder, Zaheer, & Choo, 2003), is "an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and the scientific method to make dramatic reductions in customer defined defect rates".

An even newer QM method is Lean manufacturing and it was first implemented by Toyota in the early 1990s. It consisted of identifying those activities that create value for the customer and trying to focus only on them, by eliminating other activities labeled as wasteful (Melton, 2005).

Combining the two revolutionary practices a new excellence model came forth: Lean Six Sigma. The main goal of this business improvement methodology is to maximize shareholder value through the improvement of quality, speed, customer satisfaction and costs (Pamfilie, Petcu, & Draghici, 2012).

The evolution of these business models was helped in a very large part by the development of specialized software tools and even more advanced hardware components that are capable to handle the huge amount of information needed by these QM methods (i.e. monitoring a complex and (partly) automated manufacturing process is done with the help of advanced systems that can check and track thousands of variables simultaneously).

Massive investments and large sales in the ICT sector indicate that organizations are concerned with and are implementing newer, innovative and more mature digital core and support solutions (Banes, Petroman, Orboi, & Petroman, 2013), which are capable of processing larger amounts of information. This way, organizations are capable of creating even more complex and reliable products, that can satisfy requirements expressed even by the most exigent customers and thus, survive on the market.

The emergence and evolution of electronic computational devices made possible the creation of a new, artificial environment that helps to design, interact with and test these complex products even before they physically exist, thus reducing time-to-market and other costs originating from the creation of several prototypes.

The virtual environment also extended over the design of the manufacturing flow: simulations can now be carried out for the activities and tasks necessary within the production process, that take into consideration all possible scenarios, favorable or unfavorable, that couldn't have been foreseen without observing the real-life processes. This way the design of a new manufacturing flow or even the improvement of an existing one can be optimized based on the data obtained from the simulations.

In this context, the novelty of the research approached in this doctoral study consists in the development and application of frameworks, algorithms and instruments that are based on conventional quality management principles, but are enhanced with virtual-type solutions for obtaining more precise, more reliable, fast and highly objective results, essential for managing organizations' complex processes and maintaining their competitiveness level in today's industry. Moreover, the thesis also proposes to highlight the numerous advantages and utility of such instruments providing illustrative examples and case studies resulted from the application of these proposed tools.

The motivation for selecting the research topic is encouraged by the fact that companies rely increasingly on electronic computational systems and ICT products and services to conduct their activities. As we move towards the fourth industrial revolution and the Internet-of-Things

(IoT) there is a growing trend in this area and enterprises are welcoming solutions that can "upgrade" their manufacturing processes, reduce costs, increase customer satisfaction or, in essence, increase their current level of capability for providing high quality products or services.

2. Thesis purpose and objectives

Taking into account the aspects presented above, the current thesis commits to the following main scientific investigatory objectives:

- determining the state of the art regarding virtual-type solutions / technologies / applications / instruments employed within the industry;
- developing a framework for optimized product development;
- developing two hybrid solutions that use both conventional quality management instruments and virtual computational aspects.

The first main objective was set to assess the current level of virtual-type solutions employed within the industry and identify emerging applications and technologies that are crucial for quality management. This investigation was completed within the automotive industry branch, as it was presumed to be the most likely candidate perceptible to such applications. Secondary objectives related to this demarche are the following:

- developing a methodology for analyzing the knowledge density zone obtained by intersecting two knowledge fields, (vQM and Industrie 4.0), throughout the Product Life Cycle (PLC) stages;
- identifying and hierarchize industrial applications (or new technological solutions) based on the state of the art;
- validating the proposed methodology through an online survey.

The second objective addresses the development of a framework that achieves customer oriented product development, transforming requirements into characteristics and optimizing the latter ones through a mechanism inspired by biological evolution (genetic algorithms). In this sense, the following secondary objectives were stated:

- applying proper quality tools for determining quality knowledge (product/process related information);
- describing the method in which optimization parameters were determined (genes, objective function and restrictions);
- demonstrating the applicability of the methodology through an illustrative case study.

For completing the third objective two separate solutions were developed: in the first case a manufacturing process simulation was combined with a Cause & Effect matrix, for the purpose of improving the overall performance of the process; in the second solution, an augmented reality (AR) mobile application was combined with a web platform that uses statistical process control (SPC) rules for monitoring and controlling manufacturing processes. The secondary objectives related to this are the following:

- simulating the manufacturing process using specialized software based on data observed and collected on the factory floor;
- developing the Cause & Effect Matrix based on key process inputs and outputs;
- proposing improvement measures based on data obtained from the Cause & Effect Matrix and the simulation;
- developing the AR application that is able to overlay workpiece information on top of the real environment based on specific geometrical features of the workpiece;
- developing the web platform for inserting, storing and manipulating workpiece data.

3. Thesis summary and structure

The thesis structure follows a traditional form, consisting of two main parts: **Part I – State of the art** and **Part II – Research and contributions**, both including 2 chapters consisting of 2 sections each. They are preceded by an introductory chapter, a list of figures (44 in total), a list of tables (22 in total), a list of annexes (7 in total) and a list of abbreviations with 41 terms. After the two main parts, the conclusions and synthesis of contributions follow, succeeded by the list of publications (with 17 research articles) and list of references (with 166 entries) and finally the annexes. The content of the thesis is grouped in the following headings, which are arranged in a descending manner: parts, chapters, sections, sub-sections. Their names are formulated such that they capture the essence in each section, enabling the reader to intuit what they contain.

The "**Introduction**" is made up of 3 sections, which are denominated as follow:

- Context and motivation for selecting the research topic – shortly describes the concept of quality management and what it means in the context of the current technological advancements;
- Thesis purpose and objectives – the purpose of the thesis is defined for which primary and secondary objectives are established;

- Thesis summary and structure – the thesis outline is presented, accompanied by a short description of all chapters.

The first part includes two chapters which paint a clear picture of the state of the art regarding the topic of the thesis.

Chapter 1 entitled "**The fourth industrial revolution and its dimensions**" describes the current trends and strategies and defines how modern manufacturing systems are constructed. The first section of this chapter illustrates the technological leaps of the industry over the course of time describing the main drivers that led to their development. The second section identifies and describes the strategies adopted by the main industry "actors" (countries with strong industrial background) at a global level. Within the third section the horizontal (design principles) and vertical elements (main technological pillars) are presented that construct the "Industrie 4.0" model, alongside their accurate definitions. These are structured in a table and with the help of a color-coded illustration the interactions between them are captured (the signification of each color is detailed below).

Chapter 2 denominated "**Virtual quality techniques supporting the fourth industrial revolution**" makes an incursion throughout the product life-cycle's stages and sub-phases, identifying and describing state of the art, virtual techniques, tools and instruments employed for the quality demarche that support the "Industrie 4.0" mindset. They are synthesized at the end of each phase in the form of tables. The last section of this chapter incorporates all these instruments under a recently developed concept, "virtual Quality Management", and illustrates its architecture in the form of a figure (see Figure 15).

The second part of the thesis (Research and contributions) contains two chapters, each with two sections, all of which are constructed symmetrically, with the following sub-sections: "General and conceptual aspects"; "Illustrative example"; "Conclusions".

This part begins with **Chapter 3**, called "**Conceptual and theoretical developments for vQM**", which focuses on aspects that contribute from a more conceptual and theoretical perspective to the purpose of the thesis.

The research undertaken in the **first section** of this chapter, "**vQM concept disambiguation and identification of its emerging directions using natural language processing techniques**", was born out of the need to disambiguate the vQM concept as it is a fairly new notion. In this sense, a novel methodology is outlined that contains, among other aspects, a natural language processing instrument, Latent Semantic Analysis (LSA), for offering a highly-objective, fast, and automatic text interpretation. The documentation that underwent the analysis is selected through an original method and the interpretation of the ontology charts directly resulting from the LSA is also carried out through authentic means. In addition to concept disambiguation (carried out for both vQM and Industrie 4.0) it is also aimed at identifying and hierarchizing industrial applications (or new technological solutions) that are expected to emerge from the common knowledge density zone resulting from the intersection of the two knowledge structures (obtained separately for vQM and Industrie 4.0). The identified applications are grouped into the PLC stages, according to the (ISO/IEC/IEEE 15288:2015) standard. The results are validated through the deployment of an online questionnaire focused on experts / practitioners / consultants and other stakeholders from the automotive industry.

The **second section** referred to as "**vQM model in product design and its optimization in the development phase**" deals with the development of a framework, that is based on the vQM model, but particularized for designing customer-centered, yet optimized products. Within the developed framework quality tools such as VoCT, QFD, AHP are used, which are mixed with an optimization method inspired from biological evolution, genetic algorithms, but it also requires input from in effect standard specifications, thus increasing the product's compliance not only to requirements coming from customers, but from manufacturers as well.

Chapter 4 named "**Applicative developments for vQM**" rounds up the contributions of the thesis by reaching practical aspects as well, which are included into 2 sections.

The **first section**, entitled "**Process improvements using simulation software**" makes use of the great potential offered by process simulation software for observing, analyzing, eliminating bottlenecks, reducing errors and downtime, thus overall improving and making more efficient real-life processes. The data needed for completing the simulations was gathered from an existing SME, functioning within the automotive field. In conjunction with these computer-ran simulations, well-established quality tools (e.g. Correlation matrix) are used with the purpose of maximizing their effect when implementing proposed improvements into the production process.

The **second section**, "**Assistive AR environment for quality inspection and statistical process control**", as the name suggests, develops a method that employs Augmented Reality technology (AR mobile device application) and an originally designed web platform for empowering or assisting workers on the factory floor, involved in quality inspection activities. The application overlays a virtual environment onto the existing one and by identifying certain features on the workpiece it is able to display the necessary information that can be understood even by operators without specialty training for reading complex 2D drawings. Moreover, the web platform tracks all inputted data and provides real-time process monitoring and in the case of imminent failure it prompts the user to take action, thus preventing the manufacturing process to function improperly.

The "**Conclusions and synthesis of the contributions**" chapter is comprised of 3 sections, presented in the following order:

- Conclusions – summarizing the conclusions delineated at the end of each chapter;
- Original contributions – synthesizing all contributions resulted throughout the doctoral study period;
- Future research directions – identifying potential future research endeavors that could be initiated in resonance with the thesis' topic.

The **list of references** account for all the covered publications for mostly portraying the state of the art of the chosen research topic, all of which are cited throughout and included within the body of the thesis.

Finally, **the annexes** serve as support for the presented research results, except the final annex, which contains the resume of the author.

The overall structure of the thesis is presented in Figure 1:

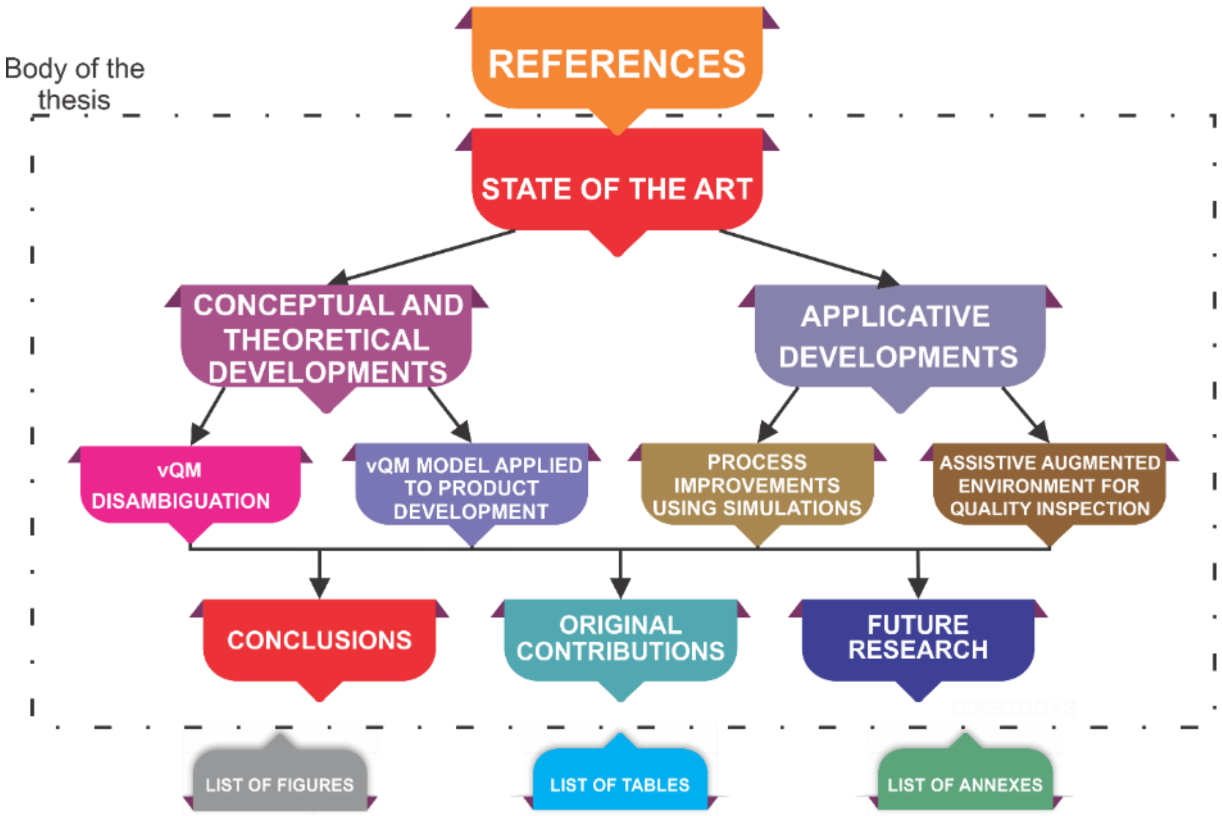


Figure 1. Thesis structure

PART I

STATE OF THE ART

Chapter 1. The fourth industrial revolution and its dimensions

1. General and conceptual aspects

Throughout history, Western civilizations' industry underwent three phases, where great leaps in productivity were obtained:

- The first industrial revolution (Mechanical automation) is represented by mechanization; the invention of the steam engine in the 18th century allowed the introduction of machines into production (Allen, 2006), which in term led to a significant improvement in productivity.
- During the second one (Industrialization), by adding electricity to production (early 20th century), this turned it into mass production, thus assembly lines were created (Jorgenson, 1984).
- The third revolution (Electronic automation) originated with the discovery of the integrated circuit (middle of the 20th century); this allowed the replacement of the analogue systems with digital technology (Moore, 1965), which evolved over time and improved their performances to the level as we know them today.

The forth industrial revolution (Smart automation) is on the verge of unfolding and the driver of it will be the integration of physical objects in the information network.

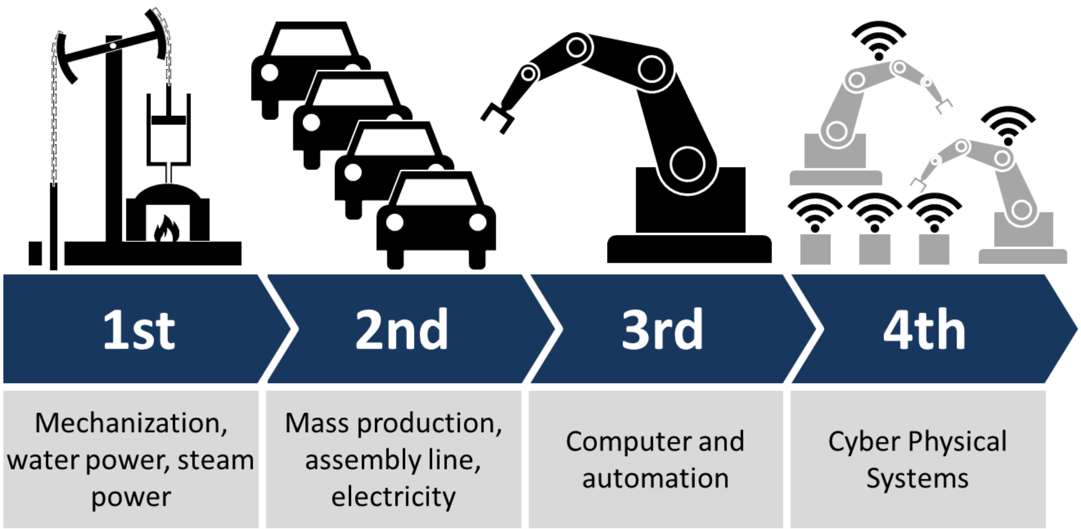


Figure 2. The four industrial revolutions

(Roser, 2015)

2. Specific regional approaches and characteristics

Advancements in ICT systems bring forward progress in almost every field. Regarding industrial production this progress was more pronounced in the late first decade of the 21^{st} century. These improvements and the introduction of the so called “Internet of Things” (IoT) and “Internet of Services” (IoS) into production are pushing the worldwide industry towards a new technological age, towards the fourth industrial revolution. Initiatives in this regard can be found all over the world, but specific to the region in which they originated. They are presented as follows, in chronological order.

2.1. Europe – “Industrie 4.0”

The main promoter of this leap in manufacturing industry is Germany, who introduced its own term “Industrie 4.0” in April 2011 at the Hannover Messe trade fair.

The year 2013 brought a clear definition of what are the requirements for the next industrial leap. In this sense, in Germany it was published the “Recommendations for implementing the strategic initiative Industrie 4.0” report, written by the German Communication Promoters Group of the Industry-Science Research Alliance, in collaboration with the National Academy of Science and Engineering and sponsored by the Federal Ministry of Education and Research. According to this report (also referred to as the Industrie 4.0 national working group report), every physical object that is connected with the manufacturing process, will be interlinked into a single network, through the IoT. This network will incorporate everything starting from the factory floor to the delivery process, i.e. multiple systems that are outlaid as “Cyber-Physical Systems” (CPS), forming the so called “Smart Factory”. This sort of system has the capability to be self-aware, thus it can actively intervene in the manufacturing processes to prevent potential faults (Lee, Kao, & Yang, 2014). Its self-awareness is given by the sensory data collected within the system. Actions that are precisely ordered are based on previously stored information, this way making the system not only self-aware, but self-maintained and self-learning.

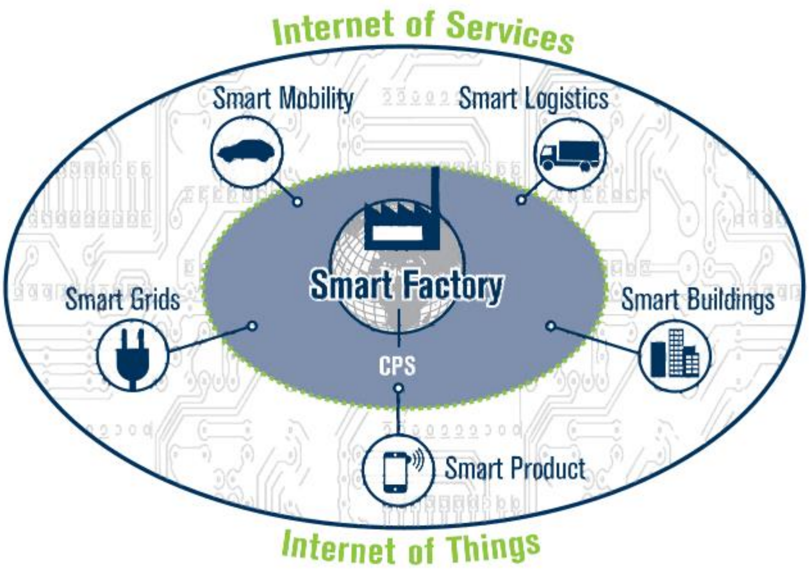


Figure 3. Industrie 4.0 and Smart Factories as part of IoT
(Forshungsunion; Acatech, 2013, p. 19)

2.2.United States of America – "National Network for Manufacturing Innovation"

Germany being the main promoter of Industrie 4.0, hence this concept is specific to Europe. In another powerful industry, in the U.S.A. a similar initiative was developed called the National Network for Manufacturing Innovation (NNMI), or Manufacturing USA in the short form, officially presented by the Obama administration in late February 2012 (McCormack, 2012). This coalition is formed of research institutes from the United States (similar to Germany's Fraunhofer Research Institutes model) and aims at developing innovative manufacturing technologies through which the US is trying to increase their competitiveness. It's able to bring together all stakeholders that are either directly connected or just briefly intersect with manufacturing, starting from universities and laboratories (responsible with R&D) to suppliers and government agencies.

The funding of this initiative is provided by the joint efforts of five federal agencies with a budget totaling 1 billion USD between 2014-2022 (Office of Management and Budget, 2013) (Office of the Press Secretary, 2016): Department of Defense (DoF), Department of Commerce (DoC), Department of Energy DoE), National Aeronautics and Space Administration (NASA) and National Science Foundation (NSF); all part of the Advanced Manufacturing National Program Office (AMNPO).

As in the case of Industrie 4.0, the framework upon which the NNMI should function was also formalized within an official report: "National Network for Manufacturing Innovation: A preliminary design", realized in January 2013 through the collaboration of three entities: Executive Office of the President; National Science and Technology Council; Advanced Manufacturing National Program Office. The main objective of the NNMI endeavor is "closing the gap between research and development (R&D) activities and the deployment of technological innovations in the domestic production of goods." (EOP; NSTC; AMNPO, 2013)

The report also details the characteristics of the institutes that will form the network, focusing on aspects such as research areas, activities, funding, eligible partners, governance and other important administrative issues.

The common ground between Industrie 4.0 and NNMI is that both of them tend to reach smart manufacturing through R&D and revolutionary technological solutions, while the difference is that Industrie 4.0 focuses on developing CPS, which connect physical objects from the manufacturing and delivery chain for increasing efficiency, while the NNMI has the aim of creating networks between stakeholders to support collaboration and specific knowledge sharing, in short, to develop and strengthen a nationwide "effective manufacturing research infrastructure".

Currently, the Manufacturing USA network includes nine research institutes, each with their own area of expertise (Office of the Press Secretary, 2016), focusing on aspects considered vital for the US industry by AMNPO:

- National Additive Manufacturing Innovation Institute (NAMII) – Research domain: 3D printing;
- Digital Manufacturing and Design Innovation Institute (DMDII) – Research domain: Digital Manufacturing;
- Lightweight Materials Manufacturing Innovation Institute (ALMMII) – Research domain: Lightweight materials;
- Next Generation Power Electronics Institute (PowerAmerica) – Research domain: Wide-bandgap semiconductors;
- Institute for Advanced Composites Manufacturing Innovation (IACMI) – Research domain: Composite materials;
- American Institute for Manufacturing Integrated Photonics (AIM Photonics) – Research domain: Photonic integrated circuits;
- Flexible Hybrid Electronics Manufacturing Innovation Institute (FHEMII) – Research domain: Flexible electronics;
- Advanced Functional Fabrics of America (AFFOA) – Research domain: Textiles

- Smart Manufacturing Innovation Institute (SMII) – Research domain: Smart manufacturing.

The DoE administrates all the above institutes, being their main contributor, but according to President Obama's budget proposal for the 2014 Fiscal Year up to 15 institutes will be part of the NNMI by the end of 2017.

2.3.South Korea – "Manufacturing Industry Innovation 3.0"

Trying to keep up with its Japanese competitor, South Korea also announced its new industry strategy called "Manufacturing Industry Innovation 3.0", which is part of a greater economic policy known as the Creative Economy Industry Engine.

It was first introduced in June 2014 (since then it suffered a few minor adjustments) consisting of four major focus areas: development and inclusion of new technologies into manufacturing (including Internet of Things, Big Data and 3D printing), enhancement of the major industry branches, activation of local manufacturing & start-ups and development of the industrial innovation infrastructure (See Figure 4). This strategy is not that detailed as its European or American counterpart, but it's very similar in orientation: computerization of manufacturing.

Figure 4. Components of Manufacturing Industry Innovation 3.0
(Kim, 2016)

Korea's strategy is the first that discerns between the technological level of manufacturing companies, depending on their size and industry sector, and proposes differentiated measures and support. It not only facilitates research and development actions, but also offers direct financial support for technologizing SMEs. The objective of this policy is the creation of 10,000 smart factories by the year 2020, thus enhancing the competitiveness at global level of the Korean manufacturing industry.

The planned budget for this strategy is totaling 5 billion US dollars, out of which 972 million US dollars from direct government investment, the rest were to be attracted from private capital sources.

2.4.China – "Made in China 2025"

The Chinese version of the Industrie 4.0 model is the "Made in China 2025" strategy, officially presented in March at the 2015 Lianghui. It's planned as the first of a three-stage plan through which China tries to revitalize its manufacturing industry and become a leading industrial nation by 2025. It consists of nine tasks that are assumed by the (Chinese State Council, 2015):

- National Manufacturing Innovation Capability
- Full Integration of Informatization and Industrialization
- Fundamental Industrial Capabilities
- Quality and Branding
- Green Production
- Breakthroughs in Major Areas
- Structural Adjustment in Manufacturing
- Service oriented Manufacturing and the Product Service Industry
- Internationalization of Manufacturing

The level of technology employed by Chinese companies is very diverse, unlike other industrialized nations, such as Germany, Japan or United States with a strong tradition in manufacturing. Although China is considered the second largest economy in the world, after the U.S., its industry has much "catching up" to do. There is a clear division between the digitalization of large corporations and SMEs, some of which are not even using computer-integrated manufacturing (Industry 3.0), let alone considering implementing Cyber Physical Systems or IoT (Kagermann, Anderl, Gausemeier, Schuh, & Wahlster, 2016). For this reason, the strategy is focused, firstly, on increasing the innovation capability, efficiency and quality of products, employing more environmentally friendly production methods and increasing the computerization and “smartness” level of all companies by 2020. Following this technology upgrade, by 2025 China will try to further improve its intelligent manufacturing level through “collaborative research” and implementation of “next generation IT and manufacturing equipment”.

China’s investment plan for supporting the “Made in China 2025” strategy greatly eclipses the ones of other countries, totaling 23.1 billion US dollars (Wübbeke, Meissner, Zenglein, Ives, & Conrad, 2016).

2.5.Japan – “Robot Revolution Initiative” and “Industrial Value Chain Initiative”

Japan’s approach for reforming the manufacturing industry is also centered around the IoT, the creation of cyber-physical production systems (Executive Board of IVI, 2015) and increasing robotic automation (Robot Revolution Initiative Council, 2015).

There were several initiatives started in resonance with the Industrie 4.0 model, but only partially coordinated, both in the business and public sector. As private proposals, we mention the “e-F@ctory Alliance” (started by Mitsubishi Electric in Jan. 2014) and the “Industry 4.1J” (started by Phoenix Contact Development & Manufacturing Inc. in March 2015), but the main strategies are included in two initiatives, both endorsed by the Japanese government: “Robot Revolution Initiative” (RRI) – May 2015 – and “Industrial Value Chain Initiative – Connected! Manufacturing” (IVI) – June 2015.

The two approaches basically promote the same course of action: building a “connected system architecture” that facilitates the “matchmaking and sharing of best practices among the relevant parties”; but the RRI follows a strategic action plan and creates one framework, while the IVI proposes a multi-model solution, each model resulted from the successful collaboration of companies from different areas. The latter one introduces the term “loosely defined standard” because it doesn’t offer one single reference model (a standard) that is universally valid, but it provides “general connection models” based on the type of the collaboration.

2.6.Taiwan – “Productivity 4.0”

The importance and development opportunities that the Industrie 4.0 model offers can’t be ignored and because it is such a trending concept Taiwan also prepared their own version, through which it is trying to impose its manufacturing industry as a worthy competitor to other major economies.

It was first presented at the “Taiwan-German Productivity/Industrie 4.0 Forum” in May 2016, having the main objective of “raising GDP per capita of manufacturing industry to 10 million NTD (New Taiwan Dollars) (about 330,000 US dollars) in 2024 (up 60% compared to 2014)” (Industry Development Bureau; Ministry of Economic Affairs, 2016).

The center point of the strategy is “smart automation” (obtained through the implementation of new robotic technologies, cyber-physical systems and the IoT), it’s mainly focused on 5 leading industries: “electronics and information; metal transportation; machine tools; food and textile”; and it consists of 6 main steps proposed within the framework document developed by the (Industry Development Bureau; Ministry of Economic Affairs, 2016):

- Step 1: Optimize smart supply chain ecosystem;
- Step 2: Foster new ventures;
- Step 3: Promote local content;
- Step 4: Obtain self-developed, game-changing technologies;
- Step 5: Cultivate experienced talents
- Step 6: Support the industry with preferential policies.

The overall budget for this endeavor is divided equally over a 9-year period (by 2025), totaling 36 billion NTD or 1.19 US dollars (Ministry of Foreign Affairs, Republic of China (Taiwan), 2015).

However, it must be noted that in a study conducted by Kasetsart Energy and Technology Management Center (Sangmahachai, 2016) not all of the 5 industries mentioned above are currently operating at “industry 3.0” capacity in Taiwan. The food and textile branches are still struggling to reach the level in which they, too will have the potential of embracing the “Productivity 4.0” practices.

3. Horizontal and vertical constitutive elements of the fourth industrial revolution

Industrie 4.0 echoed throughout the world. Although denominated differently and having slight variations according complying better each country's strategy, the fourth industrial revolution can be defined as "smart automation". The model's key technology drivers, as well as its design principles are presented in Table 1, accompanied below by their clear definition and by short description of how the two are reflected upon each other.

Table 1. Industrie 4.0 model design

<table>
<tr><td colspan="2" rowspan="3"></td><th colspan="6">Main pillars</th></tr>
<tr><td>Internet of Things / Services</td><td colspan="2">Cyber-Physical Systems</td><td colspan="3">Big Data</td></tr>
<tr><td>Connection of embedded devices</td><td>Smart equipment and systems</td><td>Universal system integration (horizontal and vertical)</td><td>Cloud infrastructure</td><td>Data analytics</td><td>Cyber-Security</td></tr>
<tr><th rowspan="5">Design principles</th><td>Interoperability</td><td bgcolor="yellow"></td><td bgcolor="red"></td><td bgcolor="#92d050"></td><td rowspan="2" bgcolor="#00b0f0"></td><td rowspan="2" bgcolor="#00b050"></td><td></td></tr>
<tr><td>Virtualization</td><td></td><td></td><td></td><td bgcolor="#ffc000"></td></tr>
<tr><td>Decentralization</td><td></td><td colspan="2" bgcolor="#7030a0"></td><td></td><td bgcolor="#7030a0"></td><td></td></tr>
<tr><td>Real-time capability</td><td colspan="2" bgcolor="#aeaaaa"></td><td></td><td colspan="2" bgcolor="#aeaaaa"></td><td></td></tr>
<tr><td>Modularity</td><td colspan="2" bgcolor="#f4b183"></td><td></td><td colspan="2" bgcolor="#f4b183"></td><td></td></tr>
</table>

Interoperability – "The ability of computer systems or software to exchange and make use of information"; (English Oxford Living Dictionary, 2017);

Virtualization – Converting real-life aspects and scenarios to be analyzed within a "computer-generated simulation of reality"; (English Oxford Living Dictionary, 2017);

Decentralization – The transfer of decision power from the central management to the Cyber Physical Systems, equipped with “distributed sensing and control, thereby providing the technology for distributed intelligence” (Wilderer & Grambow, 2016, p. 185);

Real-time capability – The ability of a system for processing “input data within milliseconds so that it is available virtually immediately as feedback to the process from which it is coming” (English Oxford Living Dictionary, 2017);

Modularity – The ability of a system to be reconfigured by combining its constructive modules in different ways. (Baldwin & Clark, 2000);

Internet of Things – “The interconnection via the Internet of computing devices embedded in everyday objects, enabling them to send and receive data” (English Oxford Living Dictionary, 2017);

Cyber-Physical Systems – “Transformative technologies for managing interconnected systems between its physical assets and computational capabilities” (Lee, Bagheri, & Kao, 2015);

Big data – “Extremely large data sets that may be analyzed computationally to reveal patterns, trends, and associations, especially relating to human behavior and interactions” (English Oxford Living Dictionary, 2017);

The color-coded interactions between the design principles and Industrie 4.0 main pillars are presented as follows, detailing the significance of each color:

- Internet Protocol v6 (IPv6) by lengthening the IP address from 32 bits to 128 permitted the endowment of ordinary objects with their own IP address, thus, from the industry’s perspective, every physical object connected with the manufacturing process could be equipped with their own IP address, thus forming a network with the purpose of exchanging information.
- By connecting the sensing, actuating and control related equipment in a CPS the whole system becomes “smarter” because it now has the ability of self-identify, self-act and self-control the whole manufacturing / value chain network

- The subsystems have the ability to not only to coordinate and exchange information between them (horizontal integration), but also to efficientize the activity of the smallest functioning equipment within those subsystems (vertical integration).
- The data obtained from devices / equipment from within the CPS is uploaded / virtualized and stored in “the cloud”, rather than locally.
- The information available in the cloud is further processed and used to conduct simulations and analyze possible scenarios. The best possible solution is retained and disposed as a measure throughout the system.
- The virtualized information can become vulnerable to outside threats. Cyber-security encrypts data and prevents disruption within the system.
- The decisions / measures adopted by and throughout the system are based on data analysis and on the information exchange within and between subsystems), thus, the entire manufacturing process, can, to a certain degree, self-sustain itself.
- The aggregate between IoT, CPS and due to the high computational power of “the cloud” (Big data analytics) permitted the system to respond efficiently in real-time to various scenarios by analyzing implications of potential solutions and provide the best possible measures.
- Through its “smart” equipment the system can reconfigure itself for optimize its activity and increase efficiency.

Chapter 2. Virtual Quality techniques supporting the fourth industrial revolution

1. General and conceptual aspects

In the context of virtualization, product design and manufacturing companies rely more and more on complex computational systems, which are capable to respond to situations that were already predicted and / or analyzed through simulations performed in the virtual environment, based on information obtained from all devices involved in the manufacturing process (Bodi, Popescu, Drăgeanu, & Popescu, 2015).

The nucleus that imposed this aspect and facilitated an upgrade for manufacturing systems was the companies' need to respond to the increase in quality and productivity demands on the market and to the expansion of the globalization level. The recent advancements in ICT technologies (Internet Protocol version 6 – IPv6 protocols and the Internet of Things – IoT) made this context "just right" for the "boom" of the fourth Industrial revolution and the Industrie 4.0 model. This model is capable to offer a solution for the collection and analysis of huge amounts of data required to respond to above-mentioned market demands, as it is based on Cyber Physical System-enabled manufacturing. This means that the virtual information flow between the actual product and the processes related to it (including supply, shipping, customer feedback and removal) will be enhanced and all information will be linked up as a Cyber-Physical System (CBS) (Lee, Bagheri, & Kao, 2015).

The new industrial revolution (Industrie 4.0) requires the virtualization or computerization of traditional ways leading to product realization or service provision. This aspect also extends over the Quality Management approaches (which accompany the fabrication of products) and requires that they should be updated or reach the same level of advancements as modern manufacturing systems.

2. Virtual quality aspects throughout the Product Life Cycle

The inclusion of CPS into manufacturing drives Quality Management Systems to cover the whole Product Life Cycle (PLC), even stronger than before, hence the QM techniques / tools / instruments are starting to be present not just in the Product Development stage (which is strongly tied to the manufacturing organization), but also in the Use and Removal stages.

The state of the art analysis, based on current literature, conducted within this chapter aims to identify these techniques that support the above-mentioned type of mindset, focusing on aspects which are more compatible with the "virtual" context.

The framework used for this analysis is proposed by (Weckenmann, 2013), denominated as an "Enhanced Quality Loop", within which virtual elements are identified that can impact the prevention / detection / correction of non-quality:

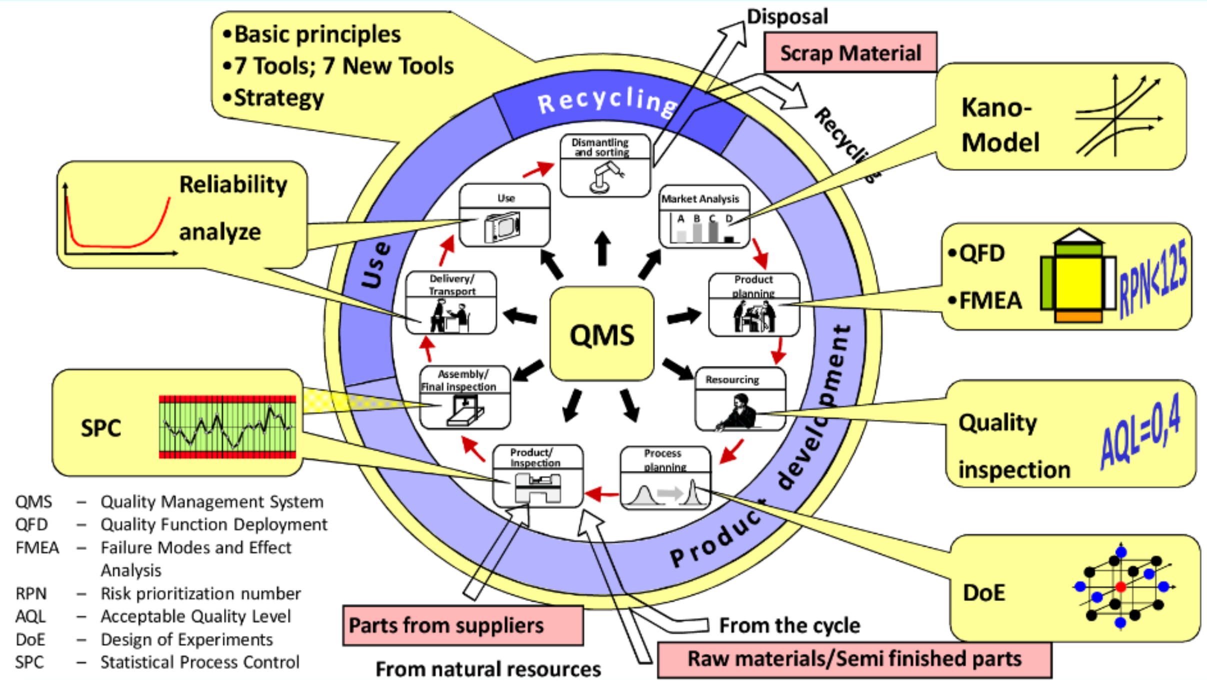


Figure 5. Enhanced Quality Loop

(Weckenmann, 2013, pp. LE 01, 9), Copyright © QFM Erlangen;

2.1. Planning, design & development stage

2.1.1. Market Analysis

The “Market analysis” is the first phase in the Planning, design & development stage within the life cycle of a product. Starting from the (ISO 9001:2015) QM standard and taking into account New Product Development best practices it can be stated, that during this phase one must focus on three main tasks: identifying customer requirements (meaning defining and understanding those needs); based on identified requirements the characteristics of a product have to be determined and finally the product has to be defined at a concept level.

In the case of a totally new product this phase is preceded by the so called “Ideation” phase or stage 0 (Yang & El-Haik, 2003, p. 4), within which it is established how the newly discovered technology and new ideas can be incorporated into the new product.

The common ground between the two and, probably, the reason why often the two stages are viewed as one, is that in both cases several options or product variants are developed out of which one is chosen that is best suited for the customer (based on his needs).

Traditionally, the first contact with the customer’s needs is the questionnaire. This method evolved over the course of time and nowadays powerful web-based software tools like Sawtooth™, QuestionPro™, SurveyMonkey™ provide not only the collection of results, but also analysis of the answers given by the customer (Kalantari, Kalantari, & Maleki, 2011), (Su, Chen, & Sha, 2006) (Leland, 2011). Of course, these requirements can also be noted through direct discussions with the customer, but this form of communication also evolved over time: instant message, video call or e-conference software programs eliminate the inconvenience of a person going to a certain location.

(Nettleton, 2014) argues that the virtualization of customer related data is done using specialized integrated CRM (Customer Relationship Management) systems or CRM application software systems. These systems make all relevant customer information easy to access, particular information is kept visible, thus each customer can receive personalized treatment or customized attention, which can lead to an increased level of customer satisfaction. Most used CRM available today are: Siebel, PeopleSoft, and Genesys, Salesforce; or cloud solutions like Microsoft CRM.

As the barrier between companies and customers was reduced with the help of the world wide web and because new technologies were developed in communications and data processing, in the past few years a new concept started to be associated with new product development and innovation: “Virtual customer integration” (VCI). Its use is mostly capitalized by major corporations and multinational enterprises (BMW, Audi, Sony, Procter & Gamble and Adidas – (Prandelli, Verona, & Raccagni, 2006), (Rohrbeck, Steinhoff, & Perder, 2008)), who come to meet their customers by enabling them to provide their insights in the design of new products. Among the main advantages that it offers, VCI reduces the risks associated with the launch of a new product, as customer feedback is obtained even from the design stage, it improves the relationship with the customer, as it helps their needs to be recognized or understood more accurately and improves the company’s image showing their preoccupation and openness towards their consumers, that can be translated in acquiring new customers or retaining them. However, it’s not widely spread due to some important limitations: information provided by the customers can be also exploited by competitors; intellectual property aspects; customers may not be able to transfer their requirements in a useful manner (Bart, Füller, Mühlbacher, & Ernst, 2012).

Another virtual aspect that gained momentum over the last few years and has increased its importance for market analysis studies is the use of social media. Communication through this type of channel has increased dramatically over the past few years (according to eMarketer.com 61% increase in the last 4 years (eMarketer.com, 2014)). By monitoring the social media data it can be understood what trends are evolving rapidly and which are the main issues discussed on a certain topic. The Australian “Commonwealth Scientific and Industrial Research Organisation” (CSIRO) developed a powerful software tool called “Vizie”, that can identify customer needs by analyzing social media content. According to (Duan, Gu, & Whinston, 2008) social media review and internet “word-of-mouth” has a direct effect upon customer purchases and customer decision making. (Jalkala & Salminen, 2009) also argues that customer references are “important marketing tools” and companies should treat them with adequate importance.

It is also common that during this stage a business feasibility study is conducted, before committing any resources, to make sure that the new product will be successful on the market (i.e. it will generate a profit) (Yang & El-Haik, 2003). Within this step, the business idea, market and competitive advantage and the financial feasibility of the business is analyzed (Indrawati, 2012).

According to (Aydin, Kwong, & Ji, 2014), after conducting the financial feasibility studies market demand estimation can be conducted using regression analysis such as: discrete choice analysis, conjoint analysis or fuzzy analysis, all of which carried out with the help of state of the art computational systems.

Table 2 summarizes all presented solutions within this phase:

Table 2. Virtual solutions used within the “Market analysis” phase:

Online survey instruments (online questionnaires): Sawtooth™, QuestionPro™, SurveyMonkey™
e-Communication: e-mail, e-conference, instant messaging, file transfers
Customer Relationship Management Systems: Siebel, PeopleSoft, and Genesys, Salesforce; Microsoft CRM.
Virtual customer integration systems
Social media analysis software: Vizie
Financial feasibility analysis methods: discrete choice analysis, conjoint analysis or fuzzy analysis.

2.1.2. Product planning

An important aspect regarding the Product planning phase within the PLC is the translation and understanding of previously identified customer needs into functional and measurable technical product specifications. This means that the new product should be capable of satisfying customer needs with its functions and characteristics or it must answer to the requirements identified through previous means. There are several well-established methods that ensure this aspect, which aren’t necessarily newly developed quality management tools and techniques, but their application shifted from the traditional to the virtual environment (useful software programs developed for this purpose are: Qualica Planning Suite, Rektron FMEA, PTC Windchill FMEA, Byteworx FMEA) and they’re worth mentioning due to their effectiveness and numerous benefits. Such a widely used instrument is the “Quality Function Deployment” or QFD (Wang & Shih, 2013), (Delice & Güngör, 2009), (Lee, Sheu, & Tsou, 2008) (See Figure 6 for QFD lay-out within the Qualica Planning Suite specialized software).

Overall, QFD is a powerful tool used for “continuous product improvement bringing forth innovation” (Cor, 2001) and for identifying novel solutions deposed for conflicts occurring between a product’s technical characteristics.

It is a method that aids organizations for the planning of all activities related to a product (or a service), keeping the focus on the customer requirements throughout the development process (Bouchereau & Rowlands, 2000), thus it helps maximize the satisfaction of the beneficiary. By translating the clients’ needs into product related criteria the resulted products or services are better placed on the market because they incorporate “critical-to-quality” aspects that define their suitability for the customer. The determination of the needs related to a certain product (which are the focal point of this method) can be obtained through various investigatory tools and techniques, some of which are presented in the previous chapter.

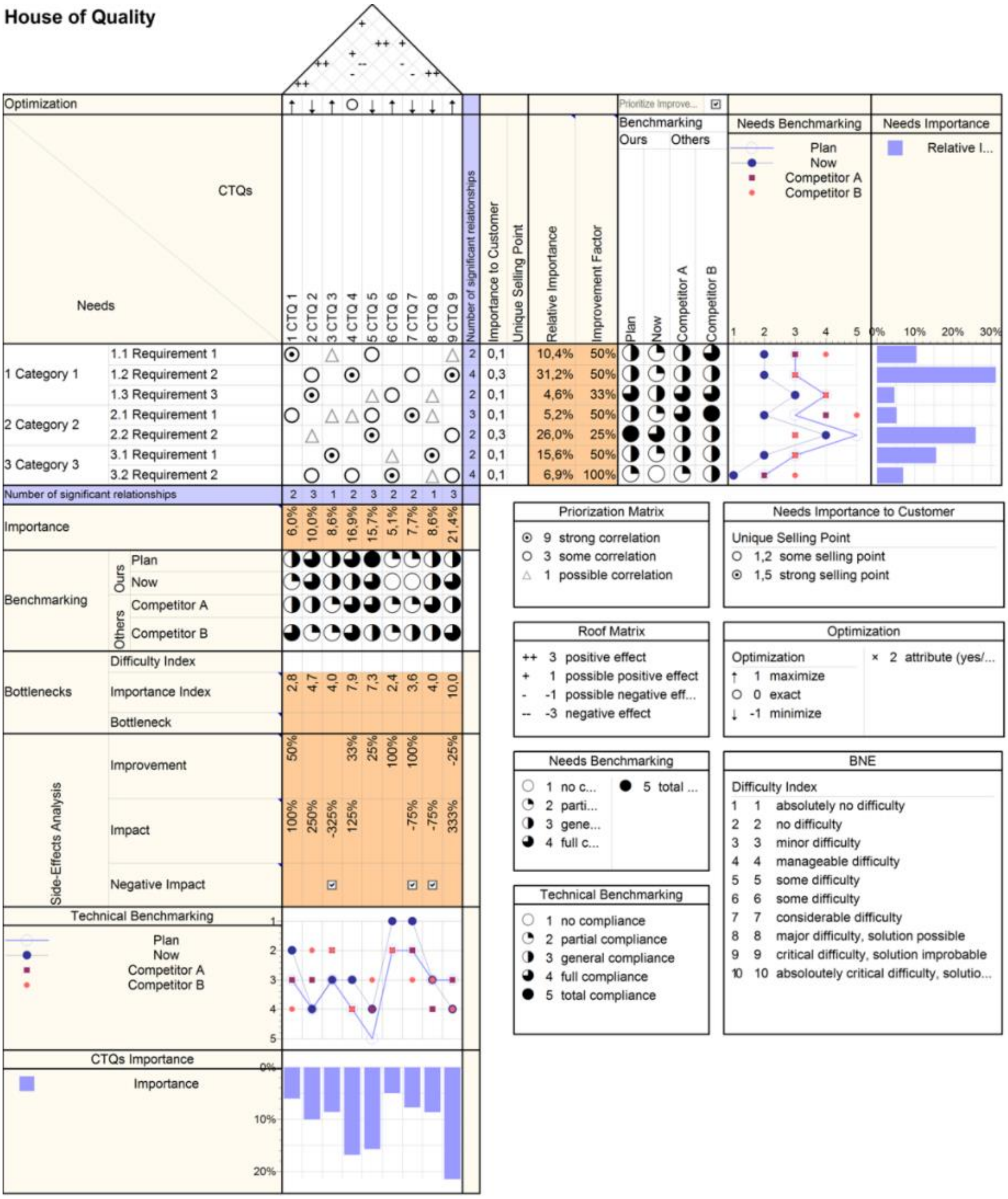


Figure 6. QFD lay-out example

(Dragomir, Iamandi, Bodi, Gohla, & Chiran, 2014)

In its extended form, the QFD process involves 4 steps: Product planning: house of quality; Product design: parts deployment; Process planning; Process control (Bouchereau &

Rowlands, 2000). This 4-step deployment is often referred to as “Cascaded QFD”, involving 4 matrices interlinked with each other (the outputs of one become the inputs of the following).

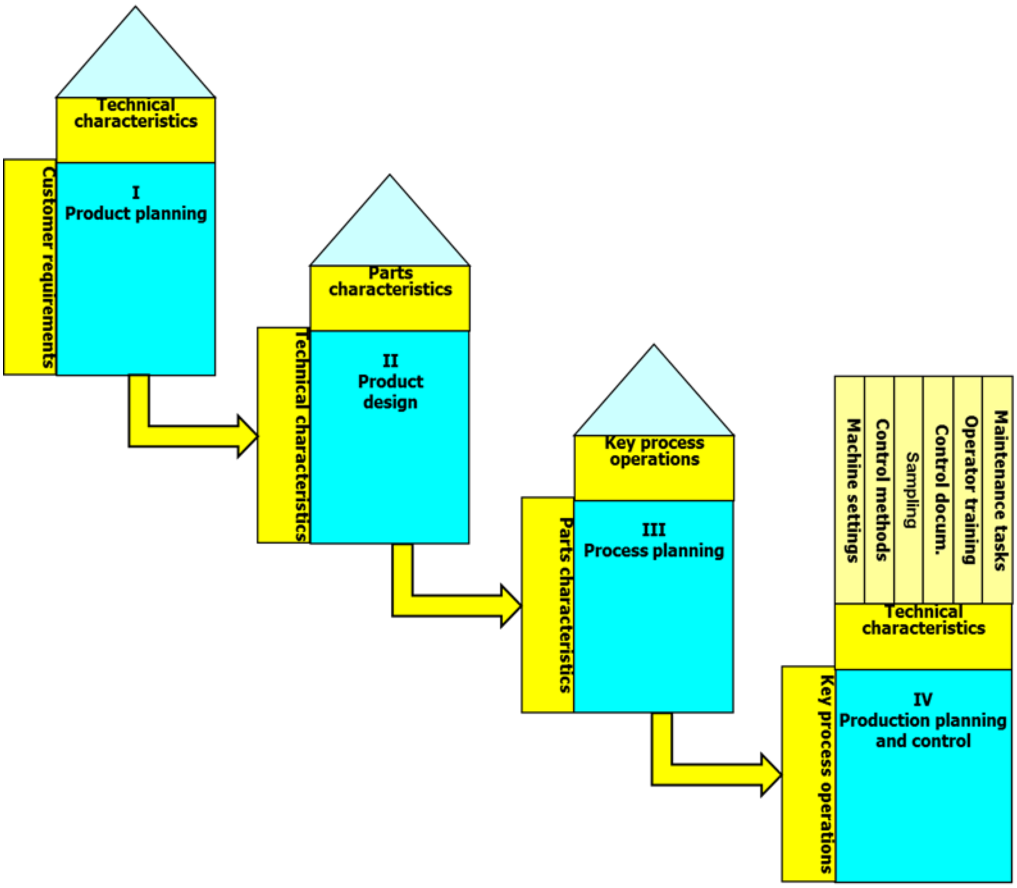


Figure 7. Cascaded form of QFD

The QFD method can also be used in conjunction with other methods like: Kano model, Analytical Hierarchy Process (AHP), Voice of the Customer Table (VoCT), Pugh method or even FMEA (Failure Mode and Effects Analysis). This way, the effect of QFD is enhanced and its application is more objective. These well-known techniques are detailed and described below.

Noriaki Kano, in his Kano model, proposed an approach in which customer needs are grouped into 3 main categories (see Figure 8 for exemplification): “basic needs (or dissatisfiers)”, “performance needs (or satisfiers)” and “excitement needs (or delighters)” (DeLayne, 2012).

The fulfilment or the incorporation into a product only of the first category requirements cannot lead to any level of customer satisfaction. If only these needs are met, which by most customers are not even explicitly mentioned, but are expected that a product should contain, by default, only a “not dissatisfied” state will be achieved. From this point of view, the Kano model solves a limitation of the QFD method: QFD checks whether or not a requirement is met, thus, unstated, but expected needs, tend to be left out; by clearly distinguishing between the types of requirements they can be more successfully managed.

The second category needs, according to the Kano model, are known as the performance attributes, which are explicitly stated by the customer. These contain information obtained directly from the customer that describe what the product should do or what requirements should fulfill in order to be deemed as of a good quality. The exact number of performance attributes regarding the same type of product may vary from customer to customer, however with respect to the most important ones there is a consensus. For determining which are the top-ranking requirements, various methods and instruments can be used, some of these are detailed further on in this chapter (see AHP or Pugh matrix).

The “excitement needs” or delighters, like in the case of the first category, contain requirements that are not stated by the customer, however, they are not expected, moreover the customer isn’t aware of them. From this point of view, the fulfilment of requirements, unknown to the customer, until product use, can lead to a high degree of satisfaction. Delighters are not conventionally included into products, and in most cases, are the results of innovation, but those that do include them have a clear competitive advantage.

There are many benefits that the Kano model offers, regarding the product development activities, among these the most important ones are considered to be the following: categorizing and distinguishing between customer requirements; Estimating the customer satisfaction level for product concepts; Conducting competitive and technical benchmarking.

A graphic representation of the Kano model can be viewed in Figure 8.

As mentioned previously, the VoCT method is often used alongside the QFD House of Quality, as its precursor, enabling designers, engineers or the team that is involved in the product development to properly understand what the customer wants or how he perceives the product and its functionality (Hanjun, JinYoung, & Yongmoo, 2014, p. 7) (Roman, 2010). Its main advantage is its simple form and easy to use graphical support and most of the time is deployed in two phases, corresponding to two table VoC Table I and VoC Table II.

The former is based on a 5W1H analysis (Bradlow, 2010): the table sections refer to questions like What? (does the customer really mean), Who? (is the customer), When? (is the product being used), Where? (is the product being used), Why? (does the customer want this), How? (can it be incorporated into the product) (Dragomir, Iamandi, Bodi, Gohla, & Chiran, 2014).

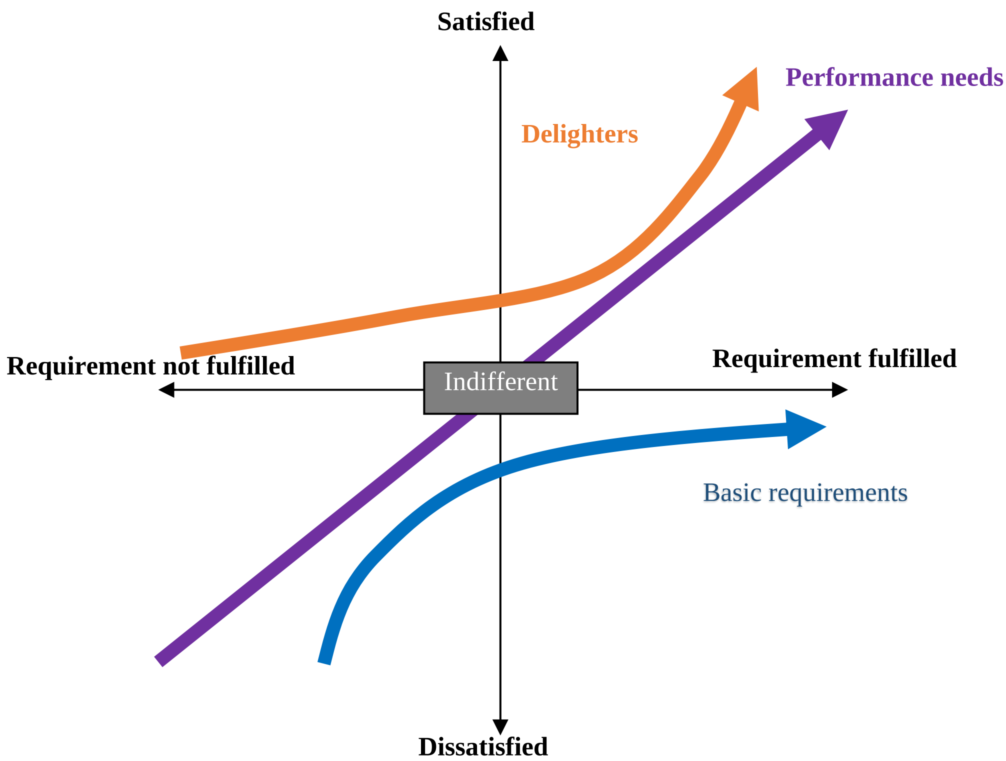


Figure 8. Kano model example

The VoCT II determines the relationship between customer requirements and their complaints (Pyon, Woo, & Sang, 2010), but also lists technical characteristics, functional aspects and requires a rephrasal of customer needs, for increasing the chance of properly understanding them by the product development team.

When dealing with small scale applications the first one is more convenient, as it does not require data mining and huge amount of data processing (Bodi, Popescu, Drăgeanu, & Popescu, 2015), however, if conducting big data analysis for this purpose, objective and more accurate results can be obtained.

Another important aspect in product planning is the ranking of requirements. This is carried out, mostly, for determining which are the most important needs in the eyes of the customer, that the product must satisfy and incorporate, but also for prioritively using the resources that are allocated for the development of the product.

A widely used instrument for this purpose is the AHP method, which ranks and weighs criteria (requirements) in a systematic way, by pair wise comparison (Guo-Niu, Jie, & Jin, 2015). The scale attribution to each comparison integrates not only qualitative, but quantitative aspects as well (Yanlai, Jiafu, Xinggang, & Jie, 2009) for determining the relative importance.

Ideally, the number of criteria that are subjected to the AHP should be around 15, 20 at the most (forming a matrix of 20 rows and columns), otherwise the percentages of each criteria tend to be closer in value, making it difficult for clearly distinguishing between them. If the requirements are more than 20, they should be grouped into categories and the ranking should be completed in stages, firstly for prioritizing the categories and secondly for ranking requirements within each category. This way situations are avoided in which the difference between two criteria is less than 0.1% and deciding which one is more important could prove difficult.

If the AHP matrix is completed correctly and consistently (usually checked by calculating the consistency index, which should be less than 10%) the final results should reflect the Pareto principle: 20% of requirements carry 80% of importance.

Many QFD applications are preceded by AHP, as QFD needs a ranking of customer requirements based on which the prioritization of technical characteristics is calculated.

The "Product planning" phase, in the context of modern quality assurance, must also contain measures that deal with the detection and prevention of diverse potential failures and containing their effects. For this purpose, the application of the Failure Mode and Effects Analysis (FMEA) method proves its main benefit: faults that can be initially avoided don't need to be corrected later.

The application of FMEA can be divided into three instances: Design FMEA (used in the Product planning phase), Process FMEA (used in the Process planning phase) and System FMEA (used for the entire PLC). In all three cases the application is similar, the difference is that it is steered towards identifying the potential failures of a designed product, process or a system.

The correct deployment of FMEA involves 5 main stages:

- Planning and preparation – mainly consists of defining the objectives, assembling the team and appointing the leader that will conduct the application of the method;
- Risk analysis – potential defects are identified regarding product components or processes;
- Risk evaluation – for all identified potential defects the causes, effects and current controls are evaluated by rating the appearance probability, the estimated effects over the customer and the detection probability; these aspects are reflected in three indicators: occurrence (O), severity (S) and detectability (D), for which a scale from

0 to 10 is attributed; the product of the three indicators provide the Risk Priority Number (RPN);

- Risk minimization – within this stage improvement measures are proposed for faults that have a RPN greater than 125, as they are labeled as "critical to quality" and need interventions that lower this risk; furthermore, faults that have a severity greater than 8 indicate the possibility of affecting human life and demand preventive actions; the proposed improvement measures must guarantee that those faults for which are intended are avoided (lowered O), or at least the effects limited (lowered S);
- Checking improvements – the proposed improvement measures are reevaluated in the light of the three indicators and the RPN in recalculated with the new values; in case it is still above 125, additional actions have to be taken, until RPN<125.

By deploying FMEA, failures are identified starting with the design of the product and the "Failure correction" curve is moved to the conceptual phase, thus obtaining the "Failure prevention" curve. The main advantage of this effort is reflected in the quality costs, which are lowered exponentially (Carlson, 2012) (see Figure 9).

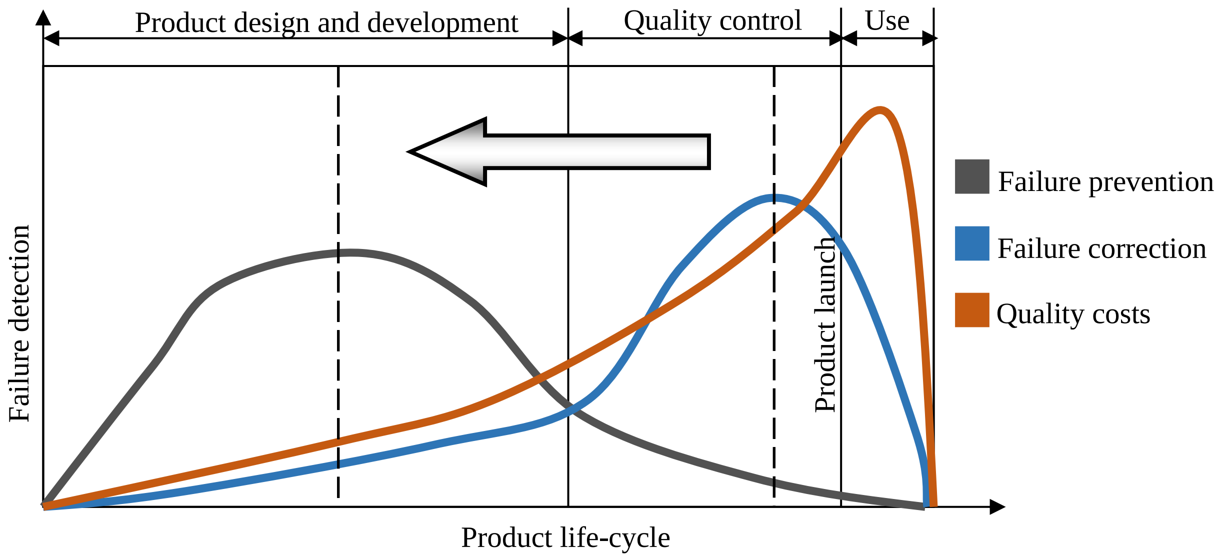


Figure 9. Failure detection using FMEA method
Adapted from (Carlson, 2012, p. 6)

When proposing solutions or improvement measures for identified faults or problems, just as in the case of FMEA there can be the case that multiple solutions will suite the same problem and only one can be selected that will respond in the best possible way to that defect. For such cases, the Pugh matrix offers a certain level of objectivization and helps equitably select the right solution. It is also referred to as the “Decision-matrix” and was invented by Stuart Pugh, who is also the creator of the Total Design methodology. It can also be used when multiple design solutions or embodiments exist for the same type of product and the best possible variant has to be chosen (Burge, 2009), (Thakker, Jarvis, Buggy, & Sahed, 2009).

The method consists in establishing a set of criteria and analyzing how that criteria is found within the proposed solutions, individually. A rating is given for each case and finally the cumulative score is calculated for each solution. The one with the highest score is considered to be the fittest solution.

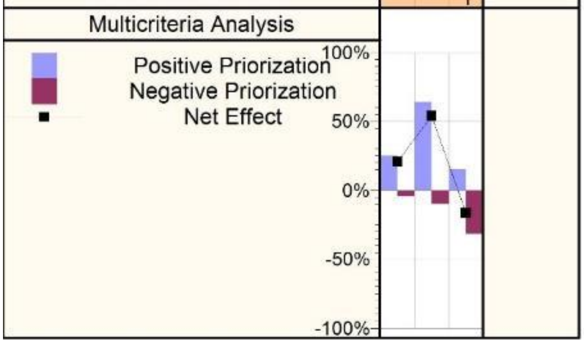
Depending on the application, the Pugh matrix can be used in various forms and adapted to numerous situations: the criteria can be hierarchized accompanied by their importance, but not necessarily; the evaluation of compliance with the criteria can be represented using scales or even symbols.

In the context of product planning and design the Decision-matrix’s widely used version is the following: the set of criteria are the customer requirements, accompanied by their importance expressed in percentages, through which proposed solution are evaluated according to their compliance with the set of needs. For this purpose, the following scale is used: -3 – strong negative compliance; -1 – weak negative compliance; 0 neutral compliance; +1 weak positive compliance; +3 strong positive compliance (Dragomir, Iamandi, Bodi, Gohla, & Chiran, 2014).

An example of Pugh matrix application is illustrated in Figure 10. Although the number of positive compliances and negative ones are the same for “Solution 2”, resulting in a net effect of 0 (for “Solution 1” is 2 and for “Solution 3” is 1), it is still the best solution considered, because it has two strong positive compliances with the two highest ranking criteria, which weighs a lot in the overall prioritization. This means, that the method doesn’t only calculate the difference between the number of positive and negative compliances, but also takes into consideration the importance of each individual criteria (which can be ranked with the AHP method) calculating a weighted average, thus increasing the accuracy for selecting a solution.

After the set of customer requirements are obtained and processed using previously mentioned techniques, CAD helps translate them into a design (Stark, 2001). The two main advantage pillars of this technology are that it helps reduce costs and shortens product development cycles, but others can be mentioned as well: because of the on-screen-display of the 3D model design flaws and errors are corrected immediately (design flaws and other errors can be easily spotted); although created in the product planning stage, the developed 3D model can be used throughout the product development phase for virtual testing, analysis or for other validatory actions.

Criteria / Proposed solutions	1 Solution 1	2 Solution 2	3 Solution 3	Importance
1 Criteria 1	+	O	-	15,6%
2 Criteria 2	O	++	+	33,7%
3 Criteria 3	++	-	+	4,9%
4 Criteria 4	+	++	--	26,4%
5 Criteria 5	+	-	O	18,5%
6 Criteria 6	--	++	O	3,7%
7 Criteria 7	-	--	++	2,1%
Positive Effects	4	3	3	
Negative Effects	2	3	2	
Neutral Effects	1	1	2	
Net Effect	2	0	1	
Positive Priorization	25,1%	63,8%	15,0%	
Negative Priorization	-4,4%	-9,9%	-31,6%	
Net Effect	20,7%	53,9%	-16,6%	



Criteria-Concepts-Matrix					
++	3	strong positive ...	--	-3	strong negative ...
+	1	some positive ...			
O	0	neutral			
-	-1	some negative ...			

Figure 10. Pugh Matrix example

On the other hand, to implement a CAD system needs a significant financial commitment at first, than employing traditional techniques, on the long run its benefits outweigh the disadvantages, providing a much faster and cheaper design. Furthermore, this way the customer can be included directly (see Virtual Customer Integration), and the actual 3D model can be done according to his specifications, on site and modifications can be made much more flexibly on the 3D model, than on a mock-up.

Implementing 3D annotation alongside the 3D model, the time needed for modifications and design flaws is even more reduced (Camba & Contero, 2014), in the benefit of shortening the duration for market launch and increasing competitive advantage.

According to (Bodein, Rose, & Caillaud, 2013), alongside 3D annotations, for introducing an "Integrated CAD Strategy" and "parametric design" the following steps are recommended: Standardization, Methodology, Generic modeling, Expert rules, Automation.

The 3D CAD model integrated with CAM and STEP-CNC-ready systems results in virtual manufacturing, which enables part manufacturing simulations to complete a fabrication cycle with the purpose of verifying errors that can appear in the process and eliminated down-times for increasing productivity (Xiao, Zheng, Huan, & Lei, 2015).

Table 3. Virtual solutions used within the "Product planning" phase

Software solutions for deploying quality tools (QFD, AHP, Pugh, FMEA, VoCT): Qualica Planning Suite, Rektron FMEA, PTC Windchill FMEA, Byteworx FMEA, Sigma Flow Modeler.
Virtual Customer Integration System
Computer Aided Design software

2.1.3. Procurement

According to ISO-IEC 15288:2008 (ISO standard which treats system life cycle processes), which includes also requirements specific to SR EN ISO 9001:2015 (ISO standard for QMS) and its previous versions, the following actions should be undertaken by the acquiring entity to assure that the acquired product/service "is within the acquirer's requirements":

- establishment of an acquisition strategy (can include information about how the actual procurement will take place, what are the requirements of the acquirer, the schedule for receiving the products and criteria upon which supplier(s) are selected);
- defining the requirements (and)
- communicating (the defined requirements) to identified supplier(s) (using communication systems that ensure the capability of accurately delivering/receiving exchange information and that are not vulnerable to outside threats);
- selecting the supplier(s) (based on established criteria and strategy);

- establishment of agreement with the supplier(s) / establishing acceptance criteria – in most cases it contains the AQL (Acceptable Quality Level) Standard for receiving / delivering the goods, to which both parties have consented; the AQL is an important statistic quality control tool, usually found in the Six Sigma approach, that helps companies weigh the added costs resulting from a more rigorous testing and consequently more product rejection due to a lower defect acceptance with the potential costs resulting from product recall. (Balamurali & Jun, 2007);
- product acceptance;
- payment.

The integration of digital technologies is also present in this phase of the PLC and created a new emerging concept called e-procurement. This enables an effectivization and efficientization of the entire procurement process making it cheaper and faster by bringing a certain level of automatization to it, but also incorporating all of the above-mentioned key aspects, formulated within the ISO standard.

According to (Yu, Yu, Itoga, & Lin, 2008) the main advantages of e-procurement are that it can reduce costs in excess of 5-10% ("it's a cost-cutting tool") and has the ability to increase efficiency of the acquisition process, thus reducing the cycle time and minimizing human errors. In addition to these the authors also found that:

- allows real-time offer proposal and acceptance;
- the selling / acquisition process is transparent;
- enhances competitiveness for companies by opening virtual distribution channels.

"With e-procurement the entire procurement process is handled online, so the company can decide to make the purchases of various types, from raw materials to services, using virtual B2B systems: these tools allow enterprises to reduce the cost and time of the procurement process, improve inventory and stocks management and, consequently, this is reflected in a decisive improvement in the management of all business processes" (Centobelli, Cerchione, Converso, & Murino, 2013).

These types of B2B solutions facilitate the interaction between acquirer and supplier, cutting out the intermediaries between the two parties, thus both saving time and resources. Moreover, these solutions enable the exchange of information for better cooperation (this evolved to e-collaboration) and they also increase the competitiveness of smaller enterprises.

When adding the "sourcing, conversion and all logistics management activities" (Hanne & Dornberger, 2017, p. 4) alongside the procurement process and taking into account all resources related to their functioning, the resulted complex structure becomes a Supply Chain Management system (SCM).

The authors of (Gunasekaran & Ngai, 2007) consider that the main objectives when implementing a SCM system are to reduce received defective products, the process cycle time and to enable better communication with suppliers / acquirers (flexible response throughout the supply-chain). In line with the Industrie 4.0 model, these are not sufficient and the “smartness” factor is added to them, thus forming Smart Supply Chain systems, which are capable of offering benefits such as real-time inventory monitoring, automated raw material order, purchase and approval and smart supplier selection & evaluation (Wu, Yue, Jin, & Yen, 2016). The architecture of a Smart Supply Chain is presented in Figure 11, which illustrates involved parties and the information flow between them.

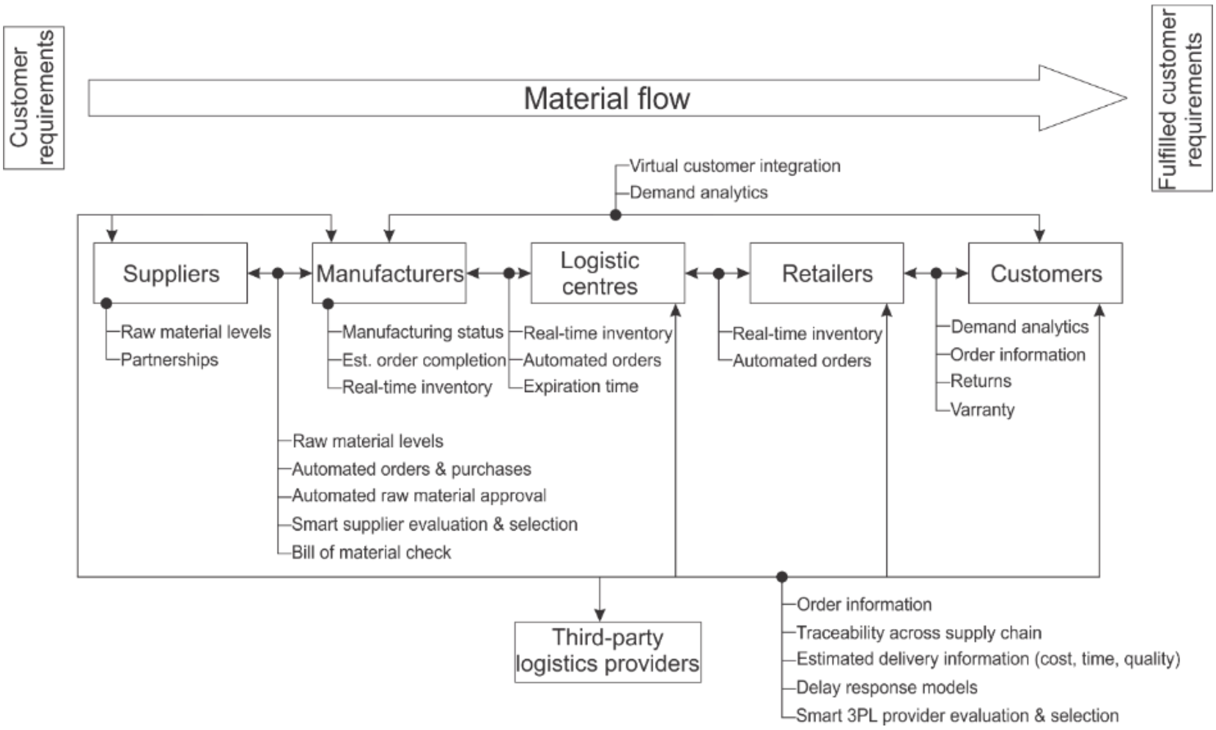


Figure 11. Smart, digitally assisted Supply Chain architecture

According to (Burnson, 2014) the most highly rated SCM software solutions on the market today are offered by: Fishbowl Inventory; QStrat QLM; Sourcing; U Route. The criteria through which he conducted his analysis are related to the platforms ability to: enhance business intelligence, inventory control and transportation management.

The importance of supplier / manufacturer / consumer networks brought together through virtual means should be mentioned as well because it adds to the competitive advantage:

communication within the network is faster and information exchange is basically in real-time, thus knowledge and best practices can be shared easily from one collaborating entity to another, creating benefits for both.

Table 4. Virtual solutions used within the "Procurement" phase

Smart Supply Chain Management System: e-procurement, e-logistics, e-auction, e-marketplace, e-payment;
Software solutions used for Supply Chain Management: QStrat QLM; Sourcing; U Route

2.1.4. Process planning

The process planning phase serves as an interface between design and manufacturing and is defined as "the activity that determines the specific technologies and operations required to manufacture a product" (Scallan, 2002).

There are two basic methods employed for process planning: manual process planning and computer-aided process planning (CAPP). The former comprises of traditional approaches and work-book approaches, and it is obvious that in the era of virtualization there are little or no longer in use. They are related to a number of limitations, having only one major advantage: it is very cheap.

CAPP systems, on the other hand, are the result of manufacturing companies' effort to automate this process so it can be more flexible in relation to changes coming from product design and production; it can be faster; it's not tied to personal experience; it increases the productivity of process planners; it is rationalized and standardized; it can be interconnected with other systems. Using CAPP in conjunction with CAD and CAM, a synergetic and integrated product development system can be obtained and CAPP serves as a direct connection between the two.

A CAPP can be deployed in two ways:

- using a variant approach, in which case an existing process plan is retried made for a similar product and it is adapted to suit the manufacturing of a new product. The plans are grouped according to part families which are made using a GT classification and coding system. This method is very conventional and it is easy to implement, however the variant approach can only be used if plans already been developed for previously manufactured part families.

- using the generative approach, through which a new CAPP is developed for every part. These types of plans are generated by computers using sophisticated analysis algorithms and they don't require human intervention.

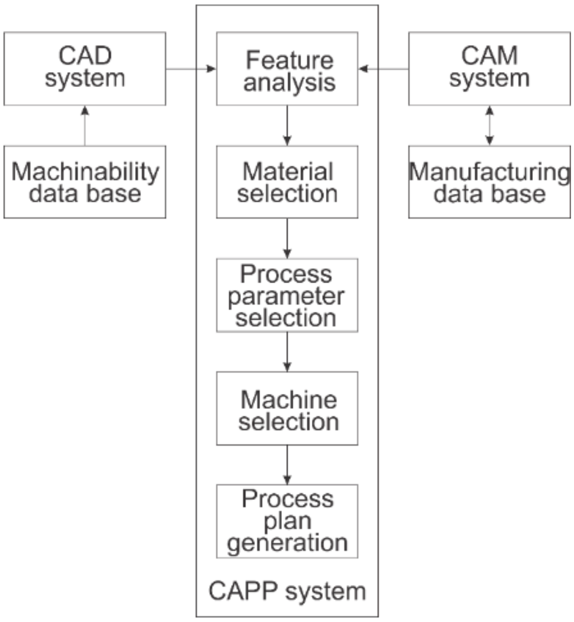


Figure 12. CAPP system model in synergy with CAD & CAM

Current trends concerning product and process development have come to rely heavily upon simulations and computer based instruments, as the complexity and required precision that must be delivered in the design stage have grown at an exponential rate (Codre, Popescu, Constantinescu, & Popescu, 2010) (Codre, Popescu, & Țifrea, 2011). For this reason, the use of process simulations with the scope of organizational improvement has stretched over from production engineering to other fields as well, such as healthcare, environmental sciences, chemical process control and even agriculture:

- Azari-Rad et al. focus on the perioperative process by diminishing the proportion of cancellations (Azari-Rad, Yontef, Aleman, & Urbach, 2014);
- Kidak and Aksarayli target bottlenecks and process speed for increasing overall productivity of a clinic (Kidak & Aksarayli, 2011);
- Robinson et al. describe the use of discrete event simulation for implementing lean management in the healthcare sector (Robinson, Radnor, Burgess, & Worthington, 2012);
- Antmann et al. propose a decision-making system in the field of waste management based on process simulations (Antmann, Shi, Celik, & Dai, 2013);

- van ’t Ooster et al. study labor intensive processes such as rose cultivation (van 't Ooster, 34-46);
- Ponsignon and Mönch address issues related to production planning in the field of semiconductor manufacturing (Ponsignon & Mönch, 2014).

As it is depicted in Figure 12, many software solutions available today, used for process planning and simulation employ the same methodology. Some even incorporate other quality tools, that can be used in conjunction with the simulations for maximizing their impact. Typically, a process represented within the simulation program is recognized as a “Work Center”, which, as a real process has variables like: resource input, time allocation, storage information, route in and route out rules and, most importantly, in a work center using the above-mentioned information is used for transforming / processing work items into a new form. They are capable of tracking the number of products, which are processed for each process individually, thus making forecasts about production capabilities.

When data generated from the real-life manufacturing cycle is analyzed and fed back into simulations, the best possible way of functioning can be obtained through optimization techniques, thus the resulted process models are highly robust, not only preventing potential failures or nonconformities, but also reaching efficiently established outcomes. In this respect, “Emulation for Logic Validation” or “Virtual commissioning” technology is also an important aspect, through which the functioning and behavior of physical hardware / equipment is simulated (Lee & Park, 2014), for minimizing correction efforts.

The use of these digital technologies and solutions, from the process planning and management point of view, can be emphasized by the following major benefits:

- A detailed understanding of all phases and activities, as well as the interactions between them with the scope of eliminating redundancies, avoiding bottlenecks and assuring a continuous workflow;
- The mathematical aspects of the modelled process simulations allow maximizing the deployment of human resources, thus increasing the performance of the organization;
- The possibility of tracking the progress of the product manufacturing, through its processes, with great detail, for being able to intervene and solve problem areas based solely on scientific data.

Table 5. Virtual solutions used within the “Process planning” phase

Computer Aided Process Planning

Process simulation software
“Emulation for Logic Validation” or “Virtual Commissioning”

2.1.5. Manufacturing

Continuing in the product life cycle, the process planning phase is followed by manufacturing. It has a very close relation with the product / process design because its functioning is highly dependent on these activities. A proper and well carried out product and process planning will be reflected in a smoothly running manufacturing cycle, increasing the organization’s performance. Figure 13 captures the interactions between all previously described PLC phases and depicts their influence on one another.

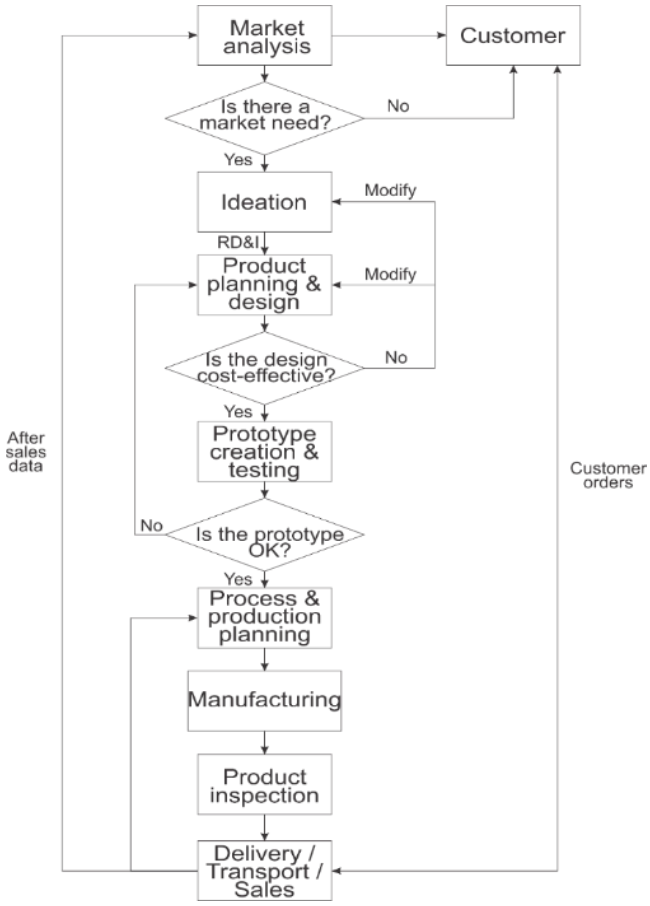


Figure 13. Interactions between the PLC stages

Adapted from (Scallan, 2002)

Although in previous phases the influence and use of digital / virtual instruments and techniques used to be more pronounced, the breakthrough of the IoT (key enabler of the 4th

industrial revolution) shifted this aspect by contributing to the creation of the Cyber-Physical Systems (CPS) (Baheti & Gill, 2011). These are networks that connect every physical object that comes in contact with the manufacturing cycle facilitating the exchange of information between them, thus increasing the level of autonomy, self-awareness and performance of the whole fabrication process. The information collected from this network are stored as “Big Data”, upon which real-time analyses are carried out and consequent actions are taken such as: “Automated smart maintenance” (machine / equipment information is analyzed for predicting and preventing potential failures related to their functioning), (Alexandru, et al., 2016) “Automated real-time process optimization” (calculating and implementing optimal process parameters for increasing efficiency) (D'Addona & Teti, 2013), “Automated process control” (automatically monitors process descriptors and, if discrepancies are detected, sends information to control mechanisms) (Oditis & Bicevskis, 2010) and others that drastically reduce disturbances within the manufacturing cycle.

Apart from CPS, there are a number of solutions employed for increasing production performances. One of these is the concept of “Virtual Cellular Manufacturing”, evolved from the classic “Cellular Manufacturing”. It integrates the lean manufacturing ideology with the “Group Technology” philosophy, which comprises in reducing the system to sub-systems, with reconfigurable manufacturing equipment, which work together to achieve greater efficiency. Among its advantages we can mention (Khilwani, Ulutas, Islier, & Tiwari, 2011) (Nomden, 2011):

- providing increased process flow and flexibility to machining areas;
- high degree of final product customization by processing groups of similar components by non-similar machines;
- classification of CAD modeled parts, which have similar shapes, into part families;
- high flexibility for changes in product requirements.

Developments were also made for digitally empowering operators. In this regard, the mentioning of “Remote equipment control and assistance” is due, that allows the provision of specialized expertise of highly trained personnel from an onshore central location to various offshore facilities in which complex intervention is required. By doing so operation resources (both human and financial) are reduced and time-to-intervention is shortened exponentially.

An article published in the Wall Street Journal (Tita, 2015) illustrates the practical uses of the Augmented reality technology and “Smart Glasses” on the factory floor and numerous benefits that they offer. Companies such as Daimler AG, Boeing and United Parcel Service Inc. said to have increased productivity by replacing printed manuals and instructions with media that helps clarify the steps that the operator needs to follow. Moreover, Daimler went as far as using this technology even for quality control, as they implemented a system in which a check-list is readily displayed on-screen for the operator to see and when a nonconformity is detected a "voice-recorded report" and a photograph is prepared on-situ, documenting that error.

Table 6. Virtual solutions used within the "Manufacturing" phase

Cyber-Physical Systems
Virtual Cellular Manufacturing
Remote equipment control and assistance
Augmented Reality technology
Computer Aided Manufacturing

2.1.6. Product inspection

According to the ISO 9000:2015 QM standard, quality control can be formulated as "part of quality management" comprising of procedures that demonstrate product compliance with "quality requirements" (ISO 9000:2015). The inspection of products is a key element of quality control that is takes place in all stages of the manufacturing cycle, thus ensuring that the work piece is qualitatively ready to move on to the next processing step. The purpose of these verification procedures is to eliminate faulty (non-conforming with requirements) workpieces from passing on to further fabrication stages, thus lowering the risks for a defective product reaching the customer.

Depending on the type of the product, there are various ways used for inspecting its quality, such as: electronic, electric or physical (mechanic) testing. However, in novel approaches the electro-optic (laser-based) inspection systems and machine vision play a key role, because not only these types of systems are more reliable and faster than other inspection methods, but the sample sizes can also be increased, without adding significant extra costs (Molleda, Usamentiaga, & García, 2013), (Shen, Li, Gu, & Chang, 2012), (Liu & Yu, 2014).

Although it is called "Product Inspection", the monitoring and measurement actions relate not only to products (which are outputs of processes), but also to the processes themselves. Making reference to the (ISO 9001:2015) standard requirements the processes functioning within the organization have to be capable for obtaining the planned results. One way of making sure that processes function within established parameters is the use of Statistical Process Control (SPC). SPC is defined by (Oakland, 2015) as "a tool that measures and achieves quality control, providing managers from a wide range of industries with the ability to take appropriate actions for business success." The use of this method also allows detection of abnormal variation, thus providing the possibility to take action even before that variation is out of tolerance or breaks trend rules, such as the 8 Nelson rules formulated by (Nelson, 1989).

SPC relies heavily on interpreting collected process data, which, in the context of CPS and "Big Data", there is in no shortage and with the help of dedicated digital solutions real-time decisions can be made. This led to the development of the "Real-time SPC" (Costantino, Di Gravio, Shaban, & Tronci, 2015), (Urban & Landryová, 2015) and the concept of "Inline Metrology" (or "Inline Monitoring"), which unlike the traditional, offline approach that measures values only at the end of the production process, this one establishes short control loops throughout the fabrication cycle for "evaluating measured data close to each process step" (Schmitt & Moenning, 2006). Basically, from the measured / collected values information is obtained about the process' functioning and its control is done accordingly. They function under an "Integrated Factory Information System" that uses local servers for storing and analyzing data.

However, even these types of approaches are starting to become obsolete. "The Cloud" eliminates the use of local servers and dedicated software solutions and replaces it with online data storage and analysis capabilities, also referred to as "Cloud Computing": "a powerful technology to perform massive-scale and complex computing" by eliminating "the need to maintain expensive computing hardware, dedicated space, and software. Massive growth in the scale of data or big data generated through cloud computing has been observed." (Hashem, et al., 2015).

The last couple of years an even newer trend started being associated with "The cloud", called "Edge Computing". The idea behind this approach was to increase even more the efficiency of "The cloud" by migrating some data analysis to the "edge" of the network, where, the actual source of the data is (Shi, Cao, Zhang, Li, & Xu, 2016). Traditional sensors designated with collecting data from processes were replaced by semi-smart sensors, which are capable, to a certain degree, of deciding what data is or isn't relevant to be relayed to "The cloud". By doing so, the computations carried out within the cloud were reduced to only essential ones.

Among other digital support instruments, related to inspection of products and monitoring processes, the increased use of mobile device applications and smart wearables can also be mentioned. A survey conducted by (Hughes, 2016) found that devices such as tablets, mobile phones, smart glasses, wearable bar code scanners and other devices using Bluetooth technology are being used on the factory floor for various inspection-type purposes and displaying process related data.

Table 7. Virtual solutions used within the “Product inspection” phase

Machine Vision systems
Real-time SPC systems
“Inline Metrology” or “Inline Monitoring”
Cloud computing
Edge computing
AR technology and smart wearables

2.2. Utilization

2.2.1. Delivery / Transport

Current logistics trends list the delivery of products from manufacturers to customers as an outsourced activity for reasons such as reducing costs and obtain better customer services. Enter the third-party logistics concept, referred to as 3PL. According to (Jiang, Wang, & Yan, 2014) "the 3PL provider is an external provider who manages, controls and delivers logistics services on the behalf of a shipper", being an integral part of the supply chain.

From the quality perspective, the logistic service, as formulated by (Shapiro & Heskett, 1985) still available today, must have "the ability to deliver the right product in the right amount at the right place at the right time for the right customer in the right condition at the right price". For these reasons, partnerships between companies and 3PL providers should be created regarding the following aspects (Salvendy, 2001), (Yan, Chaudhry, & Chaudhry, 2003), (Büyüközkan, Feyzioğlu, & Nebol, 2008):

- using the resources and infrastructure provided by the 3PL for reducing the companies' own operations regarding the shipment of products;
- increasing the efficiency of the delivery process through the 3PL providers' "professional capability and agility";
- reducing the financial commitment (investments dedicated strictly for logistic purposes) by the company for the delivery process;
- increasing competitive advantage (the competitive advantage of a company can be influenced by its strategic alliance with its 3PL).

Novel approaches, in the light of "Industrie 4.0", corresponding both to classic retail and to the ever growing e-retail, propose for the management of all logistic activities the "Smart Supply Chain Management System" (see Figure 11 for detailed architecture and information flow between involved parties), which is able of taking on not only a company's delivery operations, but also its procurement process, inventory monitoring and evaluation & selection of suppliers / partners.

The increased efficiency of this system lies in its network-type approach, thus being able of analyzing, adapting and disposing measures (automatically) based on data collected from the entire value chain. The authors of (Hanne & Dornberger, 2017) argue that computational intelligence methods employed for data processing within the "smarter" virtual supply chains are “Fuzzy logic”, “Evolutionary algorithms”, “Swarm intelligence”, “Neural networks” and “Artificial immune system”, thus solving various transportation problems.

Table 8. Virtual solutions used within the “Delivery / Transport” phase

Smart Supply Chain System with 3PL
Data processing algorithms for optimized transport: “Fuzzy logic”, “Evolutionary algorithms”, “Swarm intelligence”, “Neural networks” and “Artificial immune system”

2.2.2. Use

The entire PLC management is customer-centered, each stage is intended in such a way that ensures the possibility for maximum compliance with specified requirements, so it is considered to be natural that emotions and feelings generated by the interactions between the end product and customer determine the quality. The authors of (Tsao & Chan, 2011) divided these interactions into two categories, positive and negative one, associating the former with a higher quality perceived by the costumers. The “user-friendliness” and “intuitiveness” (in many cases considered as intrinsic requirements) play also a key role, which have to be given much thought in the design of the product, however they can’t be accurately determined, until the utilization stage of the PLC. For these reasons feedback and information obtained from the customers after product use is highly important. Moreover, (Abramovici & Lindner, Knowledge-based decision support for the improvement of standard products, 2013), (Abramovici & Lindner, 2011) argue that feedback should be the source of improvement for “existing mass-produced standard products”.

According to (Wellsandt, Hribernik, & Thoben, 2014) the majority of tools and techniques employed for obtaining information related to product use are subjective, newly developed ones, such as “product-embedded sensors” prove to be more objective, because they function “unobtrusively and therefore facilitate authentic user behavior”. Not disregarding user privacy, collected data can be further processed and integrated into the design of future products. They also proposed a set of eight techniques for collecting use information, which were rated according to established criteria and offered a qualitative evaluation of them. Their findings prove that “product-embedded sensors” are highly compatible with the “Industrie 4.0” model.

Another aspect for increasing the perceived quality of products are the customer support facilities. Within current trends the “Internet based customer communication support” can be listed here, which includes applied instruments such as:

- Knowledge base used for problem solving for known issues – consists in the use of a knowledge data base in which previously encountered problems and corresponding solutions were stored (Rowe, 2013);
- Remote access for diagnostics and trouble ticket resolution – in the case of software products trouble encountered by the customer can be easily, cost efficiently and rapidly resolved by remotely connecting with his machine (Bomgar, 2017);
- Frequently asked Questions (FAQ) page used for fault / defect identification and self-help – this type of online web page can help users to identify the defect that their product has and appropriate measures can be put to their disposal to fix the issue (Braveen, 2016);
- Automated online assistant (AOA) or “chatbots” used for tech support through live chat – this automated assistant functions similarly as the knowledge base: within certain issues described by the customer (through online chat messages) identifies keywords can provides potential solutions for problems associated with these keywords (Descoins, 2015), (Per, 2016).

Table 9. Virtual solutions used within the “Use” phase

Product-embedded sensors
Knowledge base used for problem solving for known issues
Remote access for diagnostics and trouble ticket resolution
Frequently asked Questions (FAQ) web page
Automated online assistant or “chatbots”

2.3. Disposal

2.3.1. Dismantling, sorting, reusing & recycling

The gradual depletion of material resources and environmental concerns have generated another aspect regarding PLC: the reuse / recycle of constitutive "ingredients" of end-of-life products. In this direction, the constant interest towards sustainable development for both companies and customers alike, created the concept of "Closed-loop production system", which "reintegrates components and/or materials from the end-of-life products as input flows to produce new products" (Jurascheka, Cerdasa, Posselta, & Herrmanna, 2017), (Winkler, 2011).

The design and management of "Closed-loop production systems" is done with the help of "Sustainable supply chain networks", which brings sustainability for future manufacturing into the equation of the value chain (Carter & Rogers, 2008) (Seuring, 2013).

The authors of (Jurascheka, Cerdasa, Posselta, & Herrmanna, 2017) argue that the 3D printing technology opens new possibilities in this stage of PLC. As in this case the raw material is the same for all products (but differentiated depending on the functioning principle of 3D printing machines): plastic filament, polymeric resins or polyamide powders, the dismantling of end-of-life products results in new raw materials, "substituting virgin materials", that can easily be reused for the fabrication of new products, thus closing the loop.

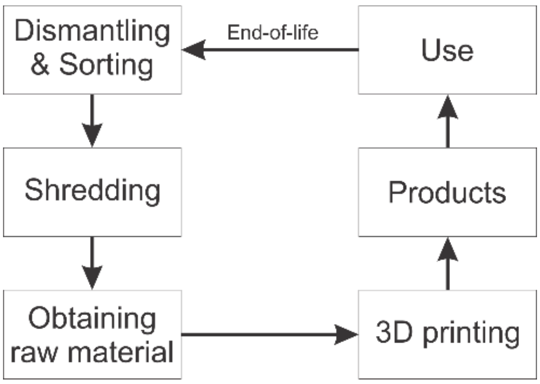


Figure 14. Closed-loop production system
Adapted from (Jurascheka, Cerdasa, Posselta, & Herrmanna, 2017)

From the customer's perspective, the recycling of used products requires some minimal effort or implication on his behalf: to properly dispose of products, specified by manufacturer or waste management organizations. Online platforms known as "Recycling assistance platforms" (European Recycling Platform, 2013) raise awareness among consumers and provide information for them regarding national / regional regulations, waste collection points, recyclable materials and products and they even bridge the gap between customers (who in this case turn to suppliers) and manufacturers who are in need for recycled raw materials.

Table 10. Virtual solutions used within the "Dismantling, sorting, reusing & recycling"

Closed-loop production system
Recycling assistance platforms

3. Virtual Quality Management (vQM)

The expansion of applications in the virtual domain opened new horizons also in the case of Quality Management, which evolved alongside the trends from modern industry. A new concept was, thus born called “Virtual Quality Management” (vQM).

“The concept of vQM is based on, but not limited to simulation studies, which are efficiently deployed for the sole purpose of generating resilient knowledge and dimensioning quality techniques that can be applied either to products or processes, before they physically exist. By doing so, products and processes reach a certain level of maturity in the planning stage, so they can be introduced straight into production, having an increased level of performance compared to ones developed using conventional methods” (Bodi, Popescu, Drăgeanu, & Popescu, 2015).

As identified from several references approaching the virtual area of quality management in manufacturing, simulation also plays an important role for vQM in developing models capable to foresee, adapt to and optimize different scenarios by analyzing existing data (Mertins, Rabe, & Gocev, 2008), to increase efficiency and implement sustainable development (Heilala & et, 2008) or even to reproduce measurement uncertainty due to temperature, humidity or other external influences (Bookjans & Weckenmann, 2010). Moreover, the approach proposed by (Stockinger, Wittmann, Martinek, Meerkamm, & Wartzack, 2010), regarding stochastic simulations for tolerance analysis “contributes to the improvement of virtual quality assessment”, which in this case, takes place already in the design stage of a product’s life cycle.

The combination between “simulation” and “virtual reality” allows operators to interact virtually with the fabrication process (Mujber, Szecsi, & Hashmi, 2004), which in term enables virtual control and even virtual inspection of the manufacturing flow (Bowman & McMahan, 2007). Immersive virtual reality applications can also be used efficiently in problem-solving activities, as demonstrated by Ferdinando Milella in (Milella, 2015). The use of “augmented reality” solutions also offers numerous advantages in quality management, such as the cases of Daimler AG, Boeing and United Parcel Service Inc., (Tita, 2015) presented in the Manufacturing phase of the PLC.

The nature of vQM is highly innovative as it is capable to provide the necessary information for deploying quality management techniques before the actual start of the manufacturing processes (Bookjans & Weckenmann, 2010). Quality and process parameters are obtained with the help of advanced modeling and simulation tools, all contributing to the process design of a manufacturing system.

Another important side of vQM is communication. The development of virtual channels (supported by the internet) brought several advantages in this field, such as improving the way we interact with each other (Sousa & Voss, 2006) or even with machines (Descoins, 2015), (Per, 2016). They also increased the speed of information transfer, narrowed the gap between supplier and customer and enabled product developers to provide their contributions remotely by forming "virtual teams" (Lipnack & Stamps, 2000), (Kalantari, Kalantari, & Maleki, 2011), (Leland, 2011), (Nettleton, 2014).

The architecture of vQM, presented in Figure 15 illustrates the above stated particularities and captures its essence.

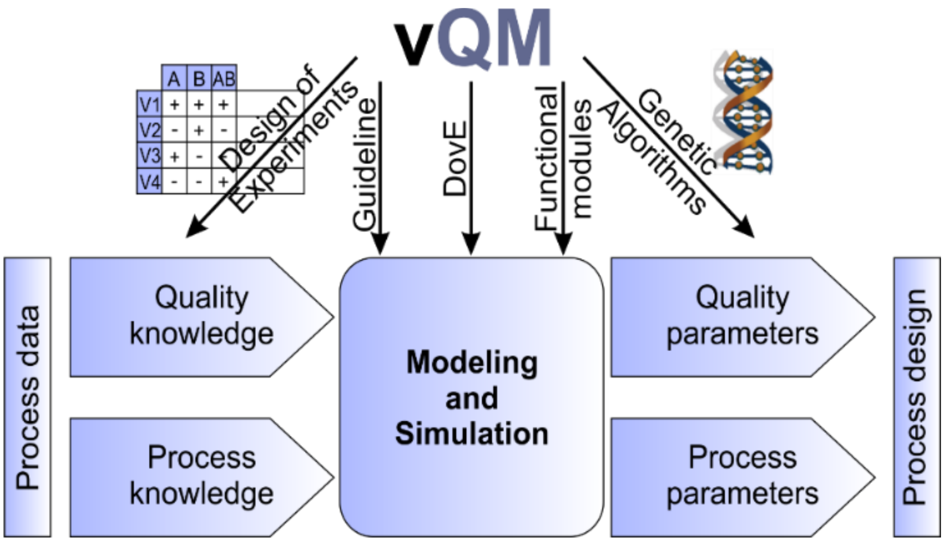


Figure 15. Architecture of vQM

Adapted from (Bookjans & Weckenmann, 2011, p. 17)

As a whole, vQM can be viewed as the successor of the more mature concept "Quality Management" (QM) as they both function similarly. The difference is that vQM was "upgraded" and improved with state of the art tools and techniques (simulation, optimization, reality augmentation) for bringing solutions to modern times, where QM might perform deficiently.

"The main advantage of this concept is that by increasing the accuracy of the process models there will be no surprises when implementing them into production. This way highly precise resource allocation can be made, which in term reduces overall costs." (Bodi, Popescu, Drăgeanu, & Popescu, 2015)

Although the nature of the concept is quite clear, it is yet to be found the impact vQM has on current manufacturing systems and quality management related concepts and how it interacts with them. For this reason, the research endeavor approached in the next chapter is to disambiguate the concept of vQM and verify how it relates to the Industrie 4.0 model. This is done by means of Natural Language Processing, specifically using Latent Semantic Analysis for this undertaking. The reason behind this is that the clarification process should begin right at the semantic value of the vQM expression, by analyzing it in the already used or possible contexts, put forth by the specialty literature of the latest years.

PART II

RESEARCH AND CONTRIBUTIONS

Chapter 3. Conceptual and theoretical developments for vQM

1. vQM concept disambiguation and identification of its emerging directions using natural language processing techniques

1.1. General and conceptual aspects

There is a strong discussion among specialists about the current high rate of increase in human knowledge. According to (Schilling, 2013) the knowledge doubling rate, average across different scientific domains, is approximately 13 months. When considering individual fields, the knowledge doubling rate slightly differs, however, in every case, it grows in an exponential fashion. The author of (Schmitt U. , 2014) associates this phenomenon with the Fourth Industrial Revolution and the emergence of the “Internet of Things” and “Big Data”; however, the increasing computational capacity and connectivity of computers could be mentioned as facilitators. Various approaches have been proposed to structure and extract essential knowledge from large amounts of information, such as the document visualization method proposed by (Alvarez & Hidalgo, 2009) or the ontology based frameworks presented in (Panov, Soldatova, & Džeroski, 2014) and in (Roos, et al., 2009).

Often, this high dynamic in research, especially in interdisciplinary fields, brings the need to express new specific contents, meanings or trends under a linguistic form. In this way, new syntagmas or concepts are brought to light and adopted by professionals as part of the specific jargon in the field. Even if their creators endowed them with a clear meaning at an incipient stage, when they become more popular in an emerging area, these concepts are quickly surrounded by a large amount of new knowledge that is developed with an amazing speed, enriching and enlarging their initial sphere.

The “virtual Quality Management” (vQM) concept could be a significant example for the circumstances described previously. It is born through a semantic operation, joining two established and mature concepts: “Virtual” and “QM”, thus it is representative for an area which is in a high dynamic development.

In this context in which the amount of information relating to new concepts quickly reaches unmanageable levels, regardless of the field, solutions that can analyze extended documentation with the purpose of disambiguating information and capturing the essentials, thus creating knowledge, become the focus of attention and gain in importance.

Traditional solutions for that purpose lay in the literature review process, trying to collect, select, filter and structure the existing and relevant information in a synthetic way. However, this solution has limits: on one hand, the large amounts of data can lead to a decrease in the ability of a research team to handle that information and on the other, the selection and interpretation of the chosen references is exposed to strong subjectivity.

Natural Language Processing, a field of computational linguistics, can be considered as a possible alternative for the above stated issues making users capable to go through large amounts of information, fast, retaining only important data. It deals with translating human language to computers enabling them to summarize and essentialize inputted information from an unlimited number of references. The computer programs deployed for this task use various algorithms, each with their own advantages and disadvantages. Among these we can mention *Reification*, *Bag-of-words model* or *Latent Semantic Analysis (LSA)*.

Latent Semantic Analysis (LSA) is based on the idea that words having the same meaning are occurring in similar passages of text (Maletic & Valluri, 1999). LSA uses Single Value Decomposition (SVD), which is a mathematical tool that allows the reduction of matrix rows, without seriously compromising the structure of columns. In the case of LSA the matrix rows m (constructed out of the body of text) are the individual word types and the columns n represent the meaning of that word encoded into sentences and paragraphs. The cells that result contain information about the reoccurrence of a word in a paragraph (Babar & Patil, 2015).

According to the authors of (Badry, Eldin, & Elzanfally, 2013) there are three main phases of LSA:

- Input matrix creation ($A = m \times n$).
- *Singular Value Decomposition* carried out using the formula $M = A\ \Sigma\ V^T$, where Σ and V^T are $n \times n$ type matrixes that represent the scaling values and the original columns of extracted values in the form of vectors, respectively.
- *Sentence Selection* in which the "most characteristic parts of text" are selected to illustrate ideas that are essential in the body of text. It must be mentioned that the resulting sentences will not constitute the summary, but only provide main ideas that can be the base of a rewritten summary.

LSA is mainly carried out with the help of software programs, as it is almost impossible to manually complete the necessary calculations. Apart from the main phases described above, additional steps should be taken to assure proper deployment and to minimize errors.

Firstly, for simplification purposes a so called “propositional hashing” is complete, which consists of a punctuation analysis. In this way, the text is split into simple sentences, which are easier to handle and the reliability of the results is increased.

Secondly, an ambiguity solving should be completed, from the grammatical and semantic perspective: alongside the words’ syntactic value it also has to be determined their signification and meaning. A word that has the same form and it is written in the same way it could be a noun, a verb or even an adjective, or it could mean two completely different things. The ambiguity solving process tries to avoid such errors.

Thirdly, the identification of classes is intended to group related nouns together, if they are close in meaning.

A convenient aspect of LSA is that only the so called “most characteristic parts of text” (Badry, Eldin, & Elzanfally, 2013) are selected from the text that capture the essence of the analyzed documentation. This information is later processed by software programs that offer intuitive graphic output, facilitating knowledge structuring and identifying the main linguistic and logical links that arise around a new concept in the literature of the field. However, despite the automatic processing of information, a certain subjectivity is persisting which is due to the logic of the users regarding the selection of inputted information and the criteria of final processing of the results.

1.2. Illustrative example

The research endeavor approached in this chapter is focused, firstly, on analyzing the knowledge density zone obtained by intersecting two knowledge structures, represented here by the vQM and Industrie 4.0 axis (Figure 16), throughout the Product Life Cycle (PLC) stages.

Secondly, in addition to concept disambiguation, it aims to identify and hierarchize industrial applications (or new technological solutions) that are expected to emerge.

Finally, a validation of the proposed methodology is intended through an online survey (see Annex 1 for the design of the questionnaire).

The intended added value of this knowledge discovery process can be summed up as follows: *determining the current and emerging practical Industrie 4.0 applications related to Virtual Quality Management throughout the entire Product Life Cycle stages.*

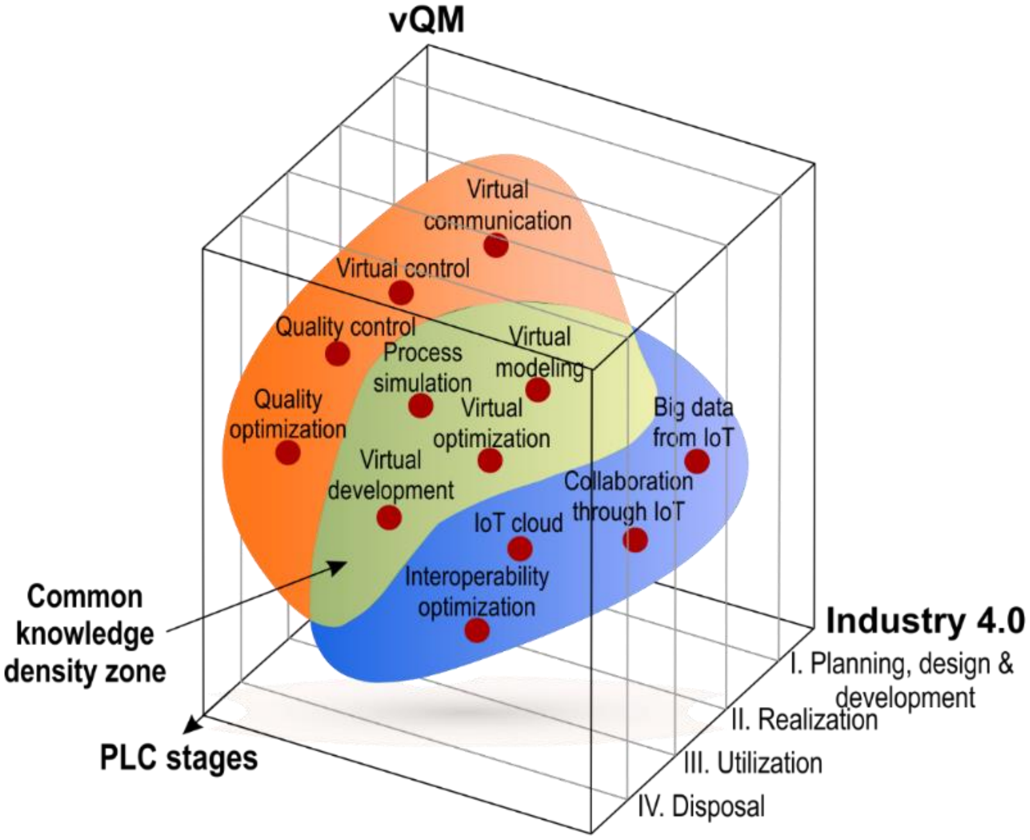


Figure 16. Knowledge density zone between vQM and Industrie 4.0 along the PLC stages

Contributing to the achievement of this endeavor the following stages were established:

- In the first stage an identification of relevant papers and scientific references is carried out for each of the two main concepts individually: vQM and Industrie 4.0. After that, a filtration process is performed for limiting as much as possible the amount of irrelevant information. The ontology charts, similar in nature as two knowledge structures, both for vQM and Industrie 4.0, are determined by applying LSA (using a dedicated software program) on the final sets of bibliographic references.
- The second stage is reserved for weighting notions that are in relation with the main concepts. Based on the ontology charts and other information provided by the software each notion relating to vQM and Industrie 4.0 was ranked by calculating their CN – correlation number. Next, associations were made between them with the scope of obtaining syntagmas (descriptors) that characterize the two main concepts. A score was also calculated for each of them signifying their importance to both concepts.

- The third stage begins with extracting the common meaningful descriptors between the two main concepts. Based on these expressions, applications are identified using search engines. This way the focus is kept only on those applications that are in close reference to vQM and Industrie 4.0.
- The fourth stage, firstly, is focused on identifying the product life cycle stages and secondly, on the construction and completion of the matrix diagram. It has as inputs on the left the product life cycle stages together with identified applications and above the common descriptors between vQM and Industrie 4.0 (associated by their weighted importance). It illustrates not only the hierarchy of the main categories of applications throughout the product life cycle stages, but also the rank of every sub-category application within the main categories.
- Within the fifth stage an online questionnaire was applied for checking results obtained from the matrix diagram against an average rating coming from experts from Romania's automotive industry.

The research methodology is summarized in the following figure showing also inputs and outputs for all its phases in the form of an extended flowchart:

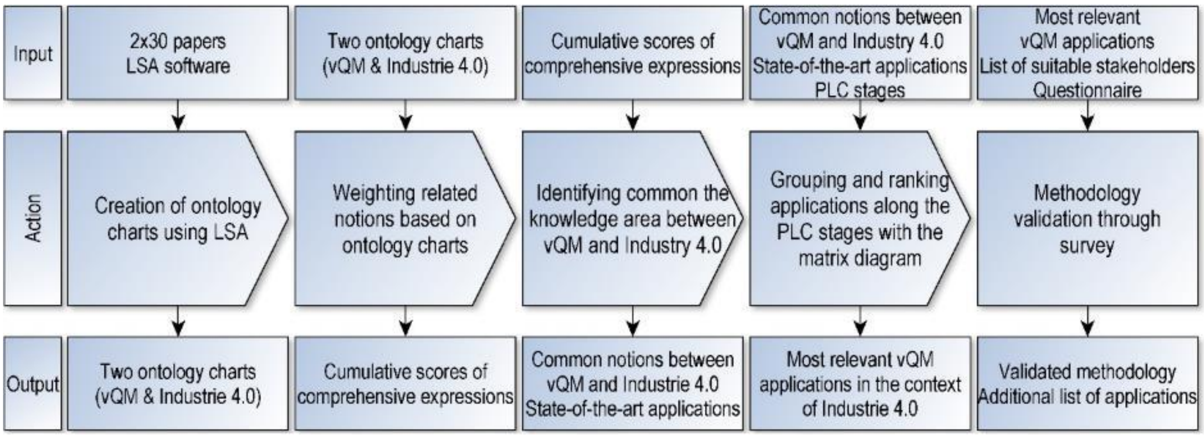


Figure 17. Methodology for concept disambiguation

1.2.1. Creation of ontology charts using latent semantic analysis

a) Identifying and filtering the documentation

The input selection in the case of the two main concepts was made in the same way. Mostly, the authors focused on gathering references with the help of search engines that have access to large databases of scientific research (Elsevier's Scopus, Elsevier's Science Direct and

Google Scholar). However, if additional documents were found with the help of traditional search engines (like Google or Yahoo) they were not disregarded, but retained only if they were considered to be relevant after the first filtration process. This type of documentation was manually converted to a format supported by the LSA software (typically .pdf or .txt).

As search engines work with keywords, the challenge was to determine those words that accurately represent the studied concepts. In the first instance the search was limited to identifying references in relation with the name of the concept, then it was extended to include certain keywords obtained from the top ten most cited scientific papers. These were restricted to six at the most for avoiding the display of insignificant documentation. The timeframe was also preset to the last 7 years for limiting outdated information. It is considered that documentation outside this framework can't accurately capture state of the art advancements in the studied fields. After a brief revision (the focus was kept on the abstract of the paper, but not limited to it) of displayed papers, a total number of 35 references were considered to be sufficient for illustration purposes for each main concept. They were downloaded and saved in separate folders. The brief review was chosen instead of an extensive literature browsing due to two reasons: the latter one would not serve to the proposed objective, which is quick identification of trending elements and concepts from a specific field of interest (meaning it is much more time consuming); and secondly, there are no guarantees that by reading the paper entirely it can be used in the semantic analysis, so there is the chance that after the review it will be disregarded.

Making sure that every selected paper is indeed relevant for the analysis, the methodology includes an additional filtration process. Each key word (mentioned above) is analyzed from its distribution perspective, throughout all the 35 papers. If the maximum number out of all keyword frequencies for each paper is not greater than 5, the paper is considered to be irrelevant and it is removed from the analysis folder, where all are saved in the convened format. For this, the following condition has to be fulfilled:

$\max_i(x_i) \leq 5$, where x represents the frequency of the i keyword (i={1,8})

For illustration purposes, the following figure contains the frequency of mentioned keywords in a certain paper:

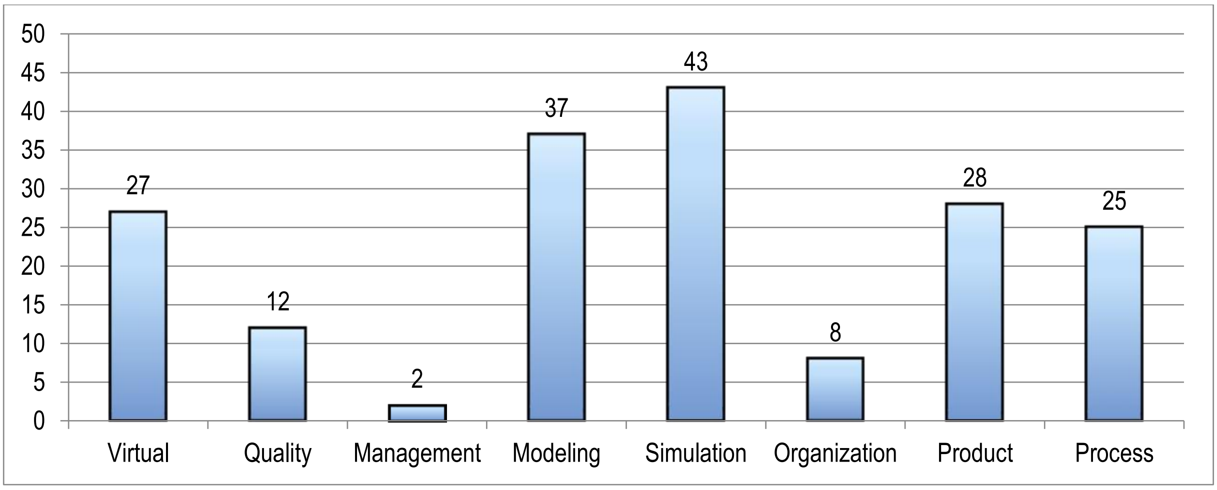


Figure 18. Occurrence of keywords in one identified paper

The above figure contains the occurrence number of each keyword for one of the 35 papers. As it can be seen, the keywords “management” and “organization” are the two least frequent ones. Although “management” appears only two times it is not sufficient to consider this paper irrelevant; for a certain scientific reference to be entirely removed from the analysis it must be scarce in all key words (their maximum must be lower than or equal to 5). It can happen that a certain paper is scarce in one key word, but rich in others; in this case the paper is taken into account, as it is the case of this example. After this final filtration process a set of 30 papers remained, which were subject to the LSA.

The semantic analysis was carried out using a software program called Tropes v8.4 (English version) capable of processing and perceiving, to a certain level, relationships between words, identifying or disregarding words specific to a domain of interest (based on input settings), counting the reoccurrence of words within different contexts and retrieving neighboring concepts for certain notions or words.

b) Defining the ontology charts

As a direct result of the semantic analysis an ontology chart of vQM was obtained and is presented in the following figure:

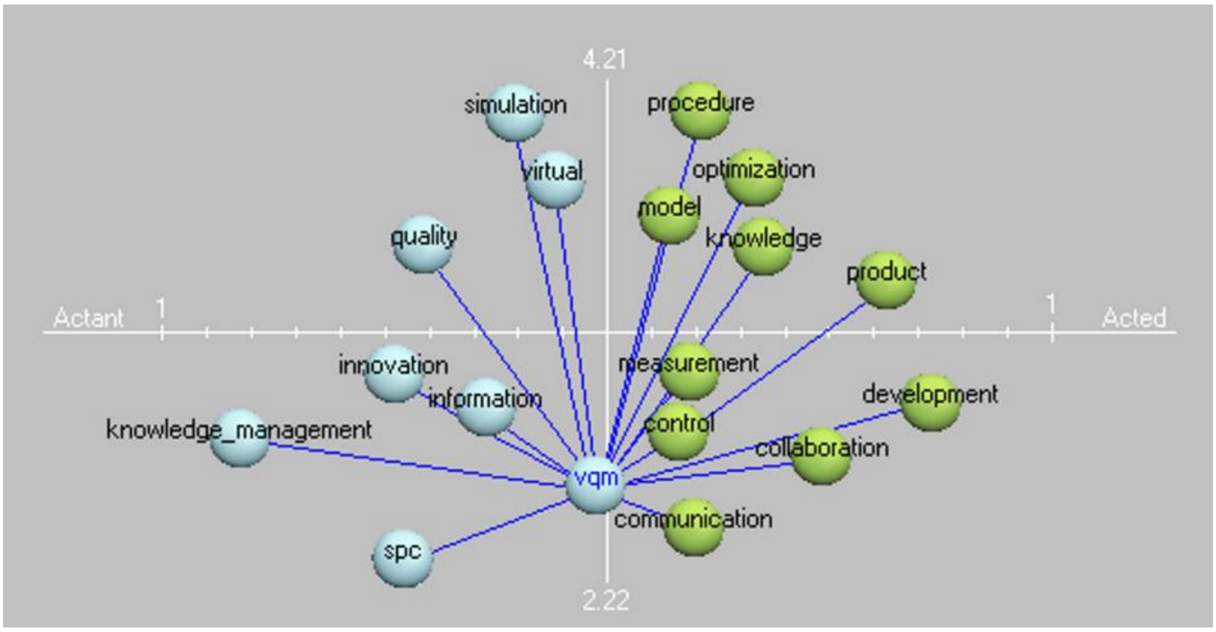


Figure 19. vQM ontology chart

The vQM ontology chart (Figure 19) contains notions that are strongly related to quality management (measurement, control, quality, innovation, SPC), some make references to instruments deployed through virtual means (such as simulation, modeling and optimization) and introduces "communication" and "collaboration" as notions linked with vQM (although having a low frequency, in sentences they are used closely together with vQM).

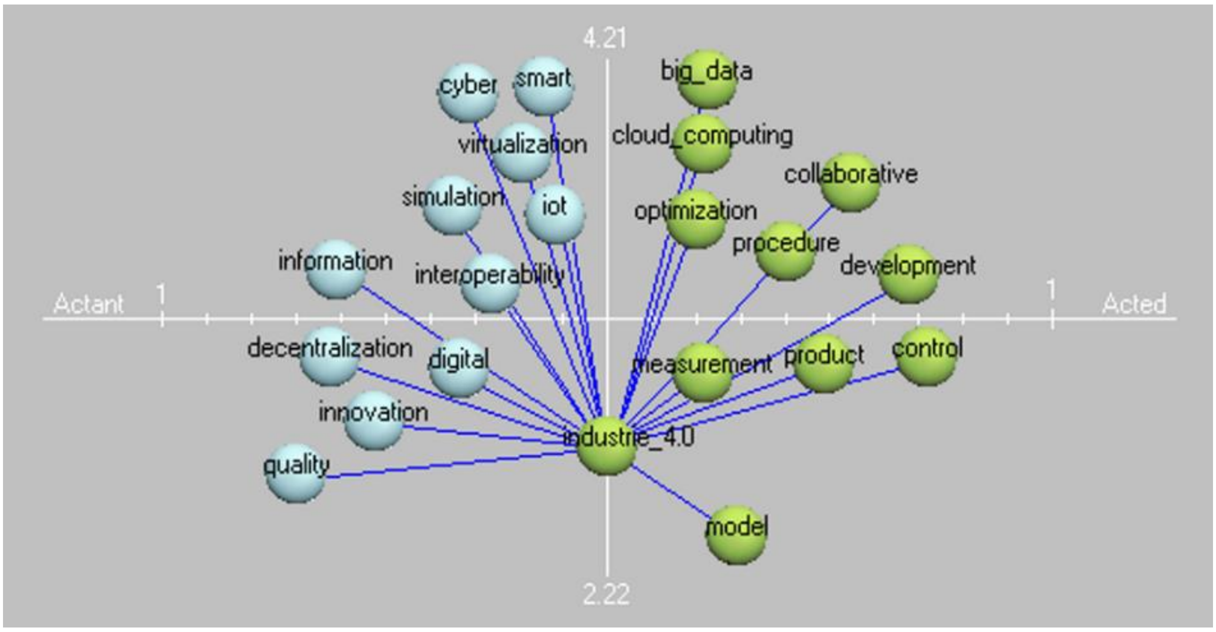


Figure 20. Industrie 4.0 ontology chart

For Industrie 4.0 appear a lot more related notions on the ontology chart than in the case of vQM, which can be explained by the fact that although the two concepts are considered to be relatively new, Industrie 4.0 is more developed and established in the scientific community as it is promoted to be the next generation of production engineering. Also, the known information on this subject reached a more mature level due to higher number of publications.

The related notions in this chart include the main pillars of Industrie 4.0, such as IoT (Internet of Things), cyber (making reference to Cyber Physical Systems), Big Data and Cloud Computing; some design principles of Industrie 4.0 as stated in the reference document (Forshungsunion; Acatech, 2013) (interoperability, decentralization, virtualization) and some notions which are also common to vQM.

The correlation degree of each current notion (denominated k) with regards to the main concept is reflected in its position on the chart. The position can be expressed as a function of the causal relation (the X axis) and the concentration of relations – or frequency of association (the Y axis) (Tropes US, 2014). Thus, the graph supports a visual comparison of the weight of relations between all concepts present on the chart with the main one.

On the X axis, the number of words separating one concept from another in sentences can be considered as a direct reference for establishing their causal relation. Taking this into account, for quantifying the causal relation for both the “actant” (predecessor, enabler or source) and “acted” (successor, consequence or attribute) concepts, a scale from 0 to 1 was attributed from the center to both ends of the chart. As a certain k notion is further apart (closer to the value 1) on the chart from the main concept it means that in sentences a significant number of words are placed between them. This value, called the Causal Relationship Value (CRV) takes values from 0 to 1:

$$CRV_k = [0 \dots 1]$$

On the Y axis, a fraction is represented between the total number of relations (or association) that each k concept has with the main one and the number of different relations. This value is called the Concentration Value or CV. The chart shows the minimum (bottom) and maximum (top) values, as they were calculated by the software program used to complete the semantic analysis. The formula for expressing the CV_k is:

$$CV_k = \frac{A}{A - B_k}$$

where A is the total number of relations and B_k is the number of relations that each concept has with the main one.

1.2.2. Weighting related notions based on ontology charts

As a consequence of attributing the two scales for the “actant” and “acted” concepts their strength of the causal relation with the main concept is inversely proportional.

The CV and the inverse of CRV having completely different calculation rules but comparable in terms of magnitude, a correlation number (CN), obtained by the product of the two, was considered to be significant for expressing the importance of each concept in relation with the main one. The formula used for determining the CN is presented as follows:

$$CN_k = CV_k \times \frac{1}{CRV_k}$$

The CN of each notion from the ontology chart is centralized in the following table starting from the highest and descending to the lowest:

Table 11. Correlation number of “actant” and “acted” notions regarding vQM

Actant	**Score**	**Acted**	**Score**
Virtual	37	Model / Modeling	24
Simulation	20	Procedure (referring to process)	20
Information	9	Control	17.4
Quality	8.3	Optimization	12.4
Innovation	5.8	Communication	12.1
SPC	4.4	Knowledge	9.4
Knowledge management	3	Measurement	5.8
		Collaboration	5.3
		Product	4.8
		Development	3.6

Table 12. Correlation number of “actant” and “acted” notions regarding Industrie 4.0

Actant	**Score**	**Acted**	**Score**
IoT (Internet of Things)	31.4	Cloud_computing	17.9
Smart	27.6	Big_data	17.8
Virtualization	19.5	Optimization	17.0
Cyber	13.6	Measurement	12.7
Interoperability	11.5	Procedure	8.3
Simulation	10.0	Model	7.6
Digital	8.2	Collaborative	6.4
Information	5.3	Product	5.8
Innovation	5.0	Development	4.6
Decentralization	4.6	Control	4.0
Quality	3.6		

In the next step combinations between the “actant” and “acted” notions were made for assuring a certain level of homogeneity between all the terms of each concept. This action is taken for bringing the specific notions of each concept more closely together with the scope of finding common grounds between them.

A cumulative score can be calculated for each resulting association by multiplying the individual correlation values of the two forming notions. This score helps maintain a certain level of hierarchy between the obtained associations. However, only the meaningful associations were retained (thus becoming descriptors for each concept) and ordered in a descending manner in the following tables:

Table 13. Cumulative scores of descriptors regarding vQM

Descriptor	**Cumulative score**	**Descriptor**	**Cumulative score**
Virtual model/modeling	888.0	Innovation model	139.2
Virtual control	634.8	Virtual development	133.2
Simulation & modeling	480.0	Process innovation	116.0
Virtual optimization	458.8	Measurement through simulation	116.0
Virtual communication	447.7	Optimization information	111.6
Process simulation	400.0	Quality optimization	102.9
Virtual knowledge	347.8	Quality communication	100.4
Virtual measurement	214.0	Quality knowledge	78.0
Virtual collaboration	196.1	Innovation knowledge	54.5
Simulation knowledge	188.0	Measurement information	52.2
Information control	156.6	Product innovation	27.8
Quality control	144.4	Innovative development	20.9

Table 14. Cumulative scores of descriptors regarding Industrie 4.0

Descriptor	**Cumulative score**	**Descriptor**	**Cumulative score**
IoT cloud	560.1	Cyber collaboration	87.0
Big_data from IoT	559.1	Process simulation	82.5
Smart cloud (computing)	494.0	Decentralized cloud	82.2
Smart measurement	352.1	Virtual(ized) control	78.4
Big_data virtualization	347.1	Decentralized optimization	78.3
Virtual(ized) optimization	331.1	Simulation & modeling	76.7
Virtual(ized) measurement	247.8	Measurement information	66.8
Cloud interoperability	205.0	Cyber development	62.3
Collaboration through IoT	199.6	Quality optimization	60.7
Interoperability optimization	195.2	Product simulation	58.2
Simulation based on big_data	178.3	Cyber control	55.0
Smart collaboration	176.1	Interoperable development	52.3
Virtual(ized) modeling	149.3	Digital collaboration	51.8
Digital (big_)data	145.2	Development through simulation	45.6
Development through IoT	143.0	Process innovation	40.5
Digital optimization	138.4	Innovation model	37.6
Measurement through simulation	127.3	Digital development	37.1

Control through IoT	126.3	Digital control	32.8
Smart development	126.1	Collaborative innovation	31.2
Virtual(ized) collaboration	123.9	Decentralized collaboration	29.3
Smart control	111.4	Product innovation	28.5
Cyber model	104.8	Quality model	27.4
Digital measurement	103.6	Innovative development	22.4
Process interoperability	94.7	Information control	21.1
Cloud information	93.8	Decentralized development	21.0
Optimization information	89.3	Decentralized control	18.5
Virtual(ized) development	88.8	Quality control	14.4

In the case of the two concepts the expressions obtained by pair-wise associations were filtered for redundancies and were verified if they have real-life applicability with the help of search engines. In some cases, connection words were added to further refine the expressions and to assure their coherence related to the main concept.

1.2.3. The common knowledge space between vQM and Industrie 4.0

Overlapping the tables containing the descriptors of vQM and Industrie 4.0 (Table 13 & Table 14) it can be observed that there are common ones between them. These are crucial for determining common ground between two apposed concepts. Ranking them is made by calculating their weighted average (thus, still respecting their importance to each main concept) and consequently their weighted importance obtained in percent:

Table 15. Common notions between vQM and Industrie 4.0

Common descriptors	LSA Score		Weighted average	Weighted importance %
	vQM	**Industrie 4.0**		
Virtual modeling	888.00	149.30	271.87	40.45 %
Virtual optimization	458.80	331.10	78.95	11.75 %
Simulation & modeling	480.00	76.70	152.74	22.73 %
Process simulation	400.00	82.50	56.93	8.47 %
Virtual measurement	214.00	247.80	62.27	9.27 %
Quality optimization	102.92	60.70	7.35	1.09 %
Measurement through simulation	116.00	127.30	11.83	1.76 %
Virtual development	133.20	88.80	5.61	0.84 %
Process innovation	116.00	40.50	16.88	2.51 %
Innovation model	139.20	37.60	6.27	0.93 %
Product innovation	27.84	28.50	0.88	0.13 %
Innovative development	20.88	22.40	0.53	0.08 %
TOTAL	3096.84	1293.2	672.10	100 %

As seen in the above table, it can be the case that there is a considerable difference between the total scores of vQM and Industrie 4.0. The weighted average provides an aggregate that accurately reflects the importance of each descriptor to both main concepts, regardless of their score difference.

Although each common notion has its own LSA score depending on the main concept (vQM or Industrie 4.0) the ranking presented in the above table is made according to the calculated weighted average of the score pairs.

The proposed solution for identifying industrial applications is similar to identifying relevant papers for the LSA. Firstly, the top 5 most important common descriptors (obtained from the LSA – see Table 15) were entered into search engines followed by keywords extracted from the top 10 most cited Industrie 4.0 references together with the "application" word that was added to limit the amount of retrieved information. This way it is assured that the search is focused on practical applications and are related to Industrie 4.0 as its representative keywords were used. As Industrie 4.0 is considered to be the new trend in production engineering, applications related to it are also categorized as emergent. The retained applications were focused on those that had connections with – or can be used in relationship to vQM. A list of applications is obtained, but they are not sorted in any way.

1.2.4. Grouping and ranking applications along the PLC stages

For taking into account the development (the third) dimension, to the two axes (vQM and Industrie 4.0) another axis is added, the PLC, along which identified applications are grouped into its stages (see Figure 16 for an overview).

There are many views when it comes to defining precisely the product life cycle stages. For this reason, the authors synthesized information from an internationally accepted standard which inclusively covers all stages of a product life cycle: (ISO/IEC/IEEE 15288:2015). The stages were grouped into main- and sub-stages accordingly. These are presented in the following table:

Table 16. Product life cycle stages

Main stage	Sub-stage
I. Planning, design & development	Stakeholder requirement definition/analysis
	Product design & validation
II. Realization	Procurement
	Manufacturing
	Measurement and control
III. Utilization	Delivery
	Customer assistance
	Maintenance
IV. Disposal	Retirement
	Recycling

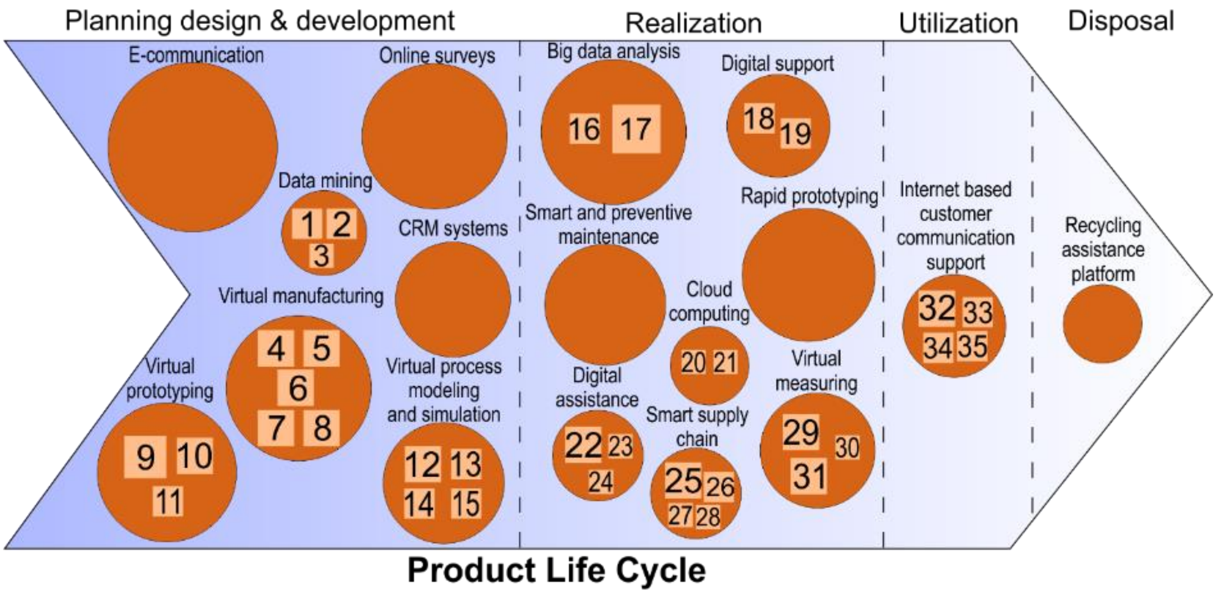
The Affinity diagram (also known as KJ diagram) was applied for grouping the set of applications into the corresponding life cycle stages, defining both categories and sub-categories of applications. The matrix diagram (presented in Annex 2) contains both these and the common notions with their weighted importance (expressed in percent).

The squares resulted at the intersection between main or sub-category applications and the common notions were filled out according to the correlation between them, with a number on a scale of 0 to 3 (0 means that there is no relation between the two and 3 signifies a strong relation). The sum of products between these correlation numbers and the weighted importance of the common notions was calculated on each line, thus obtaining an aggregate number that can be viewed as the importance of each application. If a main category application contains more sub-category items, its score is provided by the average of them (indicated in bold in Annex 2).

Having the importance scores for every sub- or main category application, they can be hierarchized for all the stages of the product life cycle (in Annex 2 the applications are already ranked). Thus, the matrix diagram contains a ranking of identified vQM applications in the context of Industrie 4.0, that are or will become essential in each stage of the product life cycle. Where blank squares exist corresponding to a life cycle stage it means that there were no suitable applications identified that fit the previously mentioned search conditions (see section 3).

It has to be noted that some of these applications are not that widely used currently at an industrial scale as others, but because they were identified in relationship with notions extracted from up to date documentation subjected to LSA, it can be stated that research endeavors are focused on them, meaning that they are emergent and because they support the quality approach at a “virtual” level, they can become indispensable in the field of vQM in the near future.

All identified applications grouped into the PLC stages are presented in the following figure:



1 – Social networking data analysis
2 – Google analytics for customer targeting
3 – Google Trends analysis used for product benchmarking
4 – Plant layout design used for production flow optimization
5 – Manufacturability analysis
6 – Work instructions design
7 – Worker ergonomics planning & design
8 – Work time study analysis
9 – CAD used for product modeling
10 – Kinematics simulation, analysis and optimization
11 – Assembly and part finite element structural analysis
12 – Simulation software used for process planning and flow analysis
13 – Virtual commissioning used for equipment automation
14 – Automated process optimization
15 – Automated process robustness prediction
16 – Preventive actions taken based on collected data
17 – Automated real-time process optimization
18 – Mobile device applications used for process monitoring & control
19 – Smart glasses employing AR used for displaying product/ process data
20 – Remote process monitoring & control
21 – Edge computing
22 – Remote equipment control and assistance
23 – Vision system used for part inspection
24 – Smart glasses employing AR used for operator empowerment
25 – Real-time inventory monitoring
26 – Automated raw material order & purchase
27 – Automated raw material approval
28 – Smart supplier evaluation and sel.
29 – Virtual CMM used for evaluation of uncertainty estimates
30 – Inline metrology used for fault, defect and deviation detection
31 – Absolute multiline technology for online precision monitoring
32 – Knowledge base used for problem solving for known issues
33 – Remote access used for diagnostics and trouble ticket resolution
34 – FAQ web page used for fault/ defect identification and self-help
35 – Automated online assistant used for tech support through live chat

Figure 21. Applications along the Product Life Cycle's stages

The circles represent the main categories of applications and their size is proportional with their importance as calculated in the matrix diagram (Annex 2). The squares correspond to actual applications and their size also represent their priority in reference to the category they belong to. The denomination of each application is presented below the figure.

1.2.5. Methodology validation through survey

One of the objectives of this chapter was the validation of the proposed LSA based methodology. This was done through an online questionnaire (see Annex 1 for the design of the questionnaire), applied to groups of professionals with relevant knowledge connected to the actual technological developments from the automotive industry.

The validation demarche raised the following challenges:

- covering the important companies from the automotive sector such that even if statistical relevance is not reached, this will be reflected by including within the survey all/most of the major actors from this field;
- selecting the target group such that it has access to relevant information;
- designing and constructing the questionnaire.

Statistically speaking, there are 510 automotive companies (NACE code 29) in Romania (according to the online database of (Romanian Companies, 2016)), but in terms of our analysis not all of them present the same relevance. An analysis of the technological level of these companies clearly leads to the conclusion of an inhomogeneity of their relevance in relation to our analysis. It is expected not to obtain similar information on new technological developments regarding Industrie 4.0 / vQM from Renault or Ford and from a small firm that supplies low complexity parts. For this reason, the focus of this study was aimed at those few major manufacturers from this industry branch (obtained by grouping them into categories) and questioning consultants, specialists, quality auditors or even managers that draw their expertise from not just one, but several important companies and can provide answers with a high degree of relevance. This way, the answers of one individual can represent feedback from more than one company, thus eliminating the need to question each of them separately.

Considering the above-mentioned aspects, the companies were grouped into 3 main categories: the first two categories (A. automotive manufacturers and B. manufacturers of major components – e.g. Dacia-Renault, Ford, Bosch, Continental, Leoni, Rombat, Daimler, Pirelli, RAAL) represent manufacturers with international notoriety; all other companies were left for a third (C.) category.

The first category had 10 representatives, the second had around 150 and in the third category 350 companies were included.

The investigation was guided towards to the first two categories, but there was also a concern about obtaining some samples as well from the third category companies, mainly from those which were preoccupied about new technologies.

Another important issue addressed was the information confidentiality. For this reason, the entire investigation was depersonalized.

The surveyed target group consisted of consultants, specialists, quality auditors or even managers that drew their expertise from not just one, but several important companies and could provide answers with a high degree of relevance. The depersonalization requirements were extended upon them, as well.

Within the survey, the above-mentioned groups were provided with a list of 41 applications determined through the LSA (presented in the Matrix Diagram – Annex 2 and in Annex 3) and they had to rate them considering their implementation or future implementation into the companies whose manufacturing processes they were familiar with. Responders also had the possibility to name and rate additional applications that were not included, but were considered to be important by them (centralized in Annex **3** & Annex **4**).

The scale for rating each application was kept the same as in the case of the matrix diagram, from 0 to 3, thus enabling an objective and direct comparison between the score calculated from the matrix diagram and the average score obtained from the survey (0 – "it's not likely to be used by manufacturing companies"; 1 – "only some manufacturing companies have or will implement it"; 2 – "most of the manufacturing companies have or will implement it"; 3 – "all manufacturing companies have or will implement it").

The table below includes the number of responses, the number of companies covered from each type and the percentage of coverage:

Table 17. Number of responses and percentage of coverage

Target group	**Responses**	**Type A companies covered**	**Type B companies covered**	**Type C companies covered**
Top management	6	0	10	9
Technical consultants	8	7	55	28
Specialists	5	2	35	11
Quality auditors	6	1	25	15
TOTAL	**25**	**10 out of 10 (100% coverage)**	**125 out of 150 (83,3% coverage)**	**63 out of 350 (18% coverage)**

As it can be seen, not all of the 510 companies were covered, however all of the type A and most of the type B companies were reached within the study.

For analyzing the responses, the chosen reference values were the ones obtained from the questionnaire because they are considered to be the "voice" of the industry. A margin of error was calculated for each score obtained from the matrix diagram and findings showed that it was not more than ± 8%. The average margin of error was even better, being just under 4 %.

The list of applications alongside their rating and margins of error can be consulted in Annex 3. This table presents not only the accuracy of the research methodology, but also prioritizes trending applications that companies will need for their own development, thus defining the emerging research directions.

1.3. Conclusions

The research endeavor focused on analyzing the common knowledge space in specific areas by intersecting the knowledge structures obtained through a concept disambiguation process. The results of this analysis were further used to determine the technological solutions that are expected to emerge from that concept intersection space. Particularly, it was analyzed the possibility of identifying emergent industrial applications by intersecting the knowledge structures of two concepts: Industrie 4.0 and vQM.

The disambiguation process is achieved with the help of a fairly new knowledge extraction method called latent semantic analysis (applied by a specialized software program), which is capable of analyzing large amounts of text and quickly identify the relationship, causality and frequency of words, thus providing an interpretation of the state of the art literature (in close connection with the two main concepts – vQM and Industrie 4.0). By applying this technique, the common areas of interest (common knowledge space) were identified in the form of descriptors that were further used for identifying applications that are defined by or relate to them.

The set of applications was grouped into the stages of product life cycle according to the ISO/IEC/IEEE 15288:2015 standard (with the help of a classic sorting tool – Affinity Diagram) and ranked considering their importance scores resulted from applying a matrix diagram. These calculated scores reflect the weighted importance of common descriptors between vQM and Industrie 4.0, as they also served as inputs into the matrix diagram.

The research loop was closed with a survey that focused on obtaining information from experts (from the field of quality) with close ties to the automotive industry, that confirms the reliability of the presented methodology with an average margin of error of just under 4%.

As illustrated through the application of the presented methodology one can note the important advantages that it offers:

- emerging technological trends can be identified from the common knowledge space of two or more concepts;
- the state of the art knowledge discovery process (concept disambiguation) is based upon an exponentially greater number of scientific references and it's reduced to a few seconds;
- the outputs of the LSA can be further analyzed, sorted and grouped by deploying various tools and techniques, thus obtaining more useful information.

Considering the above-mentioned key points, it can be stated that the resulting applications are the product of current research concerns in the two analyzed fields, vQM and Industrie 4.0. The constructed matrix diagram also provides a clever preview of industrial applications throughout the product life cycle and ranks them to depict those that are more critical to quality based on their importance scores.

The current framework has a high degree of portability and it can be applied to other concept associations as well for determining common areas or emergent aspects in a specific context.

In a broader understanding, the model can make forecasts for applications that are more likely to become popular in the next period of time. Organizations that are capable to foresee them and focus on their development and implementation have a clear competitive advantage.

2. vQM model in product design and its optimization in the development phase

2.1. General and conceptual aspects

This chapter proposes to outlay a framework for new product development by deploying tools used in vQM, in the same order and structure in which the concept was first formulated (see Figure 15 for the architecture of vQM), but slightly modified and adapted strictly to product development. By deploying the tools within the proposed framework individual product components are optimized considering the actual customer requirements. Thus, the product is not only improved from its engineering and design's perspective, but it is also quality oriented and customer-centered.

Apart from the tools and techniques that vQM uses, as presented previously, its functioning can be summed up in three main stages:

I. Determining or collecting process data – identifying (external) relevant process data, that could have an impact on the functioning of processes;

II. Modeling and simulation – modeling and simulations carried out for various scenarios considering identified process data;

III. Determining processes parameters – further optimizing the parameters that were obtained in the case of the best scenario and implementing them in the design or planning of processes.

Following the above-mentioned approach, disturbing factors don't come as a "surprise" in the functioning of real-life processes. By collecting all relevant data that can have even the slightest impact on processes and putting them through simulations, potential unfavorable situations are already predicted in the virtual environment, thus they are known of and for them preventive actions can be planned through which they are avoided. The resulting process models provide highly robust processes.

The traditional quality management approach also deals with preventive and corrective measures, however in this case real-life situations already happened and the corrective and preventive actions were taken based on previously encountered unfavorable positions. The "updated" vQM avoids the experience of damaging process functioning by optimizing parameters, thus enabling processes to respond favorably to disturbances.

Seeing the vQM model as a success for designing processes, its adaptation to product development was attempted. This endeavor started with the three main stages (previously mentioned), but they were fitted with the necessities of product development. As up to date quality management is customer-centered the resulting stages are revolving around the client's requirements:

I. Determining and collecting customer requirements – deploying various quality tools (e.g. Voice of the Customer Table) for acquiring and ranking according to their importance the customer requirements;

II. Modeling and processing customer requirements – translating the customer requirements into technical characteristics (e.g. by using a cascaded Quality Function Deployment approach; Analytical Hierarchy Process) and relating them to the product and its components;

III. Determining product & component parameters – optimizing (e.g. by using genetic algorithms) the components according to customer requirement and obtaining their parameters (length, width, height and other defining elements).

The updated architecture, based on the model presented in Figure 15, is illustrated in the figure below:

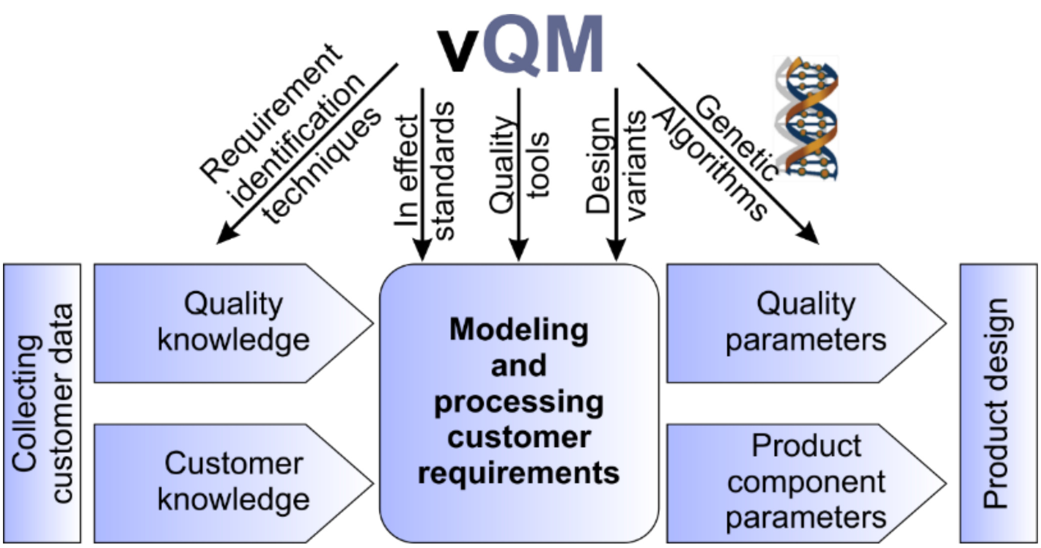


Figure 22. vQM-based product development architecture

Deployed instruments

For the first and second stage, the identification of the customer's needs is done by using instruments detailedly described in the "Product Planning" phase of the PLC.

The **VoCT** method, for example, in this case is used for understanding what the customer wanted to communicate or how the product should be in his perception. If the product development team is fully aware of the customer needs they can better incorporate them into the product, thus increasing the client's satisfaction.

For ranking the requirements, the **AHP** method proves to be an efficient one: by systematically comparing criteria (in this case needs) in a pairwise fashion and by deciding which one is more important than the other (in this case, attributing a number from the Saaty scale for each comparison) (Saaty, 2008) the final importance of each requirement can be calculated. It has to be noted that the scale attribution integrates not only qualitative, but quantitative aspects as well (Yanlai, Jiafu, Xinggang, & Jie, 2009).

The second stage of the proposed approach deals with analyzing the correlation between the customer requirements and the technical characteristics (which are critical-to-quality specifications, a.k.a. CTQs) of the product concept (design). The correlation provides proof of whether or not the requirements are embedded into the technical specs or if they are incorporated into the design. Similarly, the correlation between CTQs and product components is carried out, this time verifying if the former ones will be supported by the constructive elements of the product. For these purposes two cascading **QFD** matrixes are interlinked (by using outputs of the first matrix as inputs of the second), which also converts the importance of the requirements (obtained with the AHP) to importance of components displayed in percentages (intermediately obtaining also the ranking of the CTQs). Although in its extended form, the QFD method is comprised of 4 steps: "Product planning" (a.k.a. House of quality); "Product design" (parts deployment); "Process planning" and "Process control" (Bouchereau & Rowlands, 2000), but because the developed framework is focused on the product development stage, the QFD method will include only the first two matrixes. Doing so, the customer requirements are kept at center stage throughout the entire development process. (Bouchereau & Rowlands, 2000).

The direct output of cascaded QFD is the importance of the product's components, reflecting to a certain degree the importance of customer requirements. This way, it is made sure that the optimization process is focused only on the most important components and not on those that offer minimum return. The general assumption behind this approach is that by focusing the optimization on the top 20% most important components an overall 80% benefit is obtained. The optimization depends highly on the product in question and its application. Based on this, the objective function is defined, which can be either minimized or maximized, considering what the product is intended for.

It should be noted that the components selected for the optimization are defined by information that can be expressed numerically (e.g. width, length, material density, allowed bending stress, etc.). Some of these are known and fixed (input data), some are yet to be identified (searched variables – unknowns – genes). However, value intervals can be associated to each unknown variable. This is where the optimization process starts: a random value is selected from within the interval and by applying the two fundamental evolutionary operators, the crossover and mutation (Chan, Kwong, & Wong, 2011), new possible solutions are obtained. In case these values satisfy all defined constraints, they are considered potential candidates for the final solution and based on them the objective function is then calculated. These genes will also serve as "parents" for the solutions given by the "next generations", for which the objective function is recalculated. By comparing the former and latter objective function it can be decided which variables (genes) have a better fitness (Syberfeldt & Gustavsson, 2014), the others are excluded from the process. This cycle is repeated until the objective function reaches its minimum or maximum, depending on the desired outcome (Chan, Kwong, & Wong, 2011). It can be the case that within one optimization process, multiple solutions are obtained. All the above-mentioned steps are coded under C++ programming language (see Annex 5 & Annex 6) and calculated by an optimization software called Genesis.

Methodology description

An overview of the methodology is summarized in Figure 23:

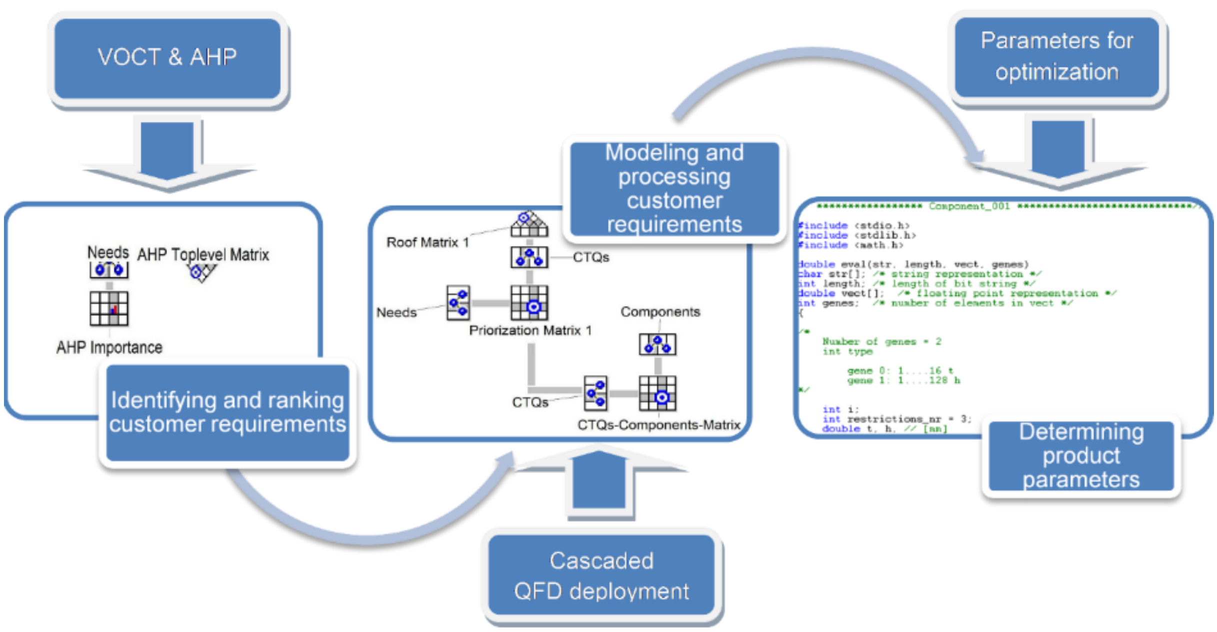


Figure 23. Proposed framework for optimized product development

The extended version, which depicts also the interactions between the stages of the framework can be consulted in Figure 24:

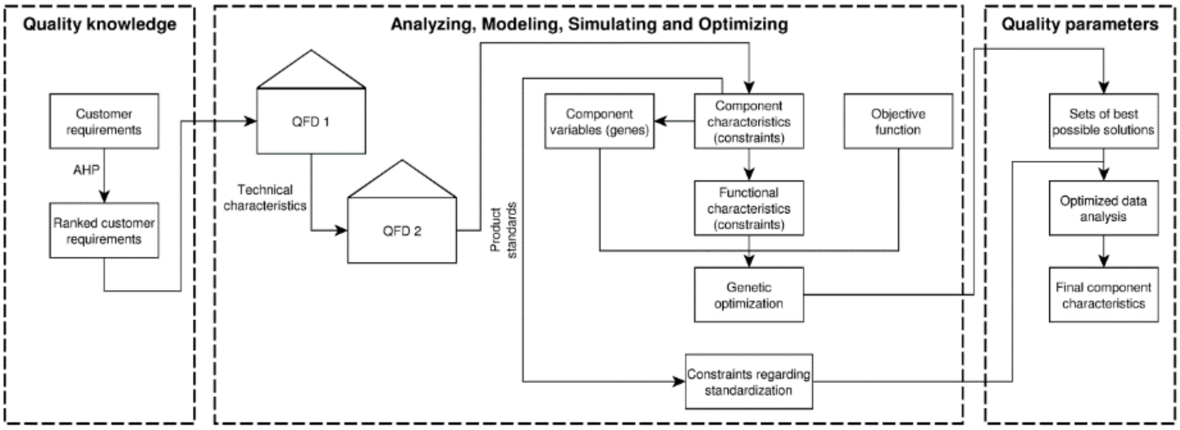


Figure 24. Detailed layout of the proposed framework for optimized product development

As depicted in Figure 24 the methodology starts with the "Quality knowledge" which comprises of identifying and collecting customer requirements. This is done with the help of various virtual instruments: online surveys and specialized software programs that employ quality tools like the VoCT, Kano model and Pugh method. Search engines can also be useful tools for identifying trending aspects related to specific products, thus accurately pinpointing "What do customers demand from a certain product?".

The above-mentioned techniques provide mostly raw data, that has to undergo further finishing. In this regard, brainstorming sessions of the product development team facilitate the accurate definition of customer requirements as key aspects are discussed collectively, redundant requirements are eliminated and all the information is sorted and grouped into categories, making it more easy to manage. These discussions also help eliminate potential ambiguity, thus the team will focus precisely on what the customer requested / meant. All these steps lead to the formulation of the final and concise set of customer requirements.

The prioritization process should also be a collective effort for minimizing as much as possible subjective outcomes. For this purpose, the proposed instrument is the AHP, with its advantages mentioned previously, but it can be replaced by other, more advanced tools such as the conjoint analysis or fuzzy logic ranking, depending on the complexity of the application.

The second stage of the methodology begins with the two cascaded QFD matrixes: the first one correlates customer requirements with technical attributes, while the second one brings together the latter with the product's components, obtaining their importance with respect to the customer needs. Based on the strong correlation within the second QFD matrix, technical specifications can also be extracted for each component.

Before even conducting the optimization, special attention should be given to the definition of the problem. Most importantly, the objective function (OF) must be formulated correctly, or else obtained genes could offer anomalous results and can't be viewed as viable solutions. The mathematical form defining the OF should contain all variables that can influence its outcome. Furthermore, the genes (the unknown variables) must also be included within the OF as they contain the information that describe the product's components. When the optimization process has more than one stages, variables identified previously can be used to formulate new objective functions.

The optimization has to take into account aspects that are given by the product's functional characteristics and individual components' restraints. For this, certain constraints are formulated, serving as inputs for the optimization process, thus assuring that the results meet criteria provided by the customers and other stakeholders.

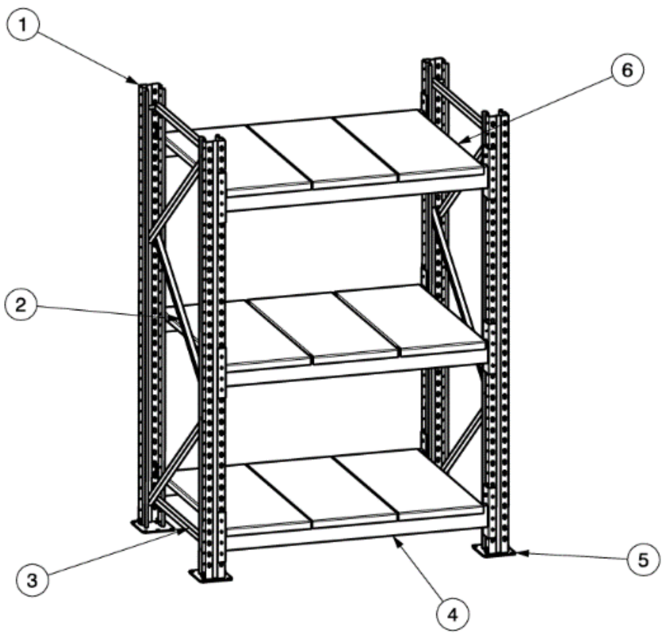
The third stage of the methodology concludes with the deployment of the genetic algorithm, which is the proposed method for the actual optimization. Based on input data (objective function and formulated constraints) the genes are identified (representing the component characteristics) out of which only the fittest ones are retained. From the product's manufacturability perspective, the set of solutions has to be further analyzed and correlated with in effect product standards, that provide standardized descriptors to the shape and size of the product. In some cases, it could prove more expensive to manufacture a product, that although "optimized" it doesn't include standardized dimensions.

2.2. Illustrative example

The reliability of the developed methodology is illustrated by its application on a simple household product, a common metallic shelf. Its modelled form is depicted in Figure 25, which was developed using a specialized 3D CAD software program. The annotations represent individual components and their captions are presented below.

The optimization problem was focused on reducing its mass in such a way that the customer requirements will not be affected and that the product shell fulfill its designed purpose, but with less material consumption, thus its manufacturing costs are also reduced.

The optimization was focused on the two most important components (as obtained from the cascaded QFD), which in this case are the "Shelf" (6) and "Support beam" (4).



Bill of components

1 – Support pillar

2 – Diagonal bracing

3 – Horizontal bracing

4 – Support beam

5 – Base plate

6 – Shelf

Figure 25. The modelled optimized product

The customer requirement analysis was done using a software program entitled “Qualica QFD”, which helped not only in the identification process (VoCT), but also in the ranking and prioritization of needs (AHP). Figure 26 contains the pair-wise comparison matrix, which, in turn, led to the ranking of the requirements, sorted in Figure 27 in a descending manner, from the most to the least important.

The top two requirements refer to the shelf’s dimensions and to the load that it should bear, having a combined importance of almost half of the total.

The ranked requirements constitute as inputs for the next phase, which starts with the first QFD matrix. Depicted in Figure 28, it offers as a direct output the importance of the technical specifications (expressed in %), calculated by verifying their correlation with customer needs. As mentioned previously, there are three correlation degrees: strong correlation, medium correlation and weak correlation.

The second QFD matrix (Figure 29), linked with the first, transforms the importance of the CTQs into importance of individual product components, expressed also in %.

For illustration purposes the optimization process was focused only on the two highest ranking components.

Group: **Top Level ITEMS** — Output — Completed: ☑

AHP Toplevel Matrix

9	9,00	an order of magnitude more important
8	8,00	absolutely more important (8x as important)
7	7,00	demonstrated more important
6	6,00	demonstrated more important (6x as important)
5	5,00	essentially more important
4	4,00	essentially more important (4x as important)
3	3,00	considerably more important
2	2,00	twice as important
+	1,50	somewhat more important
○	1,00	Equally important
-	0,67	somewhat less important
½	0,50	half as important
⅓	0,33	clearly less important
¼	0,25	essentially less important (other item 4x as important)
⅕	0,20	essentially less important
⅙	0,17	demonstrated less important (other item 6x as important)
⅐	0,14	demonstrated less important
⅛	0,13	absolutely less important (other item 8x as important)
⅑	0,11	an order of magnitude less important

Input	1 the shelf should be modular	2 open access to every item on the shelf	3 easy and fast assembly	4 it should bear a weight of 60 kg/ stand	5 it should be made out of steel	6 it should fit into a space with a volume of 1200x600x2000 mm	7 it should be light	8 it should have minimum two stands	9 the stands should be at least 500 mm apart	Importance in group
1 the shelf should be modular		3	3	¼	½	¼	⅓	2	4	8,8%
2 open access to every item on the shelf			½	⅕	⅓	⅕	½	½	-	3,6%
3 easy and fast assembly				¼	½	¼	-	○	2	5,7%
4 it should bear a weight of 60 kg/ stand					3	-	4	4	5	25,1%
5 it should be made out of steel						-	⅓	3	3	11,1%
6 it should fit into a space with a volume of 1200x600x2000 mm							3	4	4	23,7%
7 it should be light								2	2	12,5%
8 it should have minimum two stands									2	5,5%
9 the stands should be at least 500 mm apart										3,9%

Figure 26. AHP matrix for ranking customer requirements

Importances / Sorted ITEMS 1	Calculated Importance %	Final Importance %
4 it should bear a weight of 60 kg/ stand	25,1%	23,1%
6 it should fit into a space with a volu...	23,7%	22,0%
7 it should be light	12,5%	12,3%
5 it should be made out of steel	11,1%	11,1%
1 the shelf should be modular	8,8%	9,2%
3 easy and fast assembly	5,7%	6,5%
8 it should have minimum two stands	5,5%	6,3%
9 the stands should be at least 500 m...	3,9%	4,9%
2 open access to every item on the shelf	3,6%	4,6%
Most important item:	25,1%	
Least important item:	3,6%	

Figure 27. Ranked customer requirements

When the first two stages are complete, which can be viewed as preliminary information for the optimization process, the variables that are unknown have to be identified, thus pinpointing the genes, which are specific to each application. For the “Shelf” component these are considered to be the thickness of the metal sheet and the height of the side reinforcement. Based on these variables the bending stress can be calculated, which should be within acceptable limits, but it also has to be noted that the component should be as light as possible. So, in this case one restriction is given by the bending verification, it’s mathematical formula is included in Table 18, along with other information needed for the optimization process. For the “Support beam” component the genes are its the height, width and wall thickness, presented in Table 19, alongside the restrictions. Although calculated differently, with different variables, in both cases, the objective function is defined by the components’ mass, which is minimized.

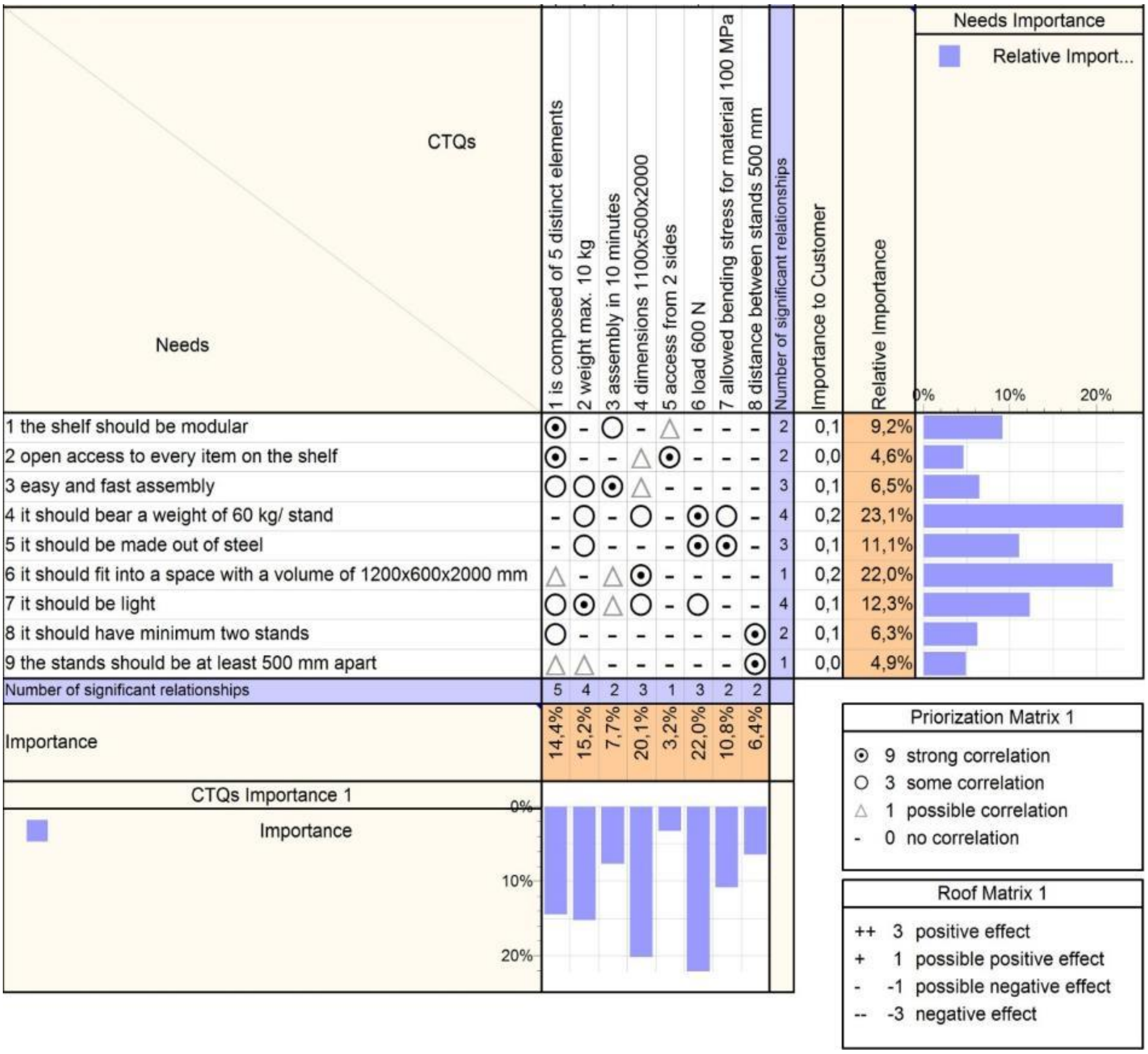


Figure 28. First QFD matrix

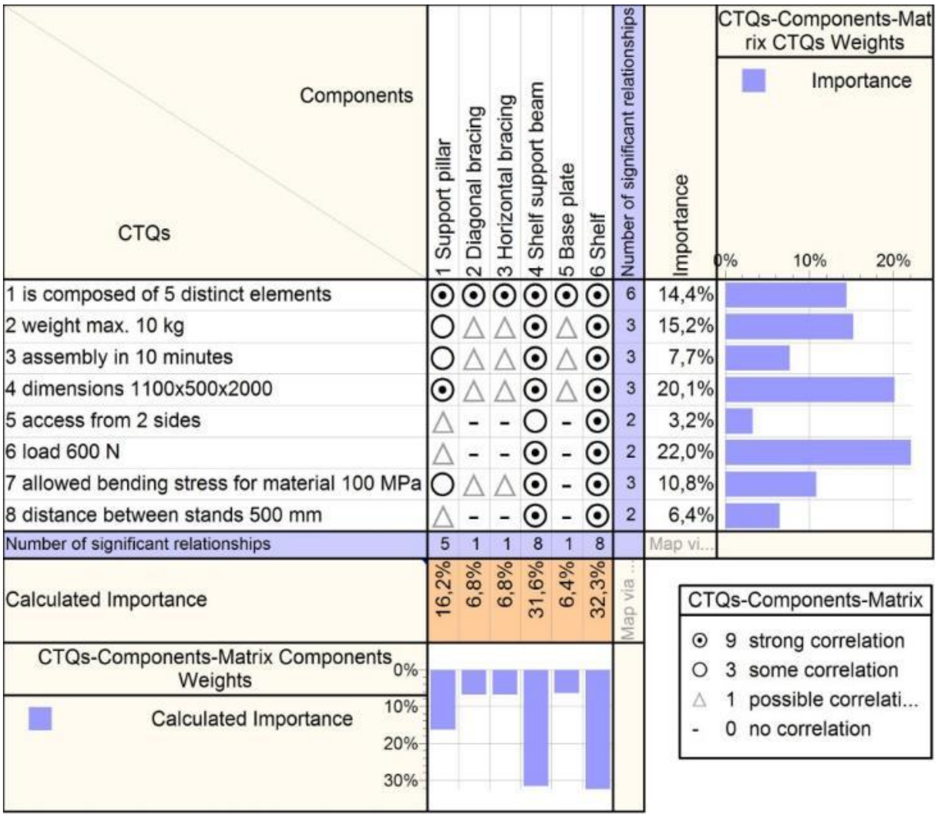


Figure 29. Second QFD matrix

The main concern when designing a product is dimensioning of components. When employing classic methods, a “pre-dimensioning” is done, which will make sure that the component will withstand the stress that is subjected to. In many cases the allowable bending stress for the material is not optimally used because the component is oversized (more material is put into the component without need). In the case of optimal design, the “pre-dimensioning” is replaced with iterations, meaning that the solution is not calculated exactly, but looked for within an interval. This way the obtained solutions are closer to an ideal case, because they are found according only to the established restrictions.

The input data for the optimization process is presented in the following two tables:

Table 18. Entry data for optimizing the “shelf” component

Known variables		Searched variables (genes)	Objective function	Restrictions
Length: l=1000 mm	Width: w=400 mm	Metal sheet thickness: t	Mass: $M = r * (h * t + w * t) * l$	1. Bending verification: $\sigma_i \leq \sigma_{ia} \rightarrow R_1 = \frac{\sigma_i}{\sigma_{ia}} - 1 \leq 0$
Load: F=600 N (≈60 kg)	Allowed bending stress: σ_a=100 MPa	Height of the shelf reinforcement: h		2. Metal sheet thickness should be at least 0.7 mm: $t \geq 0.7$ mm $\rightarrow R_2 = \frac{0.7}{t} - 1 < 0$
Material density: $r=7.87*10^{-6}$ kg/mm^3				3. The height of reinforcement should be at least 20 mm; $h \geq 20$ mm $\rightarrow R_3 = \frac{20}{h} - 1 < 0$

Table 19. Entry data for optimizing the "support beam" component

Known variables	**Searched variables (genes)**	**Objective function**	**Restrictions**
Length: l=1200 mm	Height of the beam: H	**Mass:** $M = r * (H * B - h * b) * l$	1. Bending verification: $\sigma_i \leq \sigma_{ia} \rightarrow R_1 = \frac{\sigma_i}{\sigma_{ia}} - 1 \leq 0$
Load: F=650 N (≈65 kg)	Width of the beam: B		2. Wall thickness should be at least 2 mm: $t \geq 2$ mm $\rightarrow R_2 = \frac{2}{t} - 1 < 0$
Allowed bending stress: σ_a=100 MPa	Wall thickness: t		3. The width should be smaller than the height $B < H \rightarrow R_3 = \frac{B}{H} - 1 < 0$
Material density: $r=7.87*10^{-6}$ kg/mm^3			4. The width should be at least 2 times smaller than the height: $B \geq H/2 \rightarrow R_4 = \frac{H}{2*B} - 1 \leq 0$

All this information obtained until this point is introduced in a specialized software tool, called Genesis, which will perform the actual optimization in the manner described previously (the information is transformed into a C++ code).

As outputs we obtained a set of solution, which was then compared to product standards for both components (i.e. standardized thickness, standardized width, standardized length, etc.), according to (EN 10025:2004), (EN 10219:2006), (EN 10305-5:2010).

For better illustrating the effectiveness of the described framework the authors also calculated the values for the component characteristics using classic design methods. A comparison between the two is shown in Table 20.

Table 20. Comparison between the two product development methods

"Shelf" component					
Classic product development			**Optimized product development**		
t – 1 mm	h – 20 mm		t – 0.7 mm	h – 28 mm	
Mass: 3.305 kg			**Mass: 2.358 kg**		
"Support beam" component					
Classic product development			**Optimized product development**		
H – 50 mm	B – 40 mm	t – 3 mm	H – 70 mm	B – 30 mm	t – 2 mm
Mass: 3.966 kg			**Mass: 3.022 kg**		

In the case of both components significant reduction of mass is obtained: 29% and 24% respectively.

2.3. Conclusions

As the name suggest, vQM strongly relies on the virtual environment for the purpose of generating resilient knowledge either for product or processes by deploying specific tools and instruments incorporated in software programs. The end goal is to develop the necessary information for those products/processes that will enable implementation into production with an increased performance and with a higher degree of predictability. This novel approach in QM was adapted for the product development process, thus obtaining a new framework that has at its core the customer requirements, which are transposed throughout the entire process offering optimized data regarding the characteristics of the developed product's components.

The proposed framework, subject of this chapter, is considered to be a hybrid as it combines classic, well established and simple to use quality tools (e.g. VoCT, AHP and cascaded QFD) with more advanced ones (e.g. genetic algorithms), having its main advantage the achievement of an optimized product, but without compromising or neglecting the initial customer requirements. It also has a wide applicability, as its structure provides optimization for individual components, thus the nature or type of the product in question does not limit the framework's deployment.

At the case study's level, presented previously, it has to be mentioned that the application of the framework performed very well, having as result an optimized common household item from its mass perspective, with an overall 27% in mass reduction. It also has to be noted that more complex products can be subjected to this framework, as well, even if the optimization is made from a different perspective.

Chapter 4. Applicative developments for vQM

1. Process improvements using simulation software

1.1. General and conceptual aspects

A key constitutive of the vQM model are the simulations, which reproduce the functioning of processes in the virtual environment with the purpose of improving it. In close reference with the vQM philosophy, the present chapter aims to investigate and analyze all activities, structured as processes, within a manufacturing SME from the automotive sector (called S.C. Turbocam Romania S.R.L. Târgu-Mureş – a division of Turbocam International), by transposing them into the virtual environment and conducting simulations with the main purpose of improving the firm's overall manufacturing flow. The simulations are carried out with the help of a specialized software program (SigmaFlow Modeler), which can predict how the processes will function in real-life scenarios, based on input data. Process parameters can then be fine-tuned to achieve the best possible operating performance.

Simulation software programs are powerful tools used to analyze the process flow and/or information flow of an organization, regardless of its field of activity. The main reason for conducting such an analysis is to improve the existing or designed processes or to see how they will perform once implemented, but without committing any resources. However, it's not limited to these, as information about process capability, bottlenecks, output distribution and resource allocation is put forth as a result.

According to (Bin Ali, Petersen, & Wohlin, 2014) (a literature review paper) the opinions regarding the modeling of processes by deploying simulation software programs are divided. In (Zhang, Jeffery, Houston, Huang, & Zhu, 2011) the importance of using software process simulation is presented and reference is made to the significant impact it had until now on the industry, while (Birkhölzer, 2012), (Houston, 2012), (Münch, 2012) state that its impact is unremarkable. Nevertheless, the common ground between them is that they all agree upon the usefulness of this tool. The author of (Pfahl, 2014) is one of the few who argued that the applicability of such approach is limited and the impact and benefits are quite low.

This chapter also provides arguments in support of using such convenient instruments, as they emerged out of the need for improving more and more complex processes. Moreover, process simulation is one of the trending features of our evolving industry, with applications in many fields, such as manufacturing (Thepsonthi & Özel, 2015) (Amandeep, Deepu, & Ramkumar, 2015); chemical process control (Z. Kapetaki, 2015) (Liu, Chen, Luo, Wang, & Meng, 2015); agriculture (van't Ooster, Bontsema, van Henten, & Hemming, 2014) or even environmental sciences (Jing, Chen, Zhang, & Li, 2015).

1.2. Illustrative example

The process simulations were carried out with the help of the Sigma Flow Modeler simulation software. The computer program integrates process analysis tools, statistic instruments, Lean Six Sigma and many more, which help in observing and understanding how designed processes function, even before they are put into practice (SigmaFlow, 2015). This way, time, financial and human resources are saved, because unforeseen problems are identified in the design stage, before the processes are implemented. Thus, management decisions can be taken with minimum risk, the manufacturing flow can be analyzed objectively and the improvements can be done by observing blockages and working times.

Another advantage of using process simulations is that one can observe different changes in the process, when modifying a certain activity or reallocating resources. This means that the process can be fine-tuned with minimum costs within the virtual environment and experiments can be carried out to bring the process within desired parameters. The human resource allocation can be done in the best possible way, without overloading or overstraining the operators.

The collection of the input data, based on which the simulations were carried out took place at the above-mentioned company’s headquarters by on-site observations of the functioning of processes. Among the collected data, the following are mentioned being the most important ones: working times, human and material resources allocated as well as working instructions. In order to better reflect reality, in the simulated processes the working times are entered as an average of all measured times, but the difference between them is also taken into account, being introduced in addition to each working time the standard deviation. For machine tool operations, working times are entered as fixed values without a specific deviation, since in this case the processing will have a fixed duration whenever it is performed.

Taking into consideration all these premises, in the following the input data for the simulations is presented. Firstly, it is critical to understand the interactions between the organization’s processes. In this sense in the following figure the organization’s process map is depicted:

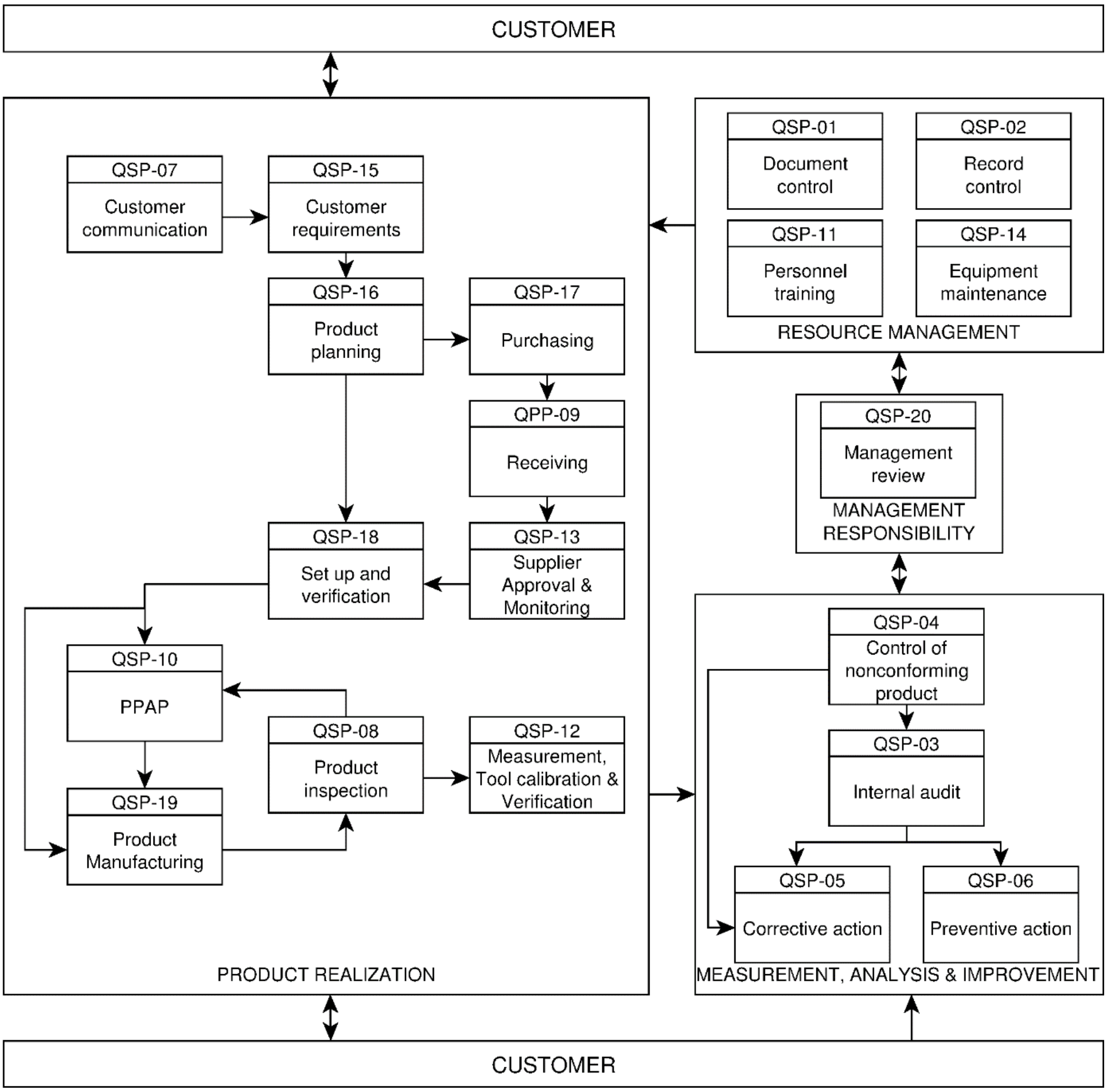


Figure 30. Organization's process map

In order to successfully simulate the manufacturing flow, without any interactions, the focus will be shifted to the processes within the product realization area. The rest of the processes will be neglected, because they support the main manufacturing ones and they basically run simultaneously with them. For not complicating the simulation algorithm it was chosen that their existence should be only mentioned and illustrated in Figure 30. Depending on the product that is to be manufactured the "Product Manufacturing" process can be understood as: turning, milling, finishing; or it can be a combination between the three. The manufacturing of the product for which the simulations were made included all three of them. Thus, the actual manufacturing cycle can be represented by the following main processes in the following order: "Receiving raw material" → "Raw material allocation" → "Raw material inspection" → "Turning" → "Eddy-current testing (ECT)" → "Quality inspection 1" →

“Milling” → “Finishing” → “Quality inspection 2” → “Product delivery”.

To increase the accuracy of the model, each process will be simulated individually with its own activities and work instructions. Within the simulation software each process activity is represented either by a so called “Work Centre” or by a “Process block”. The difference between them is that the “Work Centre” has a buffer zone and it’s capable to take on other products that already underwent previous activities. In the case of the “Process block” only one part at a time will be processed. They both have inputs like “Resource Management” (where it is specified which human resource is carrying out that particular task and what are its characteristics; i.e. number of operators, minimum/maximum of required operators and resource engagement/disengagement), “Operation Time” (where given the nature of the activity it can be specified how long it is, what is its time distribution, what is the mean and standard deviation) and “Priority” (where the priority of the activity is inserted).

The premises for the input data regarding each simulation are the following:

- the factory is operational 5 days a week; 3 shifts/day;
- the effective working time is 7200 minutes (a simulation represents the manufacturing cycle within a week)
- the manufacturing of a part depends on the milling process because it’s the longest as duration (a milling cycle for one machine is 4 hours long obtaining 15 products, which means that for one shift 30 parts are made; there are 3 milling machines allocated for this particular type of product, out of 6, which produce a total number of 1350 parts/week).

Based on the above-mentioned data the “Inter-Arrival Time” can be calculated by dividing the total number of minutes per week with the total number of parts (7200 min/1350 parts = 5.33). This is crucial for the start of the simulation cycle not only to bring a generic simulation to the specifics of a simulated process, but also to link all the processes between them. At start, each one will have different inter-arrival times for matching the output of one process to the input of the following.

For manufacturing the part for which the simulations were carried out it was found that the most complex process is the milling process. This is due to the multitude of tasks, the required high level of precision and the higher number of human resources involved. For simplification purposes only the milling process will be illustrated here. However, it must be noted that all the simulations were completed for all the processes within the manufacturing cycle, as the inter-arrival time needed to be obtained for the process in question. As it resulted from simulations, out of the 1350 semi-finished parts from the beginning, only 1340 reached milling, the rest were rejected from the quality inspection point of view or they were not finished yet and they remained blocked within previous processes. Thus, the inter-arrival time was set to be 5.373.

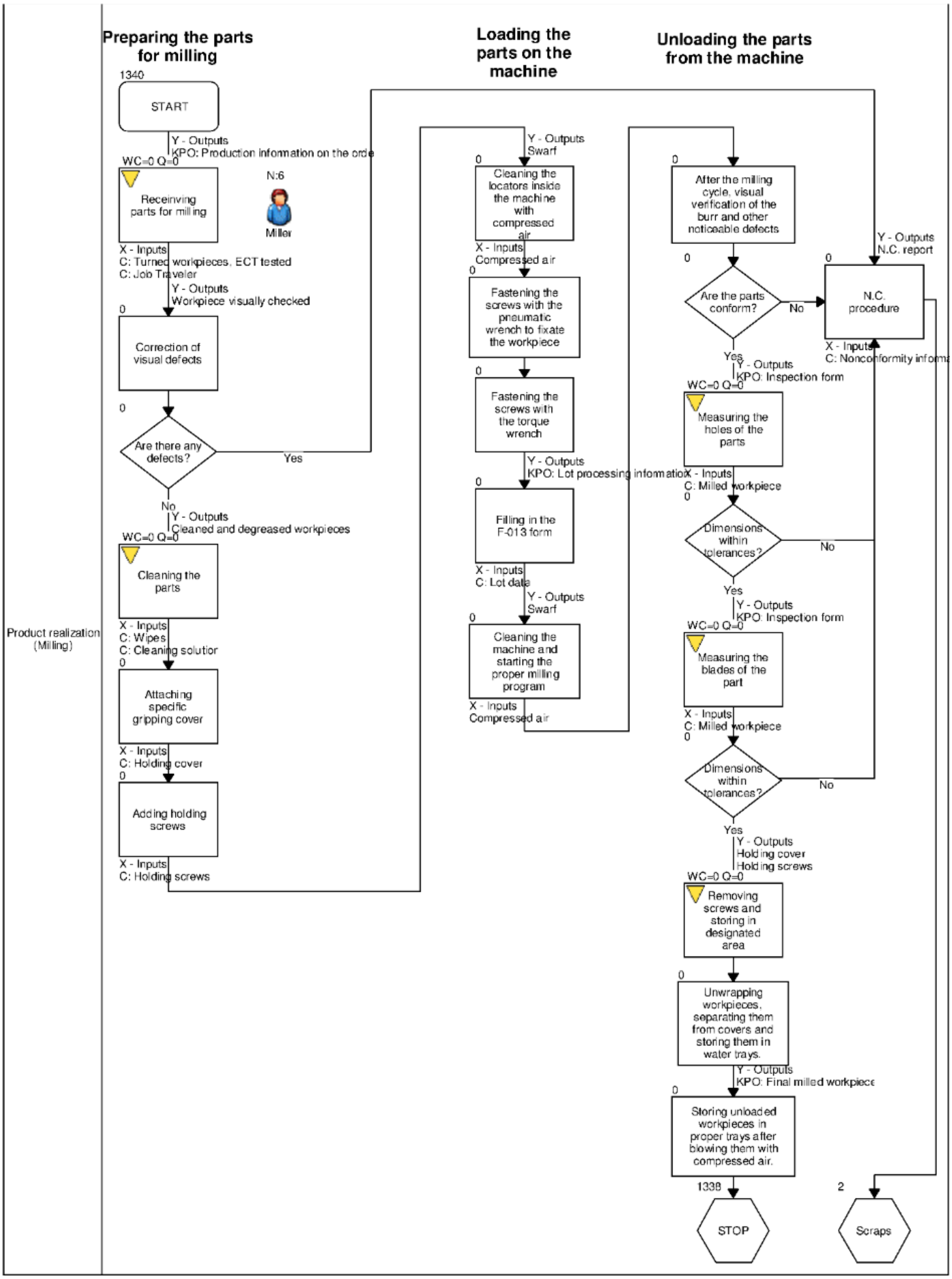


Figure 31. Simulation of the milling process

The milling process is composed out of three main stages: part preparation, part loading and part unloading, each with its own activities (see Figure 31). Due to the complexity of the process there are numerous “Work Centers”, which streamline the manufacturing flow in the critical parts of the process.

There are 6 operators, two for each milling machine, which carry out the tasks within the process. The resource allocation is made dynamically, meaning that for each activity minimum 1, maximum 6 resources are used. This way, blockages are reduced and a smoothening of the workloads is obtained. Figure 31 depicts the simulation process flow with all its activities.

The simulation for this process was designed to have two outputs: one for conforming parts (leading to “STOP”) and one for non-conforming parts (leading to “Scraps”). After running the simulation, it can be observed that the number of scraps is very few, such as it was observed in the case of the real-life process: out of the 1340 entries, 1338 workpieces and two scraped parts are obtained.

The distribution of outputs regarding the time in simulation can be viewed in:

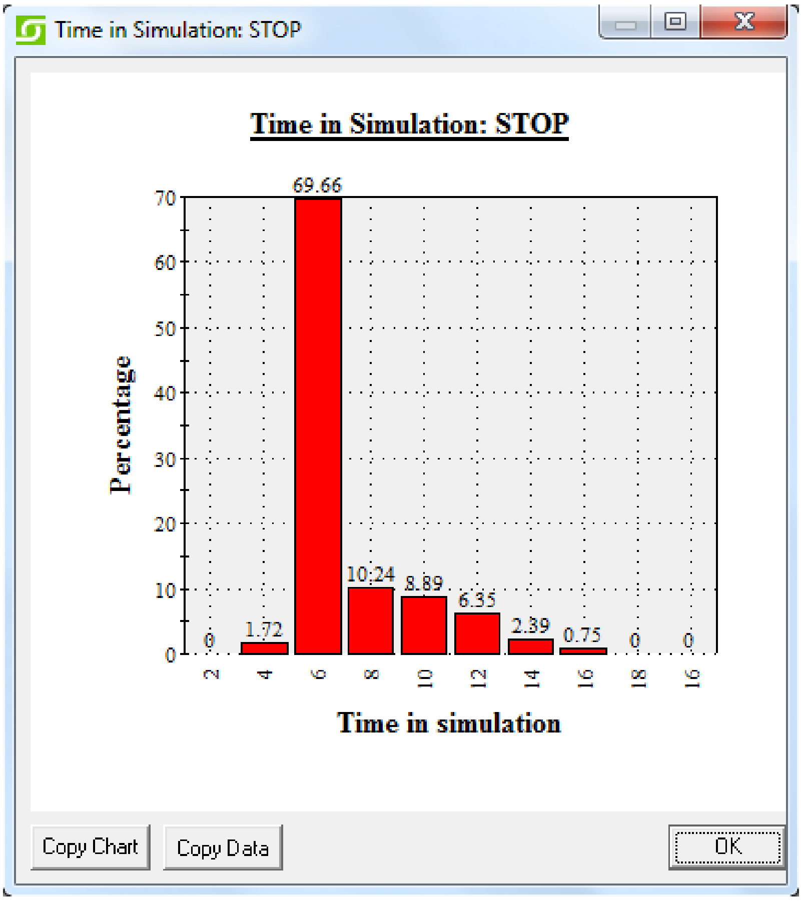


Figure 32. The output distribution for the milling process

Approximately 91% of outputs fall within limits close to the median of the graph. From this we can conclude that the process is robust and it functions between well-defined parameters, even if it is a process of high complexity.

As it can be seen, there are no blockages identified within the process flow, as all work centers and process blocks are accompanied by the number 0, meaning that there are no blocked parts. This is due to the maturity of the process, as it was implemented 4 years ago and since then it underwent all sorts of improvements. In case blockages would have been identified, they could have been traced back to a certain activity and improvements could have been focused on that particular area of the process. However, there are two scrap parts obtained at the end of the process, meaning that there is still room for improvements, but from the quality point of view. For this it is proposed to analyze the inputs and outputs, prioritize them and dispose improvement measures that target the key process inputs of outputs (KPI & KPO).

The importance of inputs & outputs is calculated by analyzing the correlation between them within a "Cause & Effect Matrix" (Figure 33). Other tools can be used just as effectively, depending on the need of the application (AHP, QFD, etc.).

By completing the matrix with numbers on a scale of 1 to 5 signifying the correlation between inputs and outputs (1 weakest, 5 strongest) and the "rating of importance" section with numbers between 1 and 10 signifying the importance of each output (1 lowest, 10 highest), the importance of each input is calculated in percentage. Knowing this information, measures can be proposed to reduce the scrap and to improve the process in question.

			#	1	2	3	4	5	6	7	8	9	10	11	12			
			Rating of Importance	8	3	1	6	1	5	9	3	7	7	2	2			
			Outputs	KPO: Production information on the order	Workpiece visually checked	Swarf	KPO: Lot processing information	Swarf	N.C. report	KPO: Final milled workpiece	Cleaned and degreased workpieces	KPO: Inspection form	KPO: Inspection form	Holding cover	Holding screws			
#	Activity Name	Item / Function / Input	Type													Total	%	Potential / Vital X
1	Receinving parts for milling	Turned workpieces, ECT tested	Controllable	5	3	0	2	0	3	5	0	3	3	0	0	163	11.70	
2	Receinving parts for milling	Job Traveler	Controllable	5	3	0	2	0	3	5	0	5	5	0	0	191	13.71	Yes
3	Attaching specific gripping cover	Holding cover	Controllable	0	3	1	0	1	0	5	0	0	0	5	5	76	5.46	
4	Adding holding screws	Holding screws	Controllable	0	3	1	0	1	0	5	0	0	0	5	5	76	5.46	
5	Cleaning the locators inside the machine with compressed air	Compressed air		0	2	3	0	3	0	1	1	0	0	0	0	24	1.72	
6	Filling in the F-013 form	Lot data	Controllable	5	0	0	5	0	0	5	0	4	4	0	0	171	12.28	
7	Cleaning the machine and starting the proper milling program	Compressed air		0	2	3	0	3	0	1	1	0	0	0	0	24	1.72	
8	N.C. procedure	Nonconformity information	Controllable	2	3	0	3	0	5	2	0	5	5	0	0	156	11.20	
9	Cleaning the parts	Wipes	Controllable	0	0	2	0	2	0	1	5	0	0	0	0	28	2.01	
10	Cleaning the parts	Cleaning solution	Controllable	0	0	2	0	2	0	1	5	0	0	0	0	28	2.01	
11	Measuring the holes of the parts	Milled workpiece	Controllable	5	3	1	5	1	4	5	0	5	5	3	3	228	16.37	Yes
12	Measuring the blades of the part	Milled workpiece	Controllable	5	3	1	5	1	4	5	0	5	5	3	3	228	16.37	Yes
			Total	216	75	14	132	14	95	369	36	189	189	32	32	**1393**		

Figure 33. Cause & Effect Matrix

Table 21. Improvement measures for KPI

Input	Calculated score	Proposed measures for improvement
Milled part	456	- the milled part must be controlled by training personnel, by keeping the maintenance plan of the machines, by using a high-quality cooling emulsion and by improving the efficiency of work instructions.
Job traveler	191	- employees must be made aware of the importance of completing the Job Traveler document, as situations were identified when the JT was not completed; raising the awareness could solve this issue.
Lot data	171	- lot data must be available at any given moment within the manufacturing cycle; its availability could mean the difference between OK and NOK workpiece.
Turned parts, ECT tested	163	- ECT inspection needs to be done for each workpiece; due to high rpm, a small crack could lead to part disintegration, hence turbine destruction, but through a rigorous testing warranty, service and client compensation costs can be eliminated; special attention must be assigned to this type of inspection and awareness must be raised amongst employees.

1.3. Conclusions

Within this chapter it is demonstrated the possibility of realizing an ample simulation for an entire production system outlining the following benefits from the process management point of view:

- simulations provide detailed information about the stages or operations within the manufacturing cycle, as well about the interactions they have, which leads to a better understanding of them by the employee and to an optimized performance of the system by eliminating redundancies, unproductive work times and blockages;
- the mathematical aspects of the simulations (allocating the operation and the inter-arrival times based on probability distributions) as well as the discreet simulation functions of the Sigma Flow Modeler software allow in-depth understanding and optimization of process parameters, like: employee workloads, percentage of scrap and process capability by determining the final result distributions;

- the detailed tracking and in-depth observation of the manufacturing cycle (with the help of the robust instruments that the software provides for each process) allows corrective intervention based on empirical data, leading to rapid achievement of high performance.

The limitations of this approach are concentrated within the company's ability to implement measures that are based on obtained information.

2. Assistive AR environment for quality inspection and statistical process control

2.1. General and conceptual aspects

In the first part of the current thesis, within the "State of the art" cutting edge technological solutions are presented, employed by today's manufacturing companies for ensuring that their products meet required specifications. The focus is put on quality control technologies that control multiple fabrication processes in an active way (Segovia, et al., 2015) and newly developed ICT instruments are increasingly present in today's manufacturing (Newman, Chang, Walters, & Wills, 2016) (Colledani, Pedrielli, Terkaj, & Urgo, 2013) (Ghinea, Popescu, Neamțu, Hurgoiu, & Popișter, 2014).

Augmented reality (AR) and its associated smart devices (smart glasses, tablets and other mobile devices) experienced an exponential growth regarding their use on the factory floor. They constitute a technology that is very appealing to workers and operators engaged in activities on the factory floor as it combines real world elements acquired using different computer vision techniques with computer generated elements. The principle on which this technology operates is quite simple: natural features of different real-world elements are used as trackers, which trigger computer-generated elements to be displayed on screen on top of the camera-captured real-life feed. As mobile devices that are capable to operate these AR applications have increased during the last years, the number of developers and researchers working within this field increased as well.

Motivating the research endeavour subject of this chapter by the above-mentioned aspects, the author of this thesis focused on the development and use of virtual type instruments that support the quality approach, but at the same time bridge the gap between currently employed industrial solutions and practices promoted by Industry 4.0. In this sense, advantages offered by smart devices alongside AR mobile applications and a web platform are developed with the potential to be introduced straight into production and used on the factory floor to empower the workers and boost the organization's quality capabilities through the virtual environment.

The solution proposed here comprises of a package of two instruments used concurrently for both quality inspection and statistical process control – an AR mobile application and a web platform – and it illustrates their combined effectiveness and importance in different manufacturing environments. The synergy between the two is emphasized in scenarios where complex operations are carried out and the part dimensional validation is primordial for future actions.

The AR mobile application serves as a virtual assisting tool for the operator, helping him to understand all information regarding the workpiece and its dimensional values, all this in a visual manner, which is very user-friendly, familiar and intuitive. This kind of application reduces the need for expert supervision in the manufacturing plant, overcoming the necessity to use 2D CAD layouts, which may be fully understood only by some employees who have the required expertise to assimilate these layouts, especially in the case of complex assemblies.

To cope with this issue, many companies replaced 2D CAD layouts with 3D CAD documentation, however their visualisation systems use only digital representation limited to complex assemblies and data sheets without any real-life inclusion or interaction.

The added value of the proposed application is that it makes use of real parts and adds an extra layer of visualization to these real parts using computer vision offered by the tablet or smartphone camera. The technology and hardware capabilities of these devices have a great potential for real time visualisation and processing due to their high computational speed, high resolution of the integrated camera and their ease of use.

Alongside the developed application a web platform was created as well, which was designed to be a safe, simple and reliable solution for inputting, storing, analysing and retrieving information from workpiece measurements.

2.2. Illustrative example

The AR application was developed using an open source code (presented in Annex 7), imported and extended in the “Unity” and “Android Studio” software programs, through which given features (trackers) can be identified in real-life, which in turn can be associated with computer-generated elements. In this case, the real-life element is a demo workpiece (illustrated in Figure 34), upon which the virtually recreated annotations, tolerances and other information is laid on top using “edge tracking” techniques for positioning.

The functionality of the application and the web platform is done using a demo cube-shaped workpiece (Figure 34), made out of aluminium with plenty of dimensions to track on each side. The AR mobile application detects the side of the workpiece and it virtually overlays information about the nominal values of the dimensions and their tolerances. Each side and dimension was numbered so that the operator knows exactly which is the dimension that he refers to and where he has to input the values, which will be uploaded to the web platform's database.

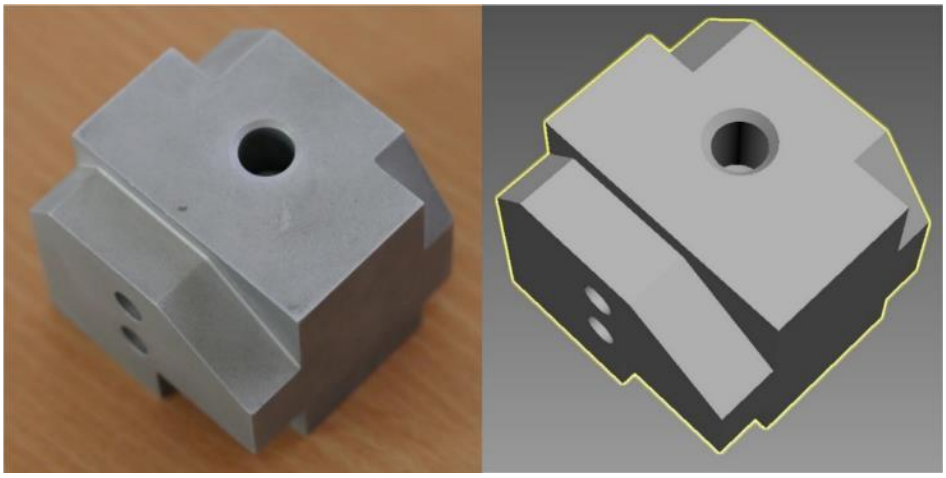


Figure 34. The workpiece and its CAD 3D model

Each facet of the workpiece, containing elements with dimensional values and their tolerances, was recreated using CAD and linked to its virtual counterpart. When the device's camera detects a certain facet of the workpiece its corresponding virtual information is superimposed in real time.

In addition, the facets were assigned a number, therefore the operator that will input the values in the database will be able to assign measured values with ease. Figure 35 illustrates two facets of the workpiece, the image is a perspective view and it has been extracted from the CAD software (3ds Max) used to create them.

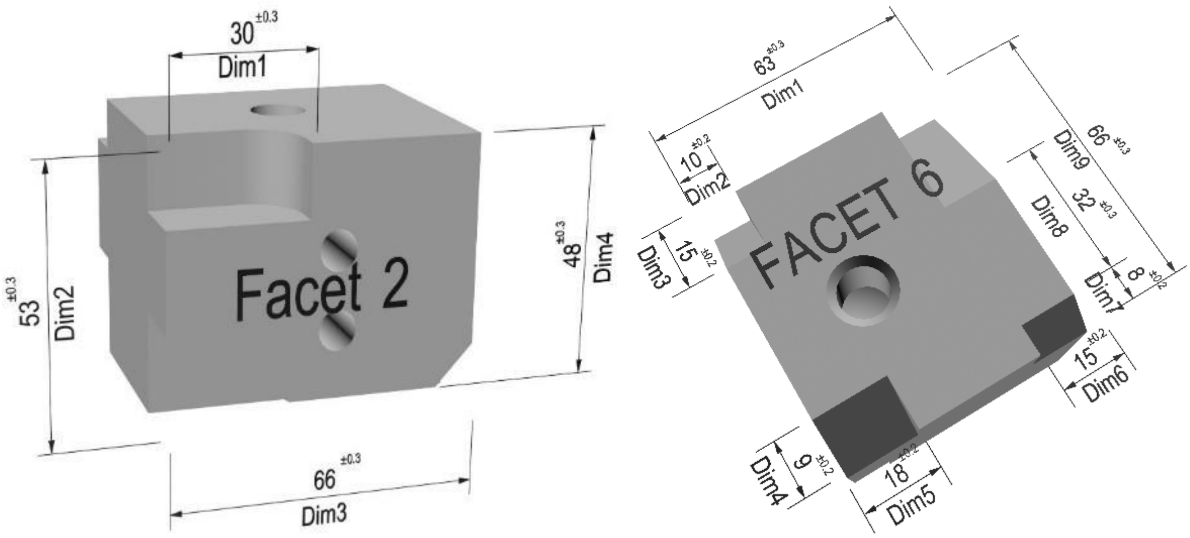


Figure 35. The dimension values and their tolerances of two facets of the workpiece

The steps for handling the AR application, linked with the web platform (and it's database) are easy, intuitive and user-friendly and the solution was designed to be as simple as possible to avoid additional training for the employees. These steps and additional explanations are presented in the following:

- Installing and starting the AR application;

The application can run both on smartphone and tablet or on any Android equipped device. It needs a one-time installation using the .apk file, after which the application can be opened by taping its icon in the menu. In order to speed up the application's edge detection system the user is required to input the ID number of the workpiece. This process will enhance the augmented reality speed since it will only have to compare a limited amount of edges from its database with the edges obtained using the device camera.

- Positioning the camera over a facet of the workpiece;

Soon after starting the application it will process the image offered by the camera and overlay the correct annotation on top of the part (see Figure 36). In the current system, the application is set to a delay of 2 seconds, this delay has a main purpose in improving the detection speed by limiting the input images that the system analyzes.

- Reading the nominal value(s) and the dimension number(s) of the geometrical dimension that will be measured on the workpiece;

The user only has to see the workpiece through the mobile device's screen in order to display the proper nominal values. In the meantime, he is also able to manipulate and inspect the workpiece while observing different values on the screen. After the user knows exactly what dimension he is going to measure and has acknowledged the nominal value and tolerance he can proceeded to the actual measurement of the dimension using a measuring device, for example a caliper.

- Opening the web platform;

After measuring the dimension, the web platform can be opened using a standard web browser. First, the login screen will appear in which the user has to input his credentials. By doing so, unauthorized access is prevented and traceability for inputted values is obtained. (Figure 37).

- Selecting the measured dimension and the dimension number corresponding to it;

After login, the operator will be able to select interactively the side of the workpiece and the dimension number from the two dropdown menus (See Figure 38). These will be linked with the value entered in the textbox below. The "Record dimension" button will upload the value into the database. If the measured dimension value is within tolerances a message will appear advising the user that the "Dimension was recorded successfully", otherwise he will be warned that the "Measured dimension is out of tolerance" (see Figure 41 for example).

The last step can be repeated as many times as there are workpieces that need to be measured and their dimensions monitored.

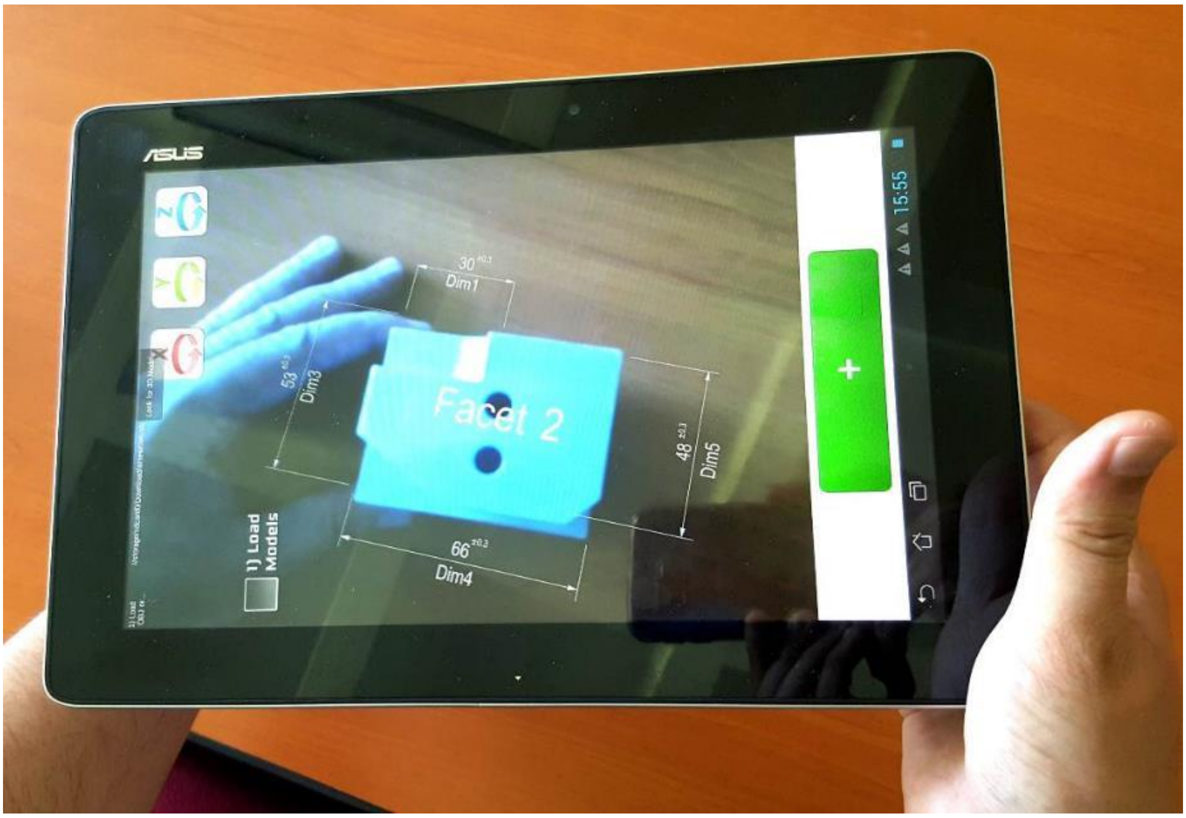


Figure 36. Visualizing the annotations in AR

For reasons of security, reliability and user traceability the web platform was designed and created separately from the application, using the simple and robust html programming language. The hosting of the platform was made possible using a free service, considering the illustration purposes of this exercise, but it can be replaced anytime with a paid, more professional service. Developing the two instruments separately brought forth another advantage and made it possible for the web platform to be accessed from any device (mobile or stationary) without being strictly tied to the Android operating system as it is the case of the AR application.

The layout of the platform is quite simple and intuitive and it was kept this way in order to avoid bugs or other failures (which are very undesirable in an industrial environment) and to be as user-friendly as possible. Its simplicity makes it appealing to both experienced and unexperienced users and makes it ready to use without a long training session. Below, captured screenshots of the web platform's design are presented alongside their description:

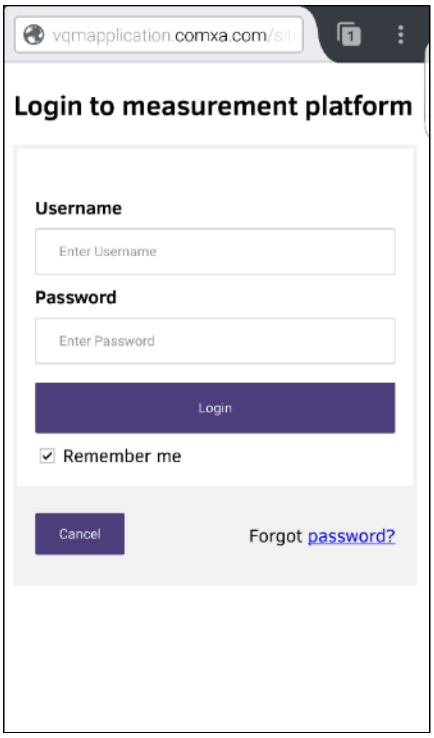


Figure 37. Login screen

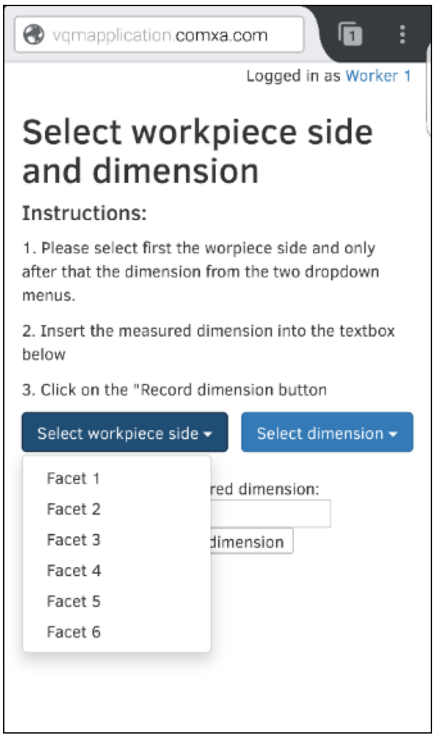


Figure 38. Workpiece info

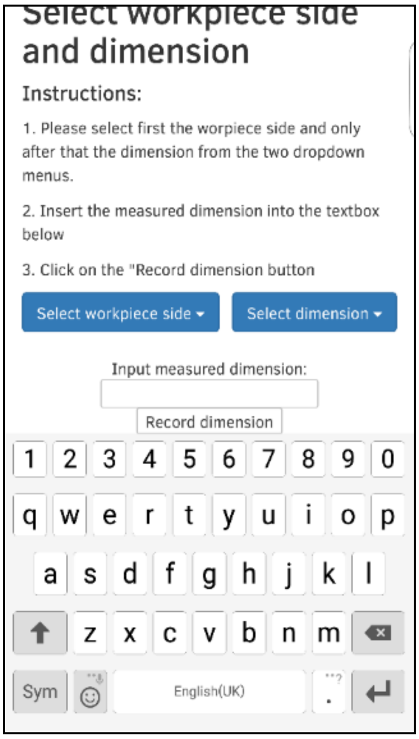


Figure 39. Record dimension

Figure 37 represents the login screen, it appears when accessing the web platform's address and it asks the user to log in. Depending on the rights that the user has he is capable to view reports of previously recorded values in the form of bar or control charts or just enter values into the database. These features, however, will be detailed below and are available only to users with administrator access (see Figure 42).

Figure 38 depicts home screen of the platform for an operator that logged in with basic rights. In this example, it can be seen on the top right corner of the screen that the logged in user is "Worker 1". The operator is reminded about the steps he needs to take in order to record a value into the database using the two dropdown menus (the first one for selecting the facet of the workpiece and the second one for selecting the number of the dimension – example of how the facets and the dimensions are numbered can be consulted in Figure 35).

In Figure 39 it can be seen that when taping the textbox below the "Input measured dimension:" label the keyboard appears making it possible for the operator to input the measured value. Once the "Record dimension" button is tapped the entered value is recorded and uploaded to the database.

The platform is equipped with control rules, which check whether the entered dimensions are within tolerances or not or if the measured values comply with the eight Nelson rules (Nelson, 1989) used for detecting "out-of-control" values. This set of rules is among the most used ones for interpreting control charts and it establishes whether a process needs intervention (corrective actions), based on final or intermediate results. The values of measured dimensions are recorded online and disposed into control charts and when a new dimension is entered into the database it's verified if it's not in conflict with the following eight conditions (Nelson rules):

Table 22. Nelson rules

Rule no.	Description
1	One or more points are disposed at more than 3 times the standard deviation (or 3σ) from the mean.
2	Nine or more consecutive points are situated only on one side of the mean.
3	Six or more consecutive points are on the same ascending or descending curve.
4	Fourteen or more consecutive points oscillate shifting their domain from one point to another, ascending then descending suddenly.
5	Two (or three) of three consecutive points are situated at more than two times the standard deviation from the mean, in the same domain.
6	Four (or five) of five consecutive points are situated at more than one standard deviation from the mean, in the same domain.
7	Fifteen or more consecutive points are situated within the first standard deviation limit, on both sides of the mean.
8	Eight or more consecutive points are situated on both sides of the mean, all exceeding the first standard deviation limit.

In case of an entered value that doesn't comply with the above-mentioned rules a warning will appear in real-time (e.g. Figure 41) and it means that operator must investigate why the last workpiece doesn't comply with the rule in question.

For example, let's presume that the operator is about to measure the Dim2 dimension on Facet 2, which has a nominal value of 53 mm with a tolerance limit of ±0.2 mm (in accordance with the (ISO 2768-1:1989) standard requirements, last revised in February 2012). After obtaining workpiece information with the help of the AR application the operator logs into the web platform using provided credentials. For illustration purposes only the last 20 values of this dimension are considered and presented in Figure 40 for showcasing the faulty value. If the measured dimensions are within tolerances, represented values on the chart range from 52.8 mm to 53.2 mm, disposed between the two orange lines on the graph (which are the upper and lower tolerance limits). When a new value is entered in the database the algorithm behind the web platform firstly calculates the mean (represented on the chart as $\bar{x}$), which is the average of all collected values, and secondly the standard deviation (represented as σ).

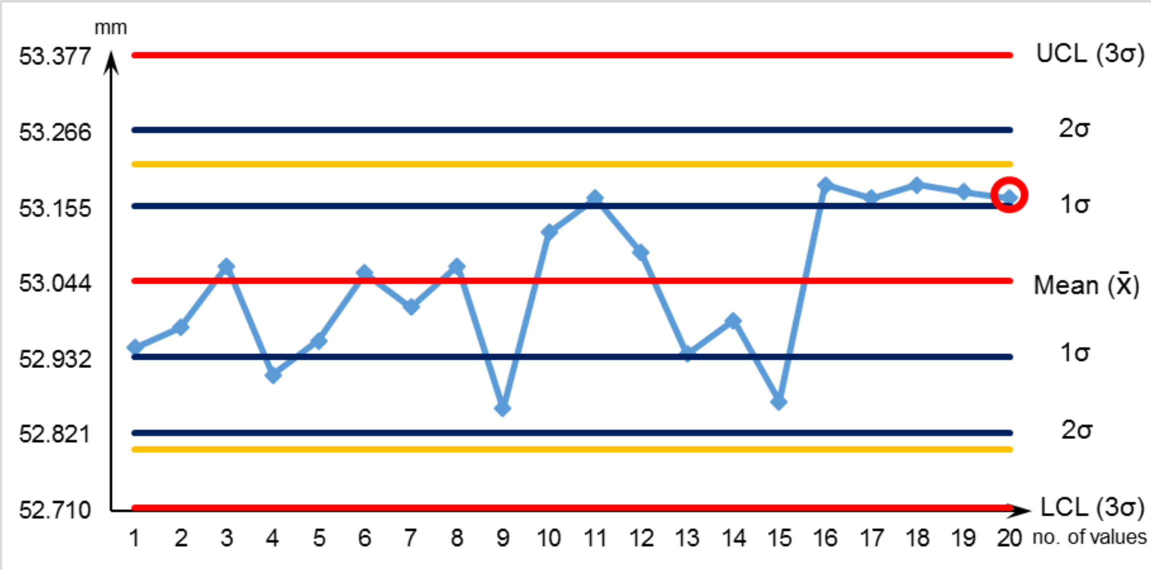


Figure 40. Control chart for Dim 2 on facet 2

Figure 40 depicts a chart that is divided into 3 zones on both sides of the mean by two dark blue lines (one and two times the standard deviation – 1σ & 2σ) and one red line (representing three times the standard deviation 3σ – coinciding also with the upper and lower control limits). The measured value (which is entered into the textbox on the web platform) is compared to previous values for making sure that the eight rules are respected. In the example from Figure 40 the final value entered is 53.17 (circled in red), which is within tolerances, but doesn't respect the 6th Nelson rule, which states that four (or five) of five consecutive points are situated at more than one standard deviation from the mean, in the same domain. Although the value is within tolerances, this is a clear indication that there is something wrong with the manufacturing process and the operator at that point is advised that further investigation is needed. A warning will pop-up relating him this issue:

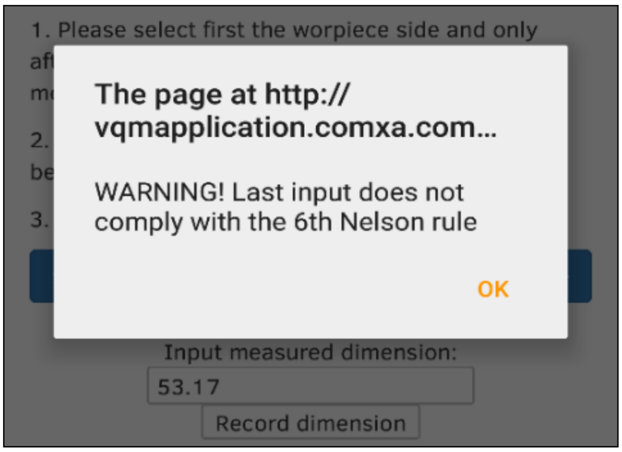


Figure 41. Screen capture with error

Aside from real-time statistical process control, the web platform can generate a number of charts based on recorded values, thus helping the user to monitor and control the manufacturing processes. They provide accurate information about how the processes function in time and whether or not they are stable and centred. Currently, the platform is capable of arranging recorded values into three types of charts, control chart, histogram and bar chart, but further development actions will focus on including other commonly used quality control charts as well, such as the Pareto diagram or correlation diagram. However, this feature is only available to users with administrator rights, the login form is the same as in Figure 37, but once logged in an additional instruction and button will appear on screen, just as in Figure 42.

As it can be seen in the "Supervisor UI" the "Generate charts" button is additional compared to users with regular access. It redirects to another page of the platform with supplementary instructions on how to display the required chart on screen. The page contains four dropdown menus from where the user selects chart type, how many values to display, workpiece side and dimension number (Figure 43). The "Display chart" button generates the chart with the selected information and displays it on screen. An example in this sense can be seen in Figure 44, which displays a histogram for the last 50 values of dimension 2 from side 2 of the workpiece. The nominal value of this dimension is 53 mm with a tolerance of ±0.2. The user can then interpret this information and take the proper actions for the processes.

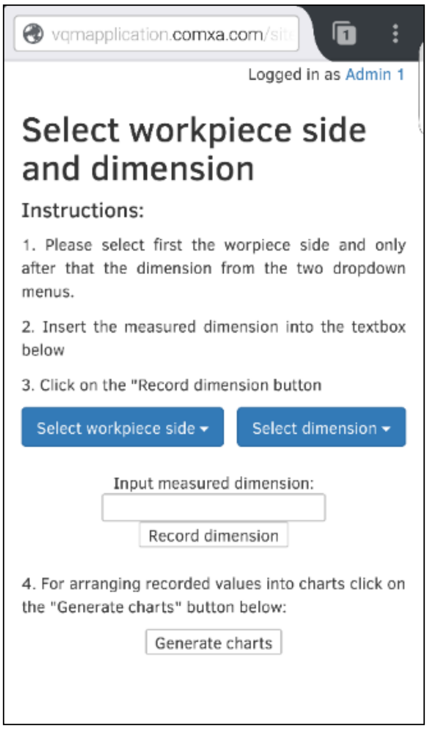


Figure 42. Supervisor UI

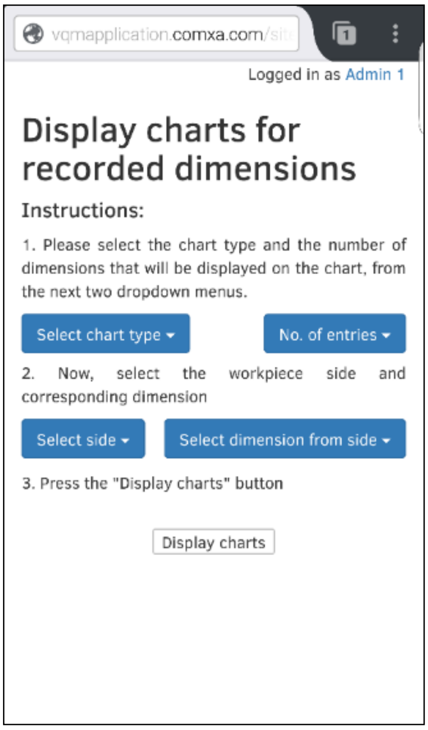


Figure 43. Chart generation

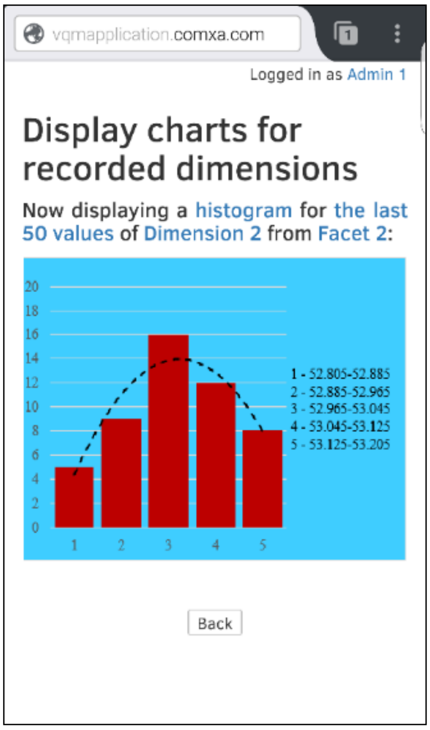


Figure 44. Chart display

2.3. Conclusions

The developed solution detailed in this chapter illustrated the possibility that an augmented reality application paired with a web database can prove to be a valuable tool for inspecting manufactured workpieces and monitoring and controlling related processes.

The AR application's use within an industrial environment enables the operator to have a better understanding and or even functioning of the processes by measuring their provided outputs (such as workpiece information). The web platform, on the other hand, warns the operator about imminent problems that the processes might encounter, providing him with information for proper corrective or preventive actions. Thus, the combination of the two instruments not only allows the inspection of individual parts, by verifying whether or not their dimensions are within tolerances, but provides an additional level of control essential for reacting in due time to possible unwanted process changes. This leads to eliminating downtimes and reducing overall production costs.

As the solution records and tracks information about all inspected workpieces, it conducts statistical analysis upon their values, which, in turn, enables for making forecasts and predictions about the overall manufacturing process.

Using this system, the workers that measure the parts don't require advance training and qualification, thus reducing the overall quality control costs.

The proposed assistive system comes to eliminate error possibilities within the measuring process, thus reducing the execution time and automatically storing all the required information in the web database. This way supervisors can analyse the automatically generated control charts for a better monitoring of the whole fabrication process.

On the other hand, there are some limitations to how this solution can perform. One of the most constant challenge that still hasn't been properly addressed is related to the illumination of the environment from which the application needs to acquire images. Excellent lighting conditions must be assured for it to function properly and without any delays or errors.

The constant internet connection is another disadvantage as the proposed system needs it in order to upload values to the web platform's database. In some industrial environments can be difficult to address this issue, however it can be solved by using a local wireless network through which the devices communicate with a local server, to which all data is uploaded.

The creation of the digital dimensional values and tolerances that will be superimposed over the real parts in the augmented reality application is time-consuming and tedious.

Currently this step is done manually within a CAD software, but it could be automated using different scripts.

Future development directions can be proposed for the AR application. For example, a feature can be included for increasing the value input speed by allowing the user to highlight a certain geometrical dimensional by double tapping it. Doing so, the application will change the color of that value and when the user accesses the web platform, the side and dimension number will be automatically selected and he just has to input the measured value into the textbox.

Previously, a limitation of this solution was mentioned regarding the need for a continuous internet connection. This aspect can be overcome by storing the data locally, within the memory of the mobile device and when an internet connection is available all values would be uploaded to the database. However, this approach does not offer real-time processes monitoring.

The developed instrument is not limited to a certain quality control operation, specific to the workpiece on which the example was presented. Its preparing and functioning is flexible and allows the inclusion of other 3D information that is related to different workpieces.

The future goal and vision of this system is to develop augmented reality applications and web databases into a support tool that can be used for almost any manufacturing and quality control system.

Conclusions and synthesis of contributions

1. Conclusions

The research endeavors undertaken within the thesis followed four methodologies corresponding to the four sections of chapters 3 and 4. They were described at a theoretical level, detailing their steps and interactions between them, but were also accompanied by illustrative examples that prove their applicability and demonstrate their compliance with real-life scenarios for which they were designed.

In the case of the LSA-based methodology, the research aimed at two aspects: analyzing the common knowledge space in specific areas by intersecting the knowledge structures obtained through a concept disambiguation process; determine the technological solutions that are expected to emerge from that concept intersection space. Particularly, it was analyzed the possibility of identifying emergent industrial applications by intersecting the knowledge structures of two concepts: vQM and Industrie 4.0. The methodology was validated by applying an online questionnaire to experts (from the field of quality) with close ties to the automotive industry and their responses confirm its reliability with an average margin of error of just under 4%. Among the advantages that this methodology offers it can be mentioned that:

- the intersection of two or more knowledge structures formed around individual concepts provides a common knowledge space that serves as an "incubator" from where future research directions are expected to emerge;
- it has a high degree of objectivity, as unlike the classic literature review, does not depend on the competence of the reviewer;
- the number of scientific references analyzed is significantly greater, thus increasing the accuracy of the results;
- the time needed to deploy this type of analysis is reduced to a few seconds, presuming the references are already selected;
- it has a high degree of portability, as it can be applied to any concept associations;
- in a broader understanding, it offers forecasts for applications that are more likely to become popular in the next period of time and by focusing on their development and implementation organizations could gain a competitive advantage.

The second methodology was designed based on the vQM model, which was adapted to product development. By doing so, it came to incorporate competitive design practices, which keep the focus on customer needs throughout the design process and optimization techniques, which find the optimal solutions to certain conflicts between the client's requirements and resources needed for complying with them. The framework was applied to the development of a common household object that fulfills all requirements, but its mass and, implicitly, its material consumption is minimum. The novelty of this approach lies in the following aspects:

- the deployed virtual instruments generate resilient knowledge for the product's design, thus minimizing physical resources involved in the development stage and reducing risks associated with product acceptance
- obtaining optimized component specifications / information based on customer requirements in relation with the whole product;
- the framework requires input from in effect standards, as well, thus assuring the designed product's manufacturability;
- by focusing the optimization process on the individual components, the applicability of the framework is not limited and it can be used regardless of the product's nature;
- the illustrative example proves the effectiveness of the framework, as an overall 27% in mass reduction was obtained for the product in question.

Apart from product improvements, presented above, the thesis proposes an approach for process improvements, as well. In this regard, the simulation of an entire production system was attempted with the purpose of pinpointing problems within the functioning of the manufacturing processes and proposing objective measures that can increase the overall efficiency of the system. From the process management point of view, the following benefits can be outlined:

- simulations are able to provide a virtual representation of the real-life processes, thus their functioning can be analyzed thoroughly and it can be better understood, without committing additional resources, which in turn leads to the elimination of redundancies, unproductive work times and blockages;
- the parameters of each process (time allocation for every operation, involved resources, employee workloads, etc.) can be fine-tuned for obtaining maximum efficiency of the whole manufacturing cycle;
- the corrective interventions are based on empirical data, leading to rapid achievement of high performance.

The second applicative development is referred to the development and design of an AR mobile application (that can be run on any Android device) used in conjunction with a web platform. The assistive augmented environment empowers operators on the factory floor, thus virtually enhancing, simplifying and making their activities more efficient that are related to quality inspection. The added value of this solution can be found in the following aspects:

- real-time process monitoring by arranging collected data into charts (e.g. histogram, pareto diagram, control chart, run chart);
- real-time imminent failure notification, allowing the supervisor to take action before the manufacturing process provides flawed outputs;
- based on the statistically relevant data, forecasts and predictions can be made about the future functioning of the fabrication cycle;
- eliminates the need for complex 2D drawings and reduces the effective of qualified personnel assigned with reading and understanding them;
- from the operators' perspective, it provides them with a technology they are familiar with in their daily lives (AR mobile applications), which is more appealing to them than a solution they encounter only at work.

2. Original contributions

The thesis brought forth both theoretical and practical contributions regarding the utilization of virtual-type solutions for supporting quality management in the context of the modern industrial developments and practices.

At a conceptual level, a novel disambiguation method is proposed (using natural language processing), that contributes to the synthetization of the virtual Quality Management concept with the help of computational linguistics, as it's a fairly new notion and it is subject to a high dynamic development. The methodology employed for this purpose also reveals trending industrial applications / technologies closely associated with vQM and the Industrie 4.0 model, which are grouped and ranked throughout the Product Life-Cycle. The validity of this approach is confirmed through surveys applied to experts with strong ties to practices employed in the automotive industry.

At a theoretical level, the contributions are related to the adaptation of the vQM architecture (model) to product development, thus enabling the optimization process (using genetic algorithms) to focus on the product's design, without disregarding initially stated customer requirements. The outcome of this approach reflects both competitive development practices and the positive influence of the optimization technique, being a mixture of the two.

Within the applicative contributions two solutions are developed, which made use of the virtual environment offered by computational devices, thus being highly effective in supporting an organization's demarche and preoccupation for quality. They are designed in such a way that are easy to implement and don't require high level training for the personnel involved in their use. In fact, they even come to simplify previously used practices and eliminate bottlenecks, making the activities within the organization more efficient. Moreover, the resources that are needed to apply these solutions are low, and make little or no disturbances in the well-established production flow of any company, thus responding and countering the potential rigidity from the firm's part regarding their implementation into the manufacturing process.

Considering the above-mentioned key aspects, below are presented in a synthetic manner all contributions incorporated throughout the thesis:

- identifying and describing regional strategies at a global level, developed by nations with strong industrial background for coping with the fourth industrial revolution's principles;

- demystifying the "Industrie 4.0" model by identifying and describing its design principles and main pillars and by coding the interactions between them with colors (the significance of colors is also explained);
- bibliographic synthesis within the selected topic and conducting a critical analysis of the virtual-type solutions used in all stages of the PLC that support the quality demarche;
- disambiguating the concept of vQM with the help of a methodology based on natural language processing and identifying applications that are expected to emerge from the common knowledge density zone resulted from the intersection of the vQM and Industrie 4.0 specific knowledge structures;
- developing a framework for product development based on the architecture of vQM incorporating competitive design and optimization techniques;
- improving the real-life processes of an existing SME from the automotive sector, by simulating them, thus identifying downtimes, bottlenecks, misuse of resources and proposing suitable measures;
- developing an AR mobile application and a web platform for assisting operators on the factory floor involved in quality inspection activities.

Regarding contributions that were not included in the thesis, but are related to its topic and resulted from the doctoral study period they were either published in internationally indexed journals or presented at international conferences. The most representative are:

- developing a low-cost 3D laser scanning solution applied to measurement and conducting virtual deviation analysis between the real-life workpiece and the scanned model (disseminated in: Popescu, Daniela; **Bodi, Ştefan**; Neamţu, Călin; Ursa, Nicușor; Low cost 3D laser scanner used for measurement; Proceedings of the 11th International Scientific Conference on "Coordinate Measuring Technique", pp. 155-160, ISBN 978-83-63713-88-1, 2-4 April 2014, Bielsko-Biała, Poland; indexed **SCOPUS**);
- improving the quality of an R&D project by using process simulation software (disseminated in: Dragomir, Mihai; **Bodi, Ştefan**; Iamandi, Oana; Dragomir, Diana; Applying Sigma Flow simulation software for improving the quality of an R&D Project; Proceedings of the 2014 International Conference on Production Research & 3rd International Conference on QIEM, pp. 152-156, ISBN 978-973-662-978-5, 1-5 July 2014, Cluj-Napoca, Romania; indexed **ISI Proceedings**);

- deploying structure optimization methods applied in the design of furniture products (disseminated in: Scurtu Liviu-Iacob; Bodi, Ştefan; Dragomir, Mihai; Optimization methods applied in CAD based furniture design; Acta Technica Napocensis - Series: Applied Mathematics, Mechanics and, Engineering, Vol. 54, Iss. 4, pp. 559-562, 2015, ISSN 1221-5872; indexed **ISI – ESCI**);
- deploying FMEA method for improving the design of a mold used for plastic injection (disseminated in: Neamţu, Călin; Bodi, Ştefan; Ghinea, Rareş; Papp, Attila; Failure Mode and Effect Analysis for mold design; Acta Technica Napocensis - Series: Applied Mathematics, Mechanics and, Engineering, Vol. 54, Iss. 4, pp. 533-536, 2015, ISSN 1221-5872; indexed **ISI – ESCI**);
- deploying TRIZ method applied for innovating the design of plastic furniture products (disseminated in: Solcan, Sergiu; Neamţu, Călin; Ghinea, Rareş; Bodi, Ştefan; Using TRIZ method for support innovation in developing plastic parts; Acta Technica Napocensis - Series: Applied Mathematics, Mechanics and, Engineering, Vol. 54, Iss. 4, 2015, pp. 605-608, ISSN 1221-5872; indexed **ISI – ESCI**).

3. Future research directions

The future directions of already tackled scientific endeavors presented throughout the thesis consist mainly in improving and making more effective the developed solutions / methods. In this sense, the following research actions are formulated that can be undertaken in the near future:

- improve the LSA-based methodology used for concept disambiguation such that it will be able to directly identify specific applications related to a certain concept, not only associated notions;
- further develop the vQM model to incorporate solutions that support not only product and process planning, but also innovation (e.g. LEAD user method);
- develop and define virtual performance indicators that can certify the robustness of a simulated process;
- improve the compatibility of the AR application with the web platform regarding the information transfer between them, thus increasing the measurement input speed and implicitly improving the efficiency of the quality inspection activities;
- include additional chart-types in the web platform that provide further information for supervisors monitoring the manufacturing processes in real-time time.

4. List of publications

The research results of this thesis and from the doctoral study period were disseminated in numerous research articles, presented at conferences or published in journals indexed by ISI Thomson Reuters or other international databases. They are presented as follow in chronological order:

Publications indexed by ISI Thomson Reuters:

1. Dragomir, Mihai; **Bodi, Ștefan**; Iamandi, Oana; Dragomir, Diana; Applying Sigma Flow simulation software for improving the quality of an R&D Project, Proceedings of the 2014 International Conference on Production Research & 3rd International Conference on QIEM, pp. 152-156, ISBN 978-973-662-978-5, 1-5 July 2014, Cluj-Napoca, Romania;
2. Neamţu, Călin; **Bodi, Ștefan**; Ghinea, Rareş; Papp, Attila; Failure Mode and Effect Analysis for mold design, Acta Technica Napocensis - Series: Applied Mathematics, Mechanics and, Engineering, Vol. 54, Iss. 4, pp. 533-536, 2015, ISSN 1221-5872;
3. Scurtu Liviu-Iacob; **Bodi, Ştefan**; Dragomir, Mihai; Optimization methods applied in CAD based furniture design, Acta Technica Napocensis - Series: Applied Mathematics, Mechanics and, Engineering, Vol. 54, Iss. 4, pp. 559-562, 2015, ISSN 1221-5872;
4. Solcan, Sergiu; Neamţu, Călin; Ghinea, Rareş; **Bodi, Ștefan**; Using TRIZ method for support innovation in developing plastic parts; Acta Technica Napocensis - Series: Applied Mathematics, Mechanics and, Engineering, Vol. 54, Iss. 4, 2015, pp. 605-608, ISSN 1221-5872;
5. Dragomir, Mihai; Dragomir, Diana; Popescu, Sorin; **Bodi, Ştefan**; Case study regarding teaching Design for quality at graduate level, Proceedings of the 3rd IETEC & 7th BRCEBE Conference, pp. 78-86; 1-4 November 2015, Sibiu, Romania; ISBN 978-0-646-94781-5.
6. Neamţu, Călin; Achelariţei Camelia; Anghel, Ion; **Bodi, Ştefan**; Designing a hardware platform for training operators of critical infrastructures, Proceedings of the 3rd IETEC & 7th BRCEBE Conference, pp. 342-350; 1-4 November 2015, Sibiu, Romania; ISBN 978-0-646-94781-5.

Publications indexed by international databases:

7. Dragomir, Diana; Cicală, Ioana; Dragomir, Mihai; **Bodi, Ştefan**; Proposed instrument for aiding in the implementation of a social responsibility management system, 2nd International Conference on Quality and Innovation in Engineering and Management, 22-24 November 2012, Cluj - Napoca, Romania; Published in a special issue of Quality - Access to Success. Vol. 13, Suppl. 5, 2012, pp. 123-126, ISSN 1582-2559 [indexed by Scopus];
8. Dragomir, Mihai; Iamandi, Oana; **Bodi, Ştefan**; Designing a roadmap for performance indicators in integrated management systems, 5th International Conference on Managerial Challenges of the Contemporary Society; 8-9 June 2012, Cluj - Napoca, Romania, Published in the journal Managerial Challenges of the Contemporary Society, Vol. 5, 2013, pp. 91-95, ISSN 2069-4229 [indexed by ProQuest];
9. Popescu, Daniela; **Bodi, Ştefan**; Neamţu, Călin; Ursa, Nicușor; Low cost 3D laser scanner used for measurement, Proceedings of the 11th International Scientific Conference on "Coordinate Measuring Technique", pp. 155-160, ISBN 978-83-63713-88-1, 2-4 April 2014, Bielsko-Biała, Poland [indexed by Scopus];
10. Dragomir, Mihai; Dragomir, Diana; **Bodi, Ştefan**; Pitic, Lucian; Dealing with component lifecycle disparity in smart furniture, Proceedings of the 3rd International Virtual Conference on Advanced Scientific Results, pp. 269-272, ISBN 978-80-554-1059-3, 25-27 May 2015 [indexed by Google Scholar];
11. **Bodi, Ștefan**; Popescu, Sorin; Drăgeanu, Călin; Popescu, Dorin; Virtual Quality Management elements in optimized new product development using genetic algorithms, Proceedings of the MakeLearn and TIIM Joint International conference, pp. 633-642, ISBN 978-961-6914-13-0, 27-29 May 2015, Bari, Italy [indexed by Google Scholar];
12. Drăgeanu, Călin; Bacali, Laura; **Bodi, Ştefan**; Research concerning the identification of performance indicators for tourist destinations on the internet, Annual Session of Scientific Papers "IMT Oradea", 28-30 May 2015, Oradea, Romania, published in the journal Annals of the Oradea University. Fascicle of Management and Technological Engineering, Vol. XXIV (XIV), Iss. 1, 2015, pp. 87-90 ISSN 1583-0691 [indexed by WorldCat];

13. Banyai, Daniel; Dragomir, Mihai; **Bodi, Ştefan**; Daylight for spaces defined by movable walls, 12th International conference on Modern Technologies in Manufacturing, 14-16 October 2015, Cluj-Napoca, Romania, Published in Applied Mechanics and Materials Vol. 808, 2015, pp. 239-245, ISSN print 1660-9336 [indexed by Google Scholar];
14. **Bodi, Ştefan**; Dragomir, Mihai; Banyai, Daniel; Dragomir, Diana; Process improvements using simulation software and quality tools, 12th International conference on Modern Technologies in Manufacturing, 14-16 October 2015, Cluj-Napoca, Romania Applied Mechanics and Materials Vol. 808, 2015, pp. 376-381, ISSN print 1660-9336 [indexed by Google Scholar];
15. **Bodi, Ștefan**; Comes, Radu; Weckenmann, Albert; Popescu, Sorin; Assistive augmented environment for quality inspection and statistical process control, Proceedings of the 2016 International Conference on Production Research & 4th International Conference on QIEM, pp. 494-499, ISBN 978-606-737-180-2, 25-30 July 2016, Cluj-Napoca, Romania [to be indexed ISI Proceedings];

Research papers under review

16. Weckenmann, Albert; **Bodi, Ştefan**; Popescu, Sorin; Dragomir, Mihai; Identifying trends in emerging concept spaces by constructing semantic knowledge structures – The case of Virtual Quality Management, [under review at “Journal of Knowledge Management”, **Impact Factor (2016): 2.053**];
17. Dragomir, Mihai; Popescu, Sorin; Neamțu, Călin; Dragomir, Diana; **Bodi, Ștefan**; Seeing the immaterial: A new instrument for evaluating integrated systems’ maturity, [pending editor’s decision at “Sustainability”, **Impact Factor (2016): 1.789**];
18. Popescu, Dorin; Popescu, Sorin; **Bodi, Ștefan**; A conceptual framework concerning education as factor of elders' acceptance for smart assistive technologies; [accepted for publication by the 8th BRCEBE & 10th ICEBE Conference, 19-22 October 2017, Sibiu, Romania].

References

1. Abramovici, M., & Lindner, A. (2011). Providing product use knowledge for the design of improved product generations. *CIRP Annals - Manufacturing Technology, 60*(1), 211-214. doi:10.1016/j.cirp.2011.03.103
2. Abramovici, M., & Lindner, A. (2013). Knowledge-based decision support for the improvement of standard products. *CIRP Annals - Manufacturing Technology, 62*(1), 159-162. doi:10.1016/j.cirp.2013.03.076
3. Alexandru, A. M., Fiasche, M., Pinna, C., Taisch, M., Fasanotti, L., & Grasseni, P. (2016). Building a smart maintenance architecture using smart devices: A web 2.0 based approach. *IEEE 2nd International Forum on Research and Technologies for Society and Industry Leveraging a better tomorrow (RTSI)*, (pp. 1-6).
4. Allen, R. C. (2006). *The British Industrial Revolution in Global Perspective. How Commerce Created The Industrial Revolution and Modern Economic Growth.* Nuffield College.
5. Alvarez, D., & Hidalgo, H. (2009). Document analysis and visualization with zero-inflated poisson. *Data mining and knowledge discovery, Vol. 19, Iss. 1*, 1-23.
6. Amandeep, S., Deepu, P., & Ramkumar, J. (2015). Quantifying green manufacturability of a unit production process using simulation. *Procedia CIRP Vol. 29*, 257-262.
7. Antmann, E. D., Shi, X., Celik, N., & Dai, Y. (2013). Continuous-discrete simulation-based decision making framework for solid waste management and recycling programs. *Computers & Industrial Engineering, Vol 65, No. 3*, 438-454.
8. Aydin, R., Kwong, C. K., & Ji, P. (2014). Market demand estimation for new product development by using fuzzy modeling and discrete choice analysis. *Neurocomputing*, 136-146.
9. Azari-Rad, S., Yontef, A., Aleman, D. M., & Urbach, D. R. (2014). A simulation model for perioperative process improvement. *Operations Research for Health Care,Vol.3, No.1*, 22-30.
10. Babar, S. A., & Patil, P. D. (2015). Improving Performance of Text Summarization. *Procedia Computer Science, Vol. 46*, 354-363.
11. Badry, R. M., Eldin, A. S., & Elzanfally, D. S. (2013). Text Summarization within the Latent Semantic Analysis Framework: Comparative Study. *International Journal of Computer Applications, Vol. 81, No. 11*, 40-45.
12. Baheti, R., & Gill, H. (2011). Cyber-physical systems. In T. Samad, & A. M. Annaswamy, *The Impact of Control Technology* (pp. 161-166). IEEE Control Systems Society. Retrieved May 16, 2017, from https://s3-us-west-2.amazonaws.com/cc-ieeecss/IoCT-FullReport_v2.pdf
13. Balamurali, S., & Jun, C.-H. (2007). Multiple dependent state sampling plans for lot acceptance based on measurement data. *European Journal of Operational Research*, 1221-1230.
14. Baldwin, C. Y., & Clark, K. B. (2000). *Design Rules, Volume 1: The Power of Modularity.* Cambridge, MA: MIT Press.
15. Banes, A., Petroman, I., Orboi, M.-D., & Petroman, C. (2013). The evolution of knowledge on IT&C in the west side of Romania. *Procedia - Social and Behavioral Sciences*, 248-253.
16. Bart, M., Füller, J., Mühlbacher, H., & Ernst, H. (2012). A Manager’s Perspective on Virtual Customer Integration for New Product Development. *Product Development & Management Association*.
17. Bin Ali, N., Petersen, K., & Wohlin, C. (2014). A systematic literature review on the industrial use of software process simulation. *The Journal of Systems and Software, 97*, 65-85.
18. Birkhölzer, T. (2012). Software process simulation is simulation too – what can be learned from other domains of simulation? *International Conference on Software and System Process (ICSSP)*, 223-225.
19. Bodein, Y., Rose, B., & Caillaud, E. (2013). A roadmap for parametric CAD efficiency in the automotive industry. *Computer-Aided Design*, 1198-1214.
20. Bodi, Ș., Popescu, S., Drăgeanu, C., & Popescu, S. (2015). Virtual Qaulity Management elements in optimized new product development usign genetic algorithms. *Managing Intellectual Capital and Innovation for Sustainable and Inclusive Society*, (pp. 633-642). Bari, Italy. Retrieved from http://www.toknowpress.net/ISBN/978-961-6914-13-0/papers/ML15-126.pdf

21. Boljevic, A. (2007). The importance of top quality management in contemporary management. *Serbian Journal of Management 2*, 217-226.
22. Bomgar. (2017). *Consolidate Remote Support for Your IT Service Desk*. Retrieved May 12, 2017, from IT Service Desk: https://www.bomgar.com/solutions/it-service-desk
23. Bookjans, M., & Weckenmann, A. (2010). Virtual Quality Management - Validation of measurement systems by the use of simulation technologies. *Physics Procedia Vol. 5 - Laser Assisted Net Shape Engineering 6, Vol. 5, Part 2*, 745-752.
24. Bookjans, M., & Weckenmann, A. (2011). Virtual Quality Management: A holistic approach for the set-up of true-to-life process models and according virtual quality management tools. *Proceedings of 1st International Conference on Quality and Innovation in Engineering and Management*, 17-22.
25. Bouchereau, V., & Rowlands, H. (2000). Methods and techniques to help quality function deployment (QFD). *Benchmarking: An International Journal, Vol. 7, No. 1*, 8-19.
26. Bowman, D. A., & McMahan, R. P. (2007). Virtual reality: How much immersion is enough? *Computer, Vol. 40, Iss. 7*, 36-42.
27. Bradlow, E. (2010). User-generated content: The "voice of the customer" in the 21st century. *Marketing Intelligent Systems using Soft Computing, Vol. 258*, 27-29.
28. Braveen, K. (2016, August 3). *The Benefits of an FAQ Page (And How to Do It Right)*. Retrieved May 12, 2017, from Shopify: https://www.shopify.com/blog/120928069-how-to-create-faq-page
29. Burge, S. (2009). The systems engineering tool box. Retrieved April 12, 2017, from https://www.burgehugheswalsh.co.uk/uploaded/1/documents/pugh-matrix-v1.1.pdf
30. Burnson, F. (2014, November 6). *Compare Supply Chain Management Software*. Retrieved from Software Advice: http://www.softwareadvice.com/scm/
31. Büyüközkan, G., Feyzioğlu, O., & Nebol, E. (2008). Selection of the strategic alliance partner in logistics value chain. *International Journal of Production Economics, 113*(1), 148-158.
32. Camba, J., & Contero, M. (2014). Extended 3D annotations as a new mechanism to explicitly communicate geometric design intent and increase CAD model reusability. *Computer-Aided design*, 61-73.
33. Carlson, C. S. (2012). *Effective FMEAs.* Hoboken, New Jersey: John Wiley & Sons, Inc., ISBN 978-1-118-00743-3.
34. Carter, C. R., & Rogers, D. S. (2008). A framework of sustainable supply chain management: moving toward new theory. *International Journal of Physical Distribution & Logistics Management, 38*(5), 360-387.
35. Centobelli, P., Cerchione, R., Converso, G., & Murino, T. (2013). E-procurement and E-supply Chain: Features and Development of E-collaboration. *IERI Procedia*, 8-14.
36. Chan, K. Y., Kwong, C. K., & Wong, T. C. (2011). Modelling customer satisfaction for product development using genetic algorithms. *Journal of Engineering Design, Vol. 22, No. 1*, 55-68.
37. Chinese State Council. (2015). *Made in China 2025.* Retrieved September 17, 2016, from http://english.gov.cn/policies/latest_releases/2015/05/19/content_281475110703534.htm
38. Codre, C. V., Popescu, S., & Țifrea, D. (2011). Enhancing product development through dedicated web applications. *Proceedings of the 1st International Conference Quality and Innovation in Engineering and Management*, 397-400.
39. Codre, C. V., Popescu, S., Constantinescu, C., & Popescu, D. (2010). PLM as a success factor of sustainable development. *Proceedings of the 1st RMEE (Review of Management and Economic Engineering) Management Conference: Twenty Years After - How Management Theory Works*, 378-389.
40. Colledani, M., Pedrielli, G., Terkaj, W., & Urgo, M. (2013). Integrated virtual platform for manufacturing systems design. *46th CIRP Conference on Manufacturing Systems 2013, Procedia CIRP, 7,* (pp. 425-430).
41. Cor, P. M. (2001). QFD not just a tool but a way of quality management. *International Journal of Production Economics, Vol. 69, Issue 2*, 151-159.
42. Costantino, F., Di Gravio, G., Shaban, A., & Tronci, M. (2015). A real-time SPC inventory replenishment system to improve supply chain performances. *Expert Systems with Applications, 42*(3), 1665-1683.

43. D'Addona, D. M., & Teti, R. (2013). Genetic Algorithm-based Optimization of Cutting Parameters in Turning Processes. *Procedia CIRP*, 323-328.
44. DeLayne, J. (2012). *The Kano Analysis: Customer Needs Are Ever Changing*. Retrieved December 3, 2016, from iSixSigma: https://www.isixsigma.com/tools-templates/kano-analysis/kano-analysis-customer-needs-are-ever-changing/
45. Delice, E. K., & Güngör, Z. (2009). A new mixed integer linear programming model for product development using quality function deployment. *Computers & Industrial Engineering*, 906-912.
46. Descoins, A. (2015, July 23). *Chatbots and automated online assistants*. Retrieved May 12, 2017, from Tryo labs: https://tryolabs.com/blog/2015/07/23/chatbots-and-automated-online-assistants/
47. Dragomir, M., Iamandi, O., Bodi, Ș., Gohla, R., & Chiran, D. (2014). *Innovation Management & Transnational Partnership - Training for SMEs and Start-ups / Entrepreneurs - Handbook.* Stuttgart, Germany: Steinbeis-Edition.
48. Duan, W., Gu, B., & Whinston, A. B. (2008). The dynamics of online word-of-mouth and product sales—An empirical investigation of the movie industry. *Journal of Retailing*, 233-242.
49. eMarketer.com. (2014, May). *The Global Social Network Landscape 2014: A Country-by-Country Guide to Social Network Usage*. Retrieved from eMarketer.com: https://www.emarketer.com/Coverage/SocialMedia.aspx
50. English Oxford Living Dictionary. (2017). *British and World English*. Retrieved April 16, 2017, from English Oxford Living Dictionary: https://en.oxforddictionaries.com/
51. EOP; NSTC; AMNPO. (2013). *National Network for Manufacturing Innovation: A preliminary design.* Retrieved August 20, 2016, from https://energy.gov/sites/prod/files/2013/11/f4/nstc_jan2013.pdf
52. European Committee for Standardization. (2004). EN 10025:2004.
53. European Committee for Standardization. (2006). EN 10219:2006.
54. European Committee for Standardization. (2010). EN 10305-5:2010.
55. European Recycling Platform. (2013). *Profile*. Retrieved February 26, 2017, from European Recycling Platform: http://erp-recycling.org/
56. Executive Board of IVI. (2015, June). *Industrial Value Chain Initiative*. Retrieved November 2016, from What is IVI?: https://iv-i.org/wp/en/what-is-ivi/
57. Forshungsunion; Acatech. (2013). *Recommendations for implementing the strategic initiative INDUSTRIE 4.0 - Final report of the Industrie 4.0 Working Group.*
58. Ghinea, R., Popescu, D., Neamțu, C., Hurgoiu, D., & Popișter, F. (2014). Using DELMIA V5 for human activity improvement in an assembly line production. *Applied Mechanics and Materials , 657*, 353-358.
59. Gunasekaran, A., & Ngai, E. W. (2007). Virtual supply-chain management. *Production Planning & Control, Vol. 15*, 584-595.
60. Guo-Niu, Z., Jie, H., & Jin, Q. (2015). An integrated AHP and VIKOR for design concept evaluation based on rough number. *Advanced Engineering Informatics*, Article in Press.
61. Hanjun, L., JinYoung, H., & Yongmoo, S. (2014). Gift or threat? An examination of voice of the customer: The case of MyStarbucksIdea.com. *Electronic Commerce Research and Applications, Vol. 13*, 205-219.
62. Hanne, T., & Dornberger, R. (2017). *Computational intelligence in logistics and supply chain management.* Springer International Publishing Switherland.
63. Hashem, I. A., Yaqoob, I., Anuar, N. B., Mokhtar, S., Gani, A., & Khan, S. U. (2015). The rise of "big data" on cloud computing: Review and open research issues. *Information Systems, 47*, 98-115.
64. Heilala, J., & et, a. (2008). Simulation-based sustainable manufacturing system design. *Proceedings of the 2008 Winter Simulation Conference*, (pp. 1922-1930).
65. Houston, D. (2012). Research and practice reciprocity in software process simulation. *International Conference on Software and System Process (ICSSP)*, 219-220.
66. Hughes, A. (2016, February 18). *Getting Mobility & Smart Connected Devices Right on the Factory Floor*. Retrieved April 26, 2017, from LNS Research: http://blog.lnsresearch.com/getting-mobility-smart-connected-devices-right-on-the-factory-floor
67. Indrawati, S. (2012). SME's Product Investment Priority and Selection Based on Local Competencies. *Procedia Economics and Finance*, 59-67.

68. Industry Development Bureau; Ministry of Economic Affairs. (2016). R.O.C. Smart Machine and Productivity 4.0 in Taiwan: Now and Future. *Proceedings of the Taiwan-Germany Productivity/Industry 4.0 Forum.* Taipei, Taiwan: 30 May 2016.
69. International Organization for Standardization. (2012). ISO 2768-1:1989. *last revised on February 10th 2012*.
70. International Organization for Standardization. (2015). *ISO 9000:2015*. Retrieved April 12, 2017, from Quality management systems - Fundamentals and vocabulary: https://www.iso.org/obp/ui/#iso:std:iso:9000:ed-4:v1:en:term:3.3.7
71. International Organization for Standardization. (2015). ISO 9001:2015.
72. International Organization for Standardization. (2015). ISO/IEC/IEEE 15288:2015.
73. Jalkala, A., & Salminen, R. T. (2009). Communicating customer references on industrial companies' Web sites. *Industrial Marketing Management*, 825-837.
74. Jiang, L., Wang, Y., & Yan, X. (2014). Decision and coordination in a competing retail channel involving a third-party logistics provider. *Computers & Industrial Engineering, 76*, 109-121. doi:10.1016/j.cie.2014.07.026
75. Jing, L., Chen, B., Zhang, B., & Li, P. (2015). Process simulation and dynamic control for marine oily wastewater treatment using UV irradiation. *Water Research Vol. 81*, 101-112.
76. Jorgenson, D. W. (1984). The Role of Energy in Productivity Growth. *American Economic Review Vol. 74 (2)*, 26-30.
77. Jurascheka, M., Cerdasa, F., Posselta, G., & Herrmanna, C. (2017). Experiencing closed loop manufacturing in a learning environment. *Procedia Manufacturing, 9*, 57-64.
78. Kagermann, H., Anderl, R., Gausemeier, J., Schuh, G., & Wahlster, W. (2016). *Industrie 4.0 in a global context - Strategies for cooperating with international partners.* Retrieved January 19, 2017, from http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Publikationen/Projektberichte/acatech_eng_STUDIE_Industrie40_global_Web.pdf
79. Kalantari, H. D., Kalantari, E., & Maleki, S. (2011). E-survey (surveys based on e-mail & web). *Procedia Computer Science*, 935-941.
80. Khilwani, N., Ulutas, B. H., Islier, A. A., & Tiwari, M. K. (2011). A methodology to design virtual cellular manufacturing systems. *Journal of Intelligent Manufacturing, 22*(4), 533–544. doi:10.1007/s10845-009-0314-6
81. Kidak, L. B., & Aksarayli, M. (2011). Simulation modeling for process improvement in a general surgery service. *Current Research Journal of Social Sciences, Vol. 3, No. 2*, 114-125.
82. Kim, H.-S. (2016, August 15). Significant changes in digital technology - Manufacturing Innovation 3.0 in Korea. Retrieved October 23, 2016, from https://www.slideshare.net/QrioCty/significant-changes-in-digital-technology-with-manufacturing-innovation-30-in-korea
83. Lee, C. G., & Park, S. C. (2014). Survey on the virtual commissioning of manufacturing systems. *Journal of Computational Design and Engineering, 1*(3), 213-222. doi:10.7315/JCDE.2014.021
84. Lee, J., Bagheri, B., & Kao, H.-A. (2015). A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters, Vol. 3*, 18–23.
85. Lee, J., Kao, H.-A., & Yang, S. (2014). Service innovation and smart analytics for Industry 4.0 and big data environment. *Procedia CIRP Vol. 16*, 3-8.
86. Lee, Y.-C., Sheu, L.-C., & Tsou, Y.-G. (2008). Quality function deployment implementation based on Fuzzy Kano model: An application in PLM system. *Computers & Industrial Engineering*, 48-63.
87. Leland, E. (2011, February). *A Few Good Online Survey Tools*. Retrieved from IdealWare: http://www.idealware.org/articles/fgt_online_surveys.php
88. Linderman, K., Schroeder, R., Zaheer, S., & Choo, A. (2003). Six Sigma: a goal-theoretic perspective. *Journal of Operations Management*, 193-203.
89. Lipnack, J., & Stamps, J. (2000). *Virtual teams: People working across boundaries with technology.* New York, U.S.A: John Wiley & Sons, Inc.
90. Liu, X., Chen, J., Luo, X., Wang, M., & Meng, H. (2015). Study on heat integration of supercritical coal-fired power plant with post-combustion CO2 capture process through process simulation. *Fuel Vol. 158*, 625-633.

91. Liu, Y., & Yu, F. (2014). Automatic inspection system of surface defects on optical IR-CUT filter based on machine vision. *Optics and Lasers in Engineering*, 243-257.
92. Maletic, J. I., & Valluri, N. (1999). Automatic Software Clustering via Latent Semantic Analysis. *Proceedings of the 14th IEEE international conference on Automated software engineering* (pp. 251-254). Washington, D.C.: IEEE Computer Society.
93. McCormack, R. A. (2012, February 28). Obama Will Unveil $1-Billion National Manufacturing Innovation Network Initiative Based On Germany's Fraunhofer Institute. *Manufacturing and Technology News, 19*(3). Retrieved October 16, 2016, from http://www.manufacturingnews.com/news/national-network-for-manufacturing-innovation-228112.html
94. Melton, T. (2005). The benefits of lean manufacturing. What Lean Thinking has to offer the process industries. *Chemical Engineering Research and Design*, 662-673.
95. Mertins, K., Rabe, M., & Gocev, P. (2008). Integration of Factory Planning and ERP/MES Systems: Adaptive Simulation Models. In T. Koch, *Lean Business Systems and Beyond* (pp. 185-193). Boston: Springer.
96. Milella, F. (2015). Problem-Solving by Immersive Virtual Reality: Towards a More Efficient Product Emergence Process in Automotive. *Multidisciplinary Engineering Science and Technology, Vol. 2, Iss. 4*, 860-867.
97. Ministry of Foreign Affairs, Republic of China (Taiwan). (2015, November 23). *Productivity 4.0 initiative to bolster agriculture industry*. Retrieved June 26, 2016, from Taiwan Today: http://taiwantoday.tw/news.php?unit=6,23,6,6&post=12427
98. Molleda, J., Usamentiaga, R., & García, D. F. (2013). An improved 3D imaging system for dimensional quality inspection of rolled products in the metal industry. *Computers in Industry*, 1186-1200.
99. Moore, G. E. (1965). Cramming more components onto integrated. *Electronics Vol. 38 (8)*, 114-117.
100. Mujber, T. S., Szecsi, T., & Hashmi, M. S. (2004). Virtual reality applications in manufacturing process simulation. *Journal of Materials Processing Technology, Vol. 155-156*, 1834-1838.
101. Münch, J. (2012). Evolving process simulators by using validated learning, . *International Conference on Software and System Process (ICSSP)*, 226-227.
102. Nair, A. (2006). Meta-analysis fo the relationship between quality management practices and firm performance - implications for quality management theory development. *Journal of Operations Management*, 948-975.
103. Nelson, L. (1989). Technical Aids. *Journal of Quality Technology, 16*(4), 238-239.
104. Nettleton, D. (2014). Chapter 13 - CRM - Customer Relationship Management and Analysis. In D. Nettleton, *Commercial data mining - Processing, Analysis and Modeling for Predictive Analytics Projects* (pp. 195-208). Morgan Kaufmann.
105. Newman, R., Chang, V., Walters, R., & Wills, G. (2016). Web 2.0 – The past and the future. *International Journal of Information Management, 36*, 591-598.
106. Nomden, G. (2011). *Virtual cellular manufacturing: relevance and development of heuristics for family-based dispatching.* Groningen: University of Groningen, SOM research school.
107. Oakland, J. S. (2015). *Statistical Process Control, 6th Edition.* Taylor & Francis. doi:10.4324/9780080551739
108. Oditis, I., & Bicevskis, J. (2010). The concept of automated process control. *Computer Science and Information Technologies, 756*, 193-203.
109. Office of Management and Budget. (2013). *Fiscal Year 2014 Budget of the U.S. Government.* p. 203, Table S-9: Executive Office of the President.
110. Office of the Press Secretary. (2016, June 20). *The White House*. Retrieved October 16, 2016, from FACT SHEET: President Obama Announces Winner of New Smart Manufacturing Innovation Institute and New Manufacturing Hub Competitions: https://obamawhitehouse.archives.gov/the-press-office/2016/06/20/fact-sheet-president-obama-announces-winner-new-smart-manufacturing
111. Pamfilie, R., Petcu, A., & Draghici, M. (2012). The importance of leadership in driving a strategic Lean Six Sigma Management. *Procedia - Social and Behavioral Sciences*, 187-196.

112. Panov, P., Soldatova, L., & Džeroski, S. (2014). Ontology of core data mining entities. *Data mining and knowledge discovery, Vol. 28, Iss. 5-6*, 1222–1265.
113. Per, E. (2016, May 13). *AI, virtual assistants and chat bots before, now and in the future*. Retrieved May 12, 2017, from Flux: https://medium.com/fluxx-studio-notes/ai-virtual-assistants-and-chat-bots-before-now-and-in-the-future-df979529ad5f
114. Pfahl, D. (2014). Process simulation – A tool for software project managers? In G. Ruhe, & C. (. Wohlin, *Software Project Management in a Changing World* (pp. 425-446). New York: Springer-Verlag Berlin Heidelberg.
115. Ponsignon, T., & Mönch, L. (2014). Simulation-based performance assessment of master planning approaches in semiconductor manufacturing. *Omega, Vol. 46*, 21-35.
116. Popescu, D., Comes, R., Neamțu, C., & Popișter, F. (2014). Using augmented reality in metrology for technical drawings and CAD data management. *Proceedings of the 11th International Scientific Conference on "Coordinate Measuring Technique".* Bielsko-Biała, Poland.
117. Prandelli, E., Verona, G., & Raccagni, D. (2006). Diffusion of web-based product innovation. *California Management Review, 48*(4), 109-135.
118. Pyon, C., Woo, J., & Sang, C. (2010). Intelligent service quality management system based on analysis and forecast of VOC. *Expert Systems with Applications, Vol. 37*, 1056-1064.
119. Robinson, S., Radnor, Z. J., Burgess, N., & Worthington, C. (2012). SimLean: Utilising simulation in the implementation of lean in healthcare. *European Journal of Operational Research, Vol. 219, No. 1*, 188-197.
120. Robot Revolution Initiative Council. (2015). *Action Plan for FY 2015.* Tokyo. Retrieved November 17, 2016, from https://www.jmfrri.gr.jp/content/files/20150925_plan_eng.pdf
121. Rohrbeck, R., Steinhoff, F., & Perder, F. (2008). Virtual customer integration in the innovation process: Evaluation of the web platforms of multinational enterprises (MNE). *Portland International Conference on Management of Engineering & Technology PICMET 2008.* Cape Town, South Africa: IEEE. doi:10.1109/PICMET.2008.4599656
122. Roman, E. (2010). *Voice-of-the-Customer Marketing: A Revolutionary 5-Step Process to Create Customers Who Care, Spend, and Stay.* McGraw-Hill.
123. Romanian Companies. (2016). *List of Romanian Companies*. Retrieved from https://www.romanian-companies.eu/
124. Roos, M., Marshall, S. M., Gibson, A. P., Schuemie, M., Meij, E., Katrenko, S., . . . Adriaans, P. W. (2009). Structuring and extracting knowledge for the support of hypothesis generation in molecular biology. *BMC Bioinformatics, Vol. 10, Suppl. 10*.
125. Roser, C. (2015, December 29). *A Critical Look at Industry 4.0*. Retrieved February 19, 2016, from AllAboutLean.com: http://www.allaboutlean.com
126. Rowe, J. (2013). *Best practices for finding customer issues to start your knowledge base*. Retrieved May 12, 2017, from Zendesk Support: https://support.zendesk.com/hc/en-us/articles/203663976-Best-practices-for-finding-customer-issues-to-start-your-knowledge-base
127. Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences, 1*(1), 83-98.
128. Salvendy, G. (2001). *Handbook of Industrial Engineering: Technology and Operations Management.* John Wiley & Sons, Inc.
129. Sangmahachai, K. (2016). *Revolution to Industry 4.0.* Retrieved February 5, 2017, from http://www.wise.co.th/wise/Knowledge_Bank/References/Everything_4/Revolution_to_Industry_4.pdf
130. Scallan, P. (2002). *Process Planning: The design/manufacture interface.* -: Elsevier Science & Technology Books.
131. Schilling, D. R. (2013, April 19). *Knowledge doubling every 12 months, soon to be every 12 hours*. Retrieved August 20, 2015, from Industry tap into news: http://www.industrytap.com/knowledge-doubling-every-12-months-soon-to-be-every-12-hours/3950
132. Schmitt, R., & Moenning, F. (2006). Ensure Success with Inline-Metrology. *XVIII IMEKO World Congress - Metrology for a Sustainable Development.* Rio de Janerio, Brazil.

133. Schmitt, U. (2014). Personal Knowledge Management Devices: The next Co-evolutionary Driver of Human Development?! *International Conference on Education and Social Sciences Abstracts & Proceedings*, (pp. 3-5). Istanbul, Tukey. doi:10.13140/2.1.4035.0401
134. Segovia, D., Ramírez, H., Mendoza, M., Mendoza, M., Mendoza, E., & González, E. (2015). Machining and dimensional validation training using augmented reality for a lean process. *Procedia Computer Science, 75*, 195-204.
135. Seuring, S. (2013). A review of modeling approaches for sustainable supply chain management. *Decision Support Systems, 54*(4), 1513-1520. doi:10.1016/j.dss.2012.05.053
136. Shapiro, R. D., & Heskett, J. (1985). *Logistics strategy: Cases and concepts.* West Pub. Co.
137. Shen, H., Li, S., Gu, D., & Chang, H. (2012). Bearing defect inspection based on machine vision. *Measurement*, 719-733.
138. Shi, W., Cao, J., Zhang, Q., Li, Y., & Xu, L. (2016). Edge computing: Vision and challenges. *IEEE Internet of Things Journal, 3*(5), 637-646.
139. SigmaFlow. (2015). *Business Excellence is our Passion*. Retrieved 12 05, 2016, from SigmaFlow: http://www.sigmaflow.com/business-process-analysis/modeler/
140. Sousa, R., & Voss, C. A. (2006). Service quality in multi-channel services employing virtual channels. *Journal of Service Research, Vol. 8, Iss. 4*, 356-371.
141. Stark, J. (2001). *Product Lifecycle Management - 21st Century Paradigm for Product Realisation.* London: Springer.
142. Stockinger, A., Wittmann, S., Martinek, M., Meerkamm, H., & Wartzack, S. (2010). Virtual Assembly Analysis: Standard tolerance analysis compared to manufacturing simulation and relative positioning. *Proceedings of the International Design Conference - DESIGN 2010,* (pp. 1421-1430). Dubrovnik, Croatia.
143. Su, C.-T., Chen, Y.-H., & Sha, D. (2006). Linking innovative product development with customer knowledge: a data-mining approach. *Technovation*, 784-795.
144. Syberfeldt, A., & Gustavsson, P. (2014). Increased robustness of Product Sequencing using Multi-Objective Optimization. *Procedia CIRP, Vol. 17* , 434-439.
145. Thakker, A., Jarvis, J., Buggy, M., & Sahed, A. (2009). 3DCAD conceptual design of the next-generation impulse turbine using the Pugh decision-matrix. *Materials & Design, 30*(7), 2676-2684. doi:10.1016/j.matdes.2008.10.011
146. Thepsonthi, T., & Özel, T. (2015). 3-D finite element process simulation of micro-end milling Ti-6Al-4Vtitanium alloy: Experimental validations on chip flow and tool wear. *Journal of Materials Processing Technology Vol. 221*, 128-145.
147. Tita, B. (2015). Smart Glasses Get New Look on Factory Floor. *The Wall Streeet Journal*. Retrieved March 19, 2017, from https://www.wsj.com/articles/smart-glasses-get-new-look-on-factory-floor-1433301177
148. Tropes US. (2014, June). Classes and relations graphs. *Help Index*. Tropes, Version 8.4.2 (build 0019).
149. Tsao, Y.-C., & Chan, S.-C. (2011). A study on embarrassment associated with product use. *Applied Ergonomics, 42*, 503-510. doi:10.1016/j.apergo.2010.09.010
150. Urban, P., & Landryová, L. (2015). Alarm processing analyses using SPC tools based on real-time data acquired from a control system. *16th International Carpathian Control Conference (ICCC)* (pp. 567-570). IEEE.
151. van 't Ooster, A. B. (34-46). Simulation of harvest operations in a static rose cultivation system. *Biosystems Engineering, Vol. 120*, 2013.
152. van't Ooster, A., Bontsema, J., van Henten, E., & Hemming, S. (2014). Simulation of harvest operations in a static rose cultivation system. *Biosystems Engineering Vol. 120*, 34-46.
153. Wang, C.-H., & Shih, C.-W. (2013). Integrating conjoint analysis with quality function deployment to carry out customer-driven concept development for ultrabooks. *Computer Standards & Interfaces*, 89-96.
154. Weckenmann, A. (2013). *Quality Management.* Erlangen, Germany: QFM Erlangen.
155. Wellsandt, S., Hribernik, K. A., & Thoben, K.-D. (2014). Qualitative comparison of requirements elicitation techniques that are used to collect feedback information about product use. *Procedia CIRP*, 212-217.

156. Wilderer, P. A., & Grambow. (2016). *Global stability through decetralization?, Strategies for sustainability*. Springer International Publishing Switzerland.
157. Winkler, H. (2011). Closed-loop production systems - A sustainable supply chain approach. *CIRP Journal of Manufacturing Science and Technology, 4*(3), 243-246.
158. Wu, L., Yue, X., Jin, A., & Yen, D. C. (2016). Smart supply chain management: a review and implications for future research. *International Journal of Logistics Management, 27*(2), 395-417. doi:10.1108/IJLM-02-2014-0035
159. Wübbeke, J., Meissner, M., Zenglein, M. J., Ives, J., & Conrad, B. (2016). *Made in China 2025 - The making of a high-tech superpower and consequences for industrial countries*. Mercator Institute for China Studies. Retrieved January 9, 2017, from https://www.merics.org/fileadmin/user_upload/downloads/MPOC/MPOC_Made_in_China_2025/MPOC_No.2_MadeinChina_2025.pdf
160. Xiao, W., Zheng, L., Huan, J., & Lei, P. (2015). A complete CAD/CAM/CNC solution for STEP-compliant manufacturing. *Robotics and Computer-Integrated Manufacturing*, 1-10.
161. Yan, J., Chaudhry, P. E., & Chaudhry, S. S. (2003). A model of decision support system based on case-based reasoning for third-party logistics evaluation. *Expert Systems, 20*(4), 196-207.
162. Yang, K., & El-Haik, B. (2003). *Design for Six Sigma - A roadmap for product development*. New-York: McGraw-Hill.
163. Yanlai, L., Jiafu, T., Xinggang, L., & Jie, X. (2009). An integrated method of rough set, Kano's model and AHP for rating customer requirements' final importance. *Expert Systems with Applications, Vol. 36, Issue 3, Part 2*, 7045-7053.
164. Yu, Y.-W., Yu, H.-C., Itoga, H., & Lin, T.-R. (2008). Decision-making factors for effective industrial e-procurement. *Technology in Society, Vol. 30*, 163-169.
165. Z. Kapetaki, P. B. (2015). Process simulation of a dual-stage Selexol process for 95% carbon capture efficiency at an integrated gasification combined cycle power plant. *International Journal of Greenhouse Gas Control Vol. 39*, 17-26.
166. Zhang, H., Jeffery, R., Houston, D., Huang, L., & Zhu, L. (2011). Impact of process simulation on software practice: An initial report. *Proceedings of the 33rd International Conference on Software Engineering (ICSE)*, 1046-1056.

Annexes

Annex 1. Questionnaire for indetifying the "Voice of the Industry"

MINISTRY OF EDUCATION AND SCIENTIFIC RESEARCH

TECHNICAL UNIVERSITY
OF CLUJ-NAPOCA

I. Survey description

The current survey addresses groups of professionals that can help assess the currently employed applications and technological readiness and performance of manufacturing companies in the automotive field. The carried-out assessment relies highly on the expertise and insights provided by these professionals and is trying to synthesize the views of several groups with the purpose of accurately capturing the "voice of the industry".
The collected information will be used to validate or disprove a research methodology that might be capable of identifying current trends and/or emerging technologies in relation to a relatively newly born concept entitled "Virtual Quality Management", using a semantic analysis technique (Latent Semantic Analysis – LSA) of scientific references that are considered to be relevant to that particular area of research.
The findings of this survey will be used in a scientific manner and will be presented within future research publications.

II. General information

1. Do you agree that the name of the company you work for can be mentioned as one of the investigated without connecting the information you've provided and the company?

○ YES
○ NO

2. Please tick the target group to which you belong. If you select other please specify your position

○ Technical consultant
○ Certification auditor
○ Quality manager
○ Technical manager
○ Other, please specify: ____________

III. Application rating

1. Based on your experience, how do you associate the following applications with the statements from the header of the table? Please check the proper square.

	It's not likely to be used by manufacturing companies	Only some manufacturing companies have or will implement it	Most of the manufacturing companies have or will implement it	All manufacturing companies have it implemented
Absolute multiline technology used for online precision monitoring	○	○	○	○
Assembly and part finite element structural analysis	○	○	○	○
Automated online assistant used for tech support through live chat	○	○	○	○
Automated process optimization	○	○	○	○
Automated process robustness prediction	○	○	○	○
Automated raw material approval	○	○	○	○
Automated raw material order & purchase	○	○	○	○
Automated real-time process optimization	○	○	○	○
CAD used for product modeling	○	○	○	○
Computer fluid dynamics simulation	○	○	○	○
Customer Relationship Management systems used for requirement analysis & sorting	○	○	○	○
E-communication: e-mail, instant messaging, file transfers	○	○	○	○
Edge computing	○	○	○	○
FAQ page used for fault / defect self-identification and self-help	○	○	○	○
Google analytics for consumer targeting	○	○	○	○
Google trends analysis for product benchmarking	○	○	○	○
Inline metrology used for fault, defect and deviation detection	○	○	○	○

	It's not likely to be used by manufacturing companies	Only some manufacturing companies have or will implement it	Most of the manufacturing companies have or will implement it	All manufacturing companies have it implemented
Kinematics simulation, analysis and optimization through software	○	○	○	○
Knowledge base used for problem solving for known issues	○	○	○	○
Manufacturability analysis	○	○	○	○
Mobile devices used for process monitoring & control	○	○	○	○
Mobile devices with AR applications	○	○	○	○
Online surveys and questionnaires	○	○	○	○
Plant layout design used for production flow optimization	○	○	○	○
Preventive actions taken based on collected data	○	○	○	○
Real-time inventory monitoring	○	○	○	○
Recycling assistance platform providing information for customers for recycling	○	○	○	○
Remote access used for diagnostics and trouble ticket resolution	○	○	○	○
Remote equipment control & assistance	○	○	○	○
Remote process monitoring and control	○	○	○	○
Simulation software used for process planning and flow analysis	○	○	○	○
Smart and preventive maintenance for equipment	○	○	○	○
Smart glasses used for operator empowerment (facilitating fast information access)	○	○	○	○
Smart supplier evaluation & selection	○	○	○	○
Social networking data analysis for requirement and stakeholder identification	○	○	○	○

	It's not likely to be used by manufacturing companies	Only some manufacturing companies have or will implement it	Most of the manufacturing companies have or will implement it	All manufacturing companies have it implemented
Virtual commissioning used for reliable equipment automation	○	○	○	○
Virtual coordinate measuring machines	○	○	○	○
Vision system used for part inspection	○	○	○	○
Work instruction design	○	○	○	○
Work time study analysis	○	○	○	○
Worker ergonomics planning & design	○	○	○	○

2. Please list and rate additional applications that were not included in the above table.

Description of application 1

Description of application 2

Description of application 3

Description of application 4

Description of application 5

Description of application 6

Please rate the applications inserted above

	It's not likely to be used by manufacturing companies	Only some manufacturing companies have or will implement it	Most of the manufacturing companies have or will implement it	All manufacturing companies have it implemented
Application 1	○	○	○	○
Application 2	○	○	○	○
Application 3	○	○	○	○
Application 4	○	○	○	○
Application 5	○	○	○	○
Application 6	○	○	○	○

Annex 2. Matrix diagram

				Virtual modeling	Simulation & modeling	Virtual optimization	Process simulation	Virtual measurement	Innovation model	Virtual development	Process innovation	Measurement through simulation	Quality optimization	Product innovation	Innovative development	**Sub-category score**	**Category score**
Life cycle stage	**Sub-stage**	**Category**	**Sub-category**	0.40	0.12	0.23	0.08	0.09	0.01	0.02	0.01	0.03	0.01	0.001	0.001		
Planning, design & development	Stakeholder requirement definition/analysis	E-communication (e-mail, e-conference, instant messaging, file transfers)	-	3	3	3	3	2	1	3	1	2	1	2	2	2.823	**2.823**
		Online surveys and questionnaires	-	3	3	3	0	1	1	3	1	0	2	0	1	2.432	**2.432**
		Customer Relationship Management (CRM) systems	-	3	3	1	0	0	0	3	0	0	1	0	1	1.856	**1.856**
		Data mining	Social networking data analysis	2	2	2	0	0	0	3	0	0	0	0	1	1.552	**1.419**
			Google analytics for customer targeting	2	1	2	0	0	1	3	0	0	0	3	3	1.451	
			Google Trends analysis used for product benchmarking	2	1	1	0	0	1	3	1	0	3	0	1	1.255	
	Product design & validation	Virtual prototyping	CAD used for product modeling	3	3	2	1	2	2	3	1	1	3	3	2	2.432	**2.313**
			Kinematics simulation, analysis and optimization through software.	3	3	3	0	1	0	3	0	1	1	1	1	2.430	
			Assembly and part finite element structural analysis	3	3	1	0	2	0	3	0	1	2	0	1	2.076	
		Virtual process modeling and simulation	Simulation software used for process planning and flow analysis	3	3	2	3	1	1	3	1	3	2	1	2	2.536	**2.059**
			Virtual commissioning used for equipment automation	2	2	3	1	1	0	3	2	1	2	0	2	2.018	
			Automated process optimization	1	3	3	3	0	0	3	2	2	3	0	1	1.841	
			Automated process robustness prediction	1	3	3	3	0	0	3	2	2	3	0	1	1.841	
		Virtual manufacturing	Plant layout design used for production flow optimization	3	3	3	2	1	1	2	1	2	3	1	1	2.645	**2.417**
			Manufacturability analysis	3	3	2	3	1	1	3	2	3	3	2	3	2.556	
			Work instructions design	2	3	3	3	2	0	3	2	2	3	0	1	2.431	
			Worker ergonomics planning & design	2	3	3	3	1	0	3	1	2	0	0	0	2.301	
			Work time study analysis	1	3	3	3	3	1	3	1	3	3	1	3	2.150	
Realization	Procurement	Smart supply chain	Real-time inventory monitoring	1	2	3	3	2	1	0	3	1	3	0	3	1.852	**1.465**
			Automated raw material order & purchase	1	1	3	0	1	0	1	3	2	3	0	3	1.420	
			Automated raw material approval	1	1	3	0	1	0	0	0	1	2	0	1	1.341	
			Smart supplier evaluation & selection	1	1	2	1	1	1	2	2	0	3	0	1	1.245	

	Manufacturing	Big data analysis	Preventive actions taken based on collected data	3	2	3	3	3	0	1	3	1	3	0	0	2.758	**2.366**
			Automated real-time process optimization	1	2	3	3	3	0	1	3	2	3	0	0	1.974	
		Rapid prototyping (Additive manufacturing)	3D printing used for product manufacturing	3	3	2	0	2	0	3	0	0	1	3	0	2.272	**2.272**
		Smart and preventive maintenance	-	2	1	3	2	2	1	0	2	2	3	0	1	2.070	**2.070**
		Digital assistance	Remote equipment control and assistance	2	1	2	1	2	1	1	2	0	3	0	1	1.725	**1.509**
			Vision system used for part inspection	1	2	2	1	2	0	0	3	0	3	0	0	1.417	
			Smart glasses employing AR for operator empowerment (displaying instructions, assigning tasks and facilitating information access)	2	1	1	0	2	0	1	1	0	2	0	0	1.384	
	Measurement and control	Virtual measuring	Virtual coordinate measuring machines used for evaluation of uncertainty estimates	2	2	3	1	3	1	2	1	3	2	0	2	2.238	**1.907**
			Inline metrology used for fault, defect and deviation detection feeding measured values back into processes for increasing efficiency and increase quality.	2	1	3	1	3	0	0	3	3	3	0	1	2.100	
			Absolute multiline technology used for online precision monitoring of equipment	1	1	2	0	3	0	1	2	3	2	0	0	1.383	
		Digital support	Mobile device applications used for process monitoring & control	2	1	1	3	3	0	0	1	1	1	0	0	1.729	**1.690**
			Smart glasses employing AR used for displaying product/ process data	2	2	1	1	3	0	0	1	0	1	0	0	1.652	
		Cloud computing	Remote process monitoring and control	1	2	2	0	2	0	1	0	1	1	0	0	1.331	**1.315**
			Edge computing	1	1	2	1	2	0	0	1	1	2	0	0	1.299	
Utilization	Delivery	-	-	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**N/A**
	Customer assistance	Internet based customer communication support	Knowledge base used for problem solving for known issues	2	2	3	1	0	3	3	3	0	3	2	1	1.952	**1.250**
			Remote access used for diagnostics and trouble ticket resolution	1	1	2	1	2	1	1	3	0	3	0	0	1.328	
			FAQ page used for fault / defect identification and self-help	0	0	3	0	1	2	0	3	1	3	1	1	0.877	
			Automated online assistant used for tech support through live chat	0	0	3	0	1	2	0	2	0	3	0	0	0.841	
	Maintenance	-	-	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**N/A**
Disposal	Retirement	-	-	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**N/A**
	Recycling	Recycling assistance platform providing info for customers for recycling	-	1	1	3	0	0	2	1	3	0	3	1	1	1.298	**1.298**

Annex 3. List of rated applications

Applications	Average of responses	Calculated from LSA	Error (MAX 8%)
Absolute multiline technology used for online precision monitoring	1.33	1.38	3.57%
Assembly and part finite element structural analysis	2.13	2.08	-2.70%
Automated online assistant used for tech support through live chat	0.87	0.84	-2.96%
Automated process optimization	2.00	1.84	-7.94%
Automated process robustness prediction	2.00	1.84	-7.94%
Automated raw material approval	1.33	1.34	0.57%
Automated raw material order & purchase	1.53	1.42	-7.42%
Automated real-time process optimization	1.87	1.97	5.44%
CAD used for product modeling	2.47	2.43	-1.40%
Customer Relationship Management systems used for requirement analysis & sorting	1.80	1.86	3.02%
E-communication: e-mail, e-conference, instant messaging, file transfers	2.87	2.82	-1.53%
Edge computing	1.33	1.30	-2.60%
FAQ page used for fault / defect self-identification and self-help	0.93	0.88	-6.08%
Google analytics for consumer targeting	1.47	1.45	-1.07%
Google trends analysis for product benchmarking	1.33	1.25	-5.91%
Inline metrology used for fault, defect and deviation detection	2.13	2.10	-1.56%
Kinematics simulation, analysis and optimization through software	2.27	2.43	6.71%
Knowledge base used for problem solving for known issues	2.07	1.95	-5.53%
Manufacturability analysis	2.53	2.56	0.88%
Mobile devices used for process monitoring & control	1.87	1.73	-7.40%
Smart glasses employing AR used for displaying product/ process data	1.60	1.65	3.12%
Online surveys and questionnaires	2.47	2.43	-1.41%
Plant layout design used for production flow optimization	2.53	2.64	4.20%
Preventive actions taken based on collected data	2.67	2.76	3.31%
Rapid prototyping (3D printing)	2.27	2.27	0.22%
Real-time inventory monitoring	1.93	1.85	-4.20%
Recycling assistance platform providing info for customers for recycling	1.40	1.30	-7.26%
Remote access used for diagnostics and trouble ticket resolution	1.40	1.33	-5.14%
Remote equipment control & assistance	1.87	1.73	-7.59%
Remote process monitoring and control	1.33	1.33	-0.15%
Simulation software used for process planning and flow analysis	2.47	2.54	2.74%
Smart and preventive maintenance for equipment	2.20	2.07	-5.93%
Smart glasses used for operator empowerment	1.47	1.38	-5.66%
Smart supplier evaluation & selection	1.33	1.25	-6.59%
Social networking data analysis for requirement and stakeholder identification	1.47	1.55	5.50%
Virtual commissioning used for reliable equipment automation	2.00	2.02	0.89%
Virtual coordinate measuring machines	2.20	2.24	1.72%
Vision system used for part inspection	1.53	1.42	-7.59%
Work instruction design	2.40	2.43	1.28%
Work time study analysis	2.27	2.15	-5.16%
Worker ergonomics planning & design	2.27	2.30	1.51%
		Average error	**3.98%**

Annex 4. List of applications nominated by survey responders

Applications	Average of responses
Risk analysis applications	2.5
SAP Smart Data Access	2
Materials Management Operations Guideline/Logistics Evaluation – MMOG/LE	1.5
Design for Lean Six Sigma (DFLSS) used for product development	1
Eight Disciples (8D) problems solving	2

Annex 5. Source code for the optimization of the “Shelf” component

```
// ***************** Component_004 ****************************//

#include <stdio.h>
#include <stdlib.h>
#include <math.h>

double eval(str, length, vect, genes)
char str[];        /* string representation */
int length;        /* length of bit string  */
double vect[];  /* floating point representation */
int genes;         /* number of elements in vect */
{

/*
        Number of genes = 2
        int type

                gene 0: 0.7....5 t
                gene 1: 20....128 h
*/
        int i;
        int restrictions_nr = 3;
        double t, h; // [mm]
        double obj=0;
        double pen=0;
        double g[3]; //Restriction vector
        double pen_coef=1e10; // Penalty coefficient

        double l=1000; // Length [mm]
        double w=400; // Width [mm]
        double F=600; // Load [N]
        double Sigma_al=100; // allowed bending stress [MPa]
        double r=7.87*10^(-6); //material density [kg/mm^3]

        double mass;

        t=vect[0];
        h=vect[1];

        if(t>=h)
                return pen_coef*pen_coef;
        else
        {
        mass=r*(h*t+w*t)*l;

        /* Restrictions */
        g[1]=Sigma_c/Sigma_al-1;
```

```
	g[2]=0.7/t-1;
	g[3]=20/h-1;

	for(i=1;i<=restrictions_nr;i++)
	{
		if(g[i]>0)
			pen=pen+g[i];
	}
	pen=pen*pen_coef;
	obj=mass+pen;
	return obj;
	}
}
```

Annex 6. Source code for the optimization of the “Support beam” component

```
// ***************** Component_006 ****************************//

#include <stdio.h>
#include <stdlib.h>
#include <math.h>

double eval(str, length, vect, genes)
char str[];         /* string representation */
int length;         /* length of bit string  */
double vect[];  /* floating point representation */
int genes;          /* number of elements in vect */
{

/*
        Number of genes = 3
        int type

                gene 0: 2....128 H
                gene 1: 1....128 B
                gene 2: 0.5....5 t

*/
        int i;
        int restrictions_nr = 3;
        double B,H, t; // [mm]
        double obj=0;
        double pen=0;
        double g[4]; //Restriction vector
        double pen_coef=1e10; // Penalty coefficient

        double l=1200; // Length [mm]
        double F=650; // Load [N]
        double Sigma_al=100; // allowed bending stress [MPa]
        double r=7.87*10^(-6); //material density [kg/mm^3]

        double mass;

        H=vect[0];
        B=vect[1];
        t=vect[2];

        if(H<=B)
                return pen_coef*pen_coef;
        else
        {
        mass=r*(H*B- (H-2*t)*(B-2*t))*l;

        /* Restrictions */
```

```
	g[1]=Sigma_c/Sigma_al-1;
	g[2]=2/t-1;
	g[3]=B/H-1;
	g[4]=H/2*B-1;

	for(i=1;i<=restrictions_nr;i++)
	{
		if(g[i]>0)
			pen=pen+g[i];
	}
	pen=pen*pen_coef;
	obj=mass+pen;
	return obj;
	}
}
```

Annex 7. Source code for trackable event handler

```
using UnityEngine;
using Vuforia;

public class TrackableEventHandler : MonoBehaviour, ITrackableEventHandler
{
    #region PRIVATE_MEMBERS
    private TrackableBehaviour mTrackableBehaviour;
    private bool mHasBeenFound = false;
    private bool mLostTracking;
    private float mSecondsSinceLost;
    #endregion // PRIVATE_MEMBERS

    #region MONOBEHAVIOUR_METHODS
    void Start()
    {
        mTrackableBehaviour = GetComponent<TrackableBehaviour>();
        if (mTrackableBehaviour)
        {
            mTrackableBehaviour.RegisterTrackableEventHandler(this);
        }

        OnTrackingLost();
    }

    void Update()
    {
        // Pause the video if tracking is lost for more than two seconds
        if (mHasBeenFound && mLostTracking)
        {
            if (mSecondsSinceLost > 2.0f)
            {
                VideoPlaybackBehaviour video =
GetComponentInChildren<VideoPlaybackBehaviour>();
                if (video != null &&
                    video.CurrentState ==
VideoPlayerHelper.MediaState.PLAYING)
                {
                    video.VideoPlayer.Pause();
                }
                mLostTracking = false;
            }

            mSecondsSinceLost += Time.deltaTime;
        }
    }

    #endregion //MONOBEHAVIOUR_METHODS


    #region PUBLIC_METHODS
    /// <summary>
    /// Implementation of the ITrackableEventHandler function called when
the
    /// tracking state changes.
    /// </summary>
    public void OnTrackableStateChanged(
                                    TrackableBehaviour.Status
previousStatus,
```

```
                                    TrackableBehaviour.Status newStatus)
    {
        if (newStatus == TrackableBehaviour.Status.DETECTED ||
            newStatus == TrackableBehaviour.Status.TRACKED ||
            newStatus == TrackableBehaviour.Status.EXTENDED_TRACKED)
        {
            OnTrackingFound();
        }
        else
        {
            OnTrackingLost();
        }
    }
    #endregion //PUBLIC_METHODS


    #region PRIVATE_METHODS
    private void OnTrackingFound()
    {
        Renderer[] rendererComponents =
GetComponentsInChildren<Renderer>();
        Collider[] colliderComponents =
GetComponentsInChildren<Collider>();

        // Enable rendering:
        foreach (Renderer component in rendererComponents)
        {
            component.enabled = true;
        }

        // Enable colliders:
        foreach (Collider component in colliderComponents)
        {
            component.enabled = true;
        }

        Debug.Log("Trackable " + mTrackableBehaviour.TrackableName + "
found");


        VideoPlaybackBehaviour video =
GetComponentInChildren<VideoPlaybackBehaviour>();
        if (video != null && video.AutoPlay)
        {
            if (video.VideoPlayer.IsPlayableOnTexture())
            {
                VideoPlayerHelper.MediaState state =
video.VideoPlayer.GetStatus();
                if (state == VideoPlayerHelper.MediaState.PAUSED ||
                    state == VideoPlayerHelper.MediaState.READY ||
                    state == VideoPlayerHelper.MediaState.STOPPED)
                {
                    // Pause other videos before playing this one
                    PauseOtherVideos(video);

                    // Play this video on texture where it left off
                    video.VideoPlayer.Play(false,
video.VideoPlayer.GetCurrentPosition());
                }
                else if (state == VideoPlayerHelper.MediaState.REACHED_END)
                {
```

```
                    // Pause other videos before playing this one
                    PauseOtherVideos(video);

                    // Play this video from the beginning
                    video.VideoPlayer.Play(false, 0);
                }
            }
        }

        mHasBeenFound = true;
        mLostTracking = false;
    }

    private void OnTrackingLost()
    {
        Renderer[] rendererComponents =
GetComponentsInChildren<Renderer>();
        Collider[] colliderComponents =
GetComponentsInChildren<Collider>();

        // Disable rendering:
        foreach (Renderer component in rendererComponents)
        {
            component.enabled = false;
        }

        // Disable colliders:
        foreach (Collider component in colliderComponents)
        {
            component.enabled = false;
        }

        Debug.Log("Trackable " + mTrackableBehaviour.TrackableName + "
lost");

        mLostTracking = true;
        mSecondsSinceLost = 0;
    }

    // Pause all videos except this one
    private void PauseOtherVideos(VideoPlaybackBehaviour currentVideo)
    {
        VideoPlaybackBehaviour[] videos = (VideoPlaybackBehaviour[])
                FindObjectsOfType(typeof(VideoPlaybackBehaviour));

        foreach (VideoPlaybackBehaviour video in videos)
        {
            if (video != currentVideo)
            {
                if (video.CurrentState ==
VideoPlayerHelper.MediaState.PLAYING)
                {
                    video.VideoPlayer.Pause();
                }
            }
        }
    }
    #endregion //PRIVATE_METHODS
     }
```

Annex 8. Curriculum vitae

CURRICULUM VITAE

PERSONAL INFORMATION	
First name / Surname	**Ştefan, Bodi**
Address	5 Vasile Alecsandri Street, Ap. 5, 420010 Bistriţa, Bistriţa-Năsăud, Romania
Telephone	-
E-mail	stefan.bodi@muri.utcluj.ro
Nationality	Romanian
Date of birth	22.04.1988
Gender	Male
Desired employment / Occupational field	-
PROFESSIONAL EXPERIENCE	
Period	**October 2014 – Present**
Occupied work position	**Asisstant lecturer**
Activities and main responsibilities	Student training teaching activities in the areas of computer aided design and quality management.
Name and address of employer	Technical University of Cluj-Napoca 103-105 Muncii Blvd., 400641 Cluj-Napoca, Cluj, Romania
Type of activities or business sector	University education.
Period	**May 2014 – November 2015**
Occupied work position	**Design researcher**
Activities and main responsibilities	Design activities for innovative furniture products and designing the corresponding technological processes.
Name and address of employer	S.C. Smart Furniture S.R.L. 53 Branului Street, 400641 Cluj-Napoca, Cluj, Romania
Type of activities or business sector	Research, 3D design, technology flow design.
Period	**November 2013 – September 2014**
Occupied work position	**Technology transfer specialist**
Activities and main responsibilities	Technology and research transfer activities to the industry
Name and address of employer	Danube Transfer Center Cluj-Napoca 103-105 Muncii Blvd., 400641 Cluj-Napoca, Cluj, Romania
Type of activities or business sector	Research, technology transfer, innovation training for companies
Period	**October 2011 – July 2013**
Occupied work position	**Research internship**
Activities and main responsibilities	Research activities, volunteer at Interuniversitary Research Centre for Quality Management and Engineering.
Name and address of employer	Technical University of Cluj-Napoca 103-105 Muncii Blvd., 400641 Cluj-Napoca, Cluj, Romania
Type of activities or business sector	Research, development, innovation in quality management and engineering and design for quality.

EDUCATION AND TRAINING	
Period	**October 2013 – present**
Title of qualification awarded	**PhD. Student** in management and engineering Topic: Research and contributions regarding the use of the virtual environment for supporting quality management
Principal subjects covered /professional skills aquired	- quality management and engineering; - quality management techniques and tools; - industrial metrology; - statistical process control; - process improvement through simulation.
Name and type of organisation providing education and training	Technical University of Cluj-Napoca
Period	**October 2011 – July 2013**
Title of qualification awarded	**Master of engineering** in Quality Management and Engineering
Principal subjects covered /professional skills aquired	- quality management and engineering; - quality engineering techniques and tools; - industrial metrology; - design for quality and environment; - six sigma; - intellectual property management; - integrated management systems; - methods and equipment for industrial process control; - geometrical product specification.
Name and type of organisation providing education and training	Technical University of Cluj-Napoca
Period	**12-14 December 2011**
Title of qualification awarded	ISO 9001:2008 Internal Quality Auditor
Principal subjects covered /professional skills aquired	- auditing quality management systems using the ISO 9001:2008 standard requirements
Name and type of organisation providing education and training	S.C. Calitop S.R.L.
Period	**August 2010 – December 2010**
Title of qualification awarded	**Erasmus mobility**
Principal subjects covered /professional skills aquired	- automating manufacturing processes; - industrial process control softwares; - practical activity: developing an educational production line; - computer programming using ".net" language; - manufacturing equipment maintenance.
Name and type of organisation providing education and training	HAMK – University of applied sciences, Finland

Period: **October 2007 – October 2011**

Title of qualification awarded: **Bachelor of Engineering** in Robotics

Principal subjects covered /professional skills aquired:
- robot mechanics;
- robot engineering;
- robotized manufacturing;
- manufacturing processes technology;
- industrial software;
- computer aided design;
- flexible manufacturing systems.

Name and type of organisation providing education and training: Technical University of Cluj-Napoca

Period: **September 2003 – October 2007**

Title of qualification awarded: **High school diploma**

Principal subjects covered /professional skills aquired:
- computer programing;
- mathematics;
- physics;
- chemistry;
- English;
- German.

Name and type of organisation providing education and training: “Andrei Mureşanu” National High School of Bistriţa

PERSONAL SKILLS

Mother tongues: **Hungarian, Romanian**

Other languages: **English, German**

Self-assessment	Understanding		Speaking		Writing
European level (*)	Listening	Reading	Spoken interaction	Listening	Reading
English	C1 Proficient user	C2 Proficient user	C1 Proficient user	C1 Proficient user	C2 Proficient user
German	B2 Independent user	B1 Independent user	B1 Independent user	B1 Independent user	B1 Independent user

(*) Common European Framework of Reference for Languages

Social skills and competences:
- team work: I’ve acquired teamwork skills both within the research team of the university and during academic studies, by participating in various practical activities and projects;
- communication abilities;
- presentation abilities.

Organisational / managerial skills and competences:
- leadership skills;
- perseverance;
- objectivness;
- dynamic personality;
- desire for self-improvement;
- professional discipline;
- adaptability to change;
- balanced in stressful situations.

Technical skills and competences

- design skills in Mechanical Engineering and Robotics;
- design of processes for machine building;
- basic knowledge in optimal designing.

Computer skills and competences

- advanced programming knowledge in C++, FoxPro, Java languages;
- advanced modeling knowledge in 3D CAD in CATIA (12 modules) and SolidWorks;
- knowledge in offline robot programming in RobotStudio;
- advanced user in Microsoft Office programs.

Other skills

- ambition;
- perspicacity and enthusiasm;
- imagination;
- charisma.

Driving licence

A, B, C, CE vehicle category driving licence.

ADDITIONAL INFORMATION

Publications

Out of the 17 publications in total, 5 are selected and presented here:

1. Dragomir, Mihai; **Bodi, Ştefan**; Iamandi, Oana; Dragomir, Diana; *Applying Sigma Flow simulation software for improving the quality of an R&D Project*, Proceedings of the 2014 International Conference on Production Research & 3rd International Conference on QIEM, pp. 152-156, ISBN 978-973-662-978-5, 1-5 July 2014, Cluj-Napoca, Romania; indexed ISI proceedings;
2. **Bodi, Ştefan**; Popescu, Sorin; Drăgeanu, Călin; Popescu, Dorin; *Virtual Quality Management elements in optimized new product development using genetic algorithms*; Proceedings of the MakeLearn and TIIM Joint International conference, pp. 633-642, ISBN 978-961-6914-13-0, Bari, Italy, 27-29 May 2015;
3. **Bodi, Ştefan**; Dragomir, Mihai; Banyai, Daniel; Dragomir, Diana; *Process improvements using simulation software and quality tools*, 12th International conference on Modern Technologies in Manufacturing, 14-16 October 2015, Cluj-Napoca, Romania, published in Applied Mechanics and Materials Vol. 808, 2015, pp. 376-381, ISSN print 1660-9336;
4. Neamţu, Călin; **Bodi, Ştefan**; Ghinea, Rareş; Papp, Attila; *Failure Mode and Effect Analysis for mold design*; Acta Technica Napocensis - Series: Applied Mathematics, Mechanics and, Engineering, Vol. 54, Iss. 4, pp. 533-536, 2015, ISSN 1221-5872, indexed ISI;
5. **Bodi, Ștefan**; Comes, Radu; Weckenmann, Albert; Popescu, Sorin; *Assistive augmented environment for quality inspection and statistical process control*, Proceedings of the 2016 International Conference on Production Research & 4th International Conference on QIEM, pp. 494-499, ISBN 978-606-737-180-2, 25-30 July 2016, Cluj-Napoca, Romania; indexed ISI proceedings.

Conferences

- Antreprenor Viitor Durabil, 27-28 September 2011, 15-16 March 2012 and 16-18 May 2012, Cluj-Napoca, Romania;
- 2nd International conference on Quality and Innovation in Engineering and Management (QIEM), 21-25 November 2012, Cluj-Napoca, Romania;
- Disruptive Innovation in Manufacturing Engineering – Towards the 4th Industrial Revolution, 3rd October 2013, Cluj-Napoca, Romania;
- 11th International Scientific Conference on Coordinate Measuring Technique, 2-4 April 2014 Bielsko-Biala, Poland;
- 2014 International Conference on Production Research & 3rd International Conference on QIEM, 1-5 July 2014, Cluj-Napoca, Romania;
- MakeLearn and TIIM Joint International conference, 27-29 May 2015, Bari, Italy;
- 12th International conference on Modern Technologies in Manufacturing, 14-16 October 2015, Cluj-Napoca, Romania;
- 3rd International Engineering and Technology Education Conference & 7th Balkan Region Conference on Engineering and Business Education, 1-4 November, Sibiu, Romania;
- 2016 International Conference on Production Research & 4th International Conference on QIEM, 25-30 July 2016, Cluj-Napoca, Romania.

References

- Prof. Univ. Dr. Ing. Popescu Sorin, e-mail: sorin.popescu@muri.utcluj.ro;
- Prof. Univ. Dr. Ing. Popescu Daniela, e-mail: daniela.popescu@muri.utcluj.ro;
- Conf. Dr. Ing. Neamțu Călin, e-mail: calin.neamtu@muri.utcluj.ro;
- Conf. Dr. Ing. Dragomir Mihai, e-mail: mihai.dragomir@muri.utcluj.ro

Managing Intellectual Capital and Innovation for Sustainable and Inclusive Society
27–29 May 2015
Bari • Italy
make learn TIIM
Management, Knowledge and Learning
Joint International Conference 2015
Technology, Innovation and Industrial Management

VIRTUAL QUALITY MANAGEMENT ELEMENTS IN OPTIMIZED NEW PRODUCT DEVELOPMENT USING GENETIC ALGORITHMS

Stefan Bodi
Technical University of Cluj-Napoca, Romania
stefan.bodi@muri.utcluj.ro

Sorin Popescu
Technical University of Cluj-Napoca, Romania
sorin.popescu@muri.utcluj.ro

Calin Drageanu
Technical University of Cluj-Napoca, Romania
calin.drageanu@muri.utcluj.ro

Dorin Popescu
Technical University of Cluj-Napoca, Romania
dorin.popescu@de3.ro

Abstract:
The contribution of this paper is placed in the field of vQM (virtual Quality Management) supposing the use of software techniques in product and its manufacturing process planning. The research was focused on laying out a framework, which brought together quality techniques used in competitive design (VOCT, AHP, QFD) and mechanisms inspired by biological evolution (genetic algorithms), achieving in the same time customer oriented development and optimization of new product characteristics. Both quality techniques and genetic algorithm were deployed in the virtual environment based on specialized software tools (Qualica, Genesis). The methodology supposes as stages: “Acquiring and ranking customer knowledge” (VOCT and AHP in identifying customer requirements and their degree of importance); “Turning requirements into characteristics” (cascaded QFD is translating successively customer requirements into technical characteristics of product and its components) and “Product optimization” (genetic algorithm optimizes the component characteristics). The genetic algorithm itself contains several constraints derived either from the customer requirements or product functionality. Thus, each component’s shape, size and fitness is determined by the objective function, formulated within the genetic algorithms code. By complying with the above described framework, each component is optimally designed to constitute a product that will best serve customer needs. The proposed methodology is illustrated on the development of furniture industry products that cover diverse design situation. The product optimization and the objective function derived were focused on minimizing the product mass, implicitly its raw material consumption.

Keywords: new product development; information technology; genetic algorithms; virtual quality management

1. INTRODUCTION

In the context of virtualization, product design and manufacturing companies rely more and more on complex computational systems, which are capable to respond to situations already predicted through simulations performed in the virtual environment, based on information obtained from all devices involved in the manufacturing process.

As the need grows for ever increasing productivity, current manufacturing systems are not capable to manage the huge amount of data needed to reach the required level of productivity. Industry 4.0 can offer a solution to this problem as it is based on Cyber Physical System-enabled manufacturing. This means that the virtual information flow between the actual product and the processes related to it (including supply, shipping and customer feedback) will be enhanced and all information will be linked up as a Cyber-Physical System (CBS) (Lee, Bagheri, & Kao, 2015).

The concept of vQM (virtual Quality Management), in addition to this, takes into account also the environmental issues and any other factors that can influence the final product (i.e. Quality Knowledge and Process Knowledge) and with the help of “Design of Virtual Experiments” and “Quality Oriented process models”, through modelling and simulation the so called “Quality Parameters” and process parameters are obtained. The latter ones can be further processed in the sense that they can be optimized, this way obtaining the best possible solution, which can be implemented and used in real-life scenarios (Bookjans & Weckenmann, 2011).

This paper proposes to out lay a framework for new product development by deploying tools used in vQM, in the same order and structure in which the concept was first formulated (Figure 1), but slightly modified and adapted strictly to product development.

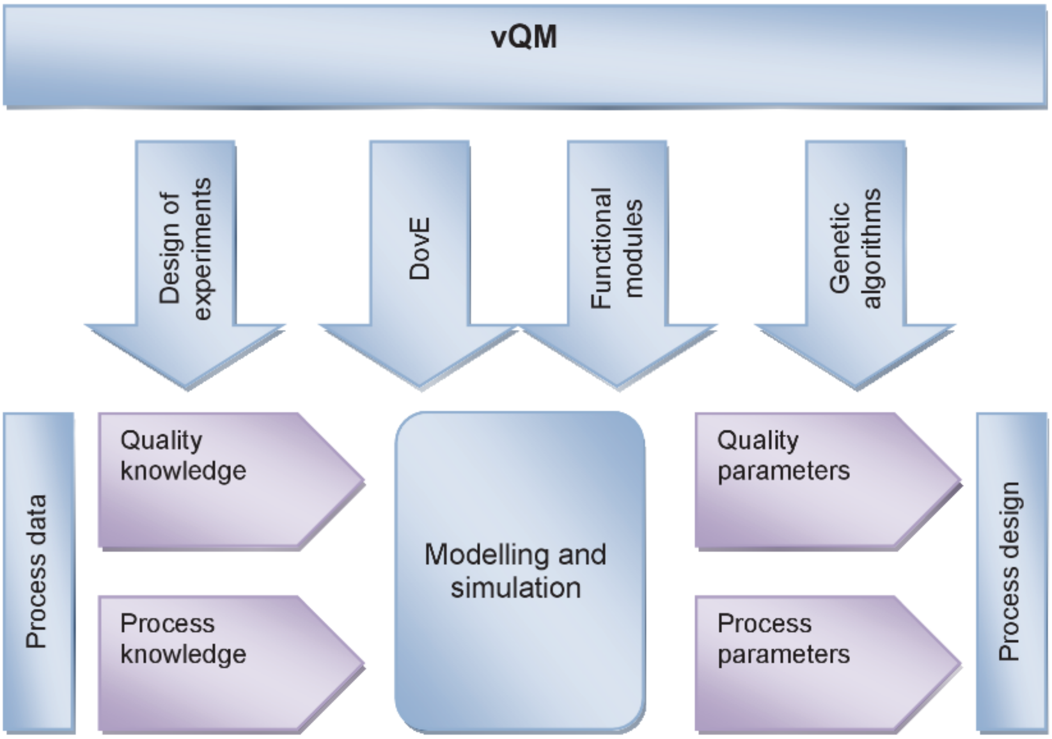
The framework presented in this paper will be illustrated by a simple example that will refer to a common household item. The product in question will be put through all the stages of the framework and the results will prove its effectiveness.

2. THEORETICAL FRAMEWORK AND LITERATURE REVIEW

The concept of virtual Quality Management is based on, but not limited to simulation studies, which are efficiently deployed for the sole purpose of “generating resilient knowledge and dimensioning quality techniques” (Bookjans & Weckenmann, 2010) that can be applied either to products or processes, before they physically exist. By doing so, products and processes reach a certain level of maturity in the planning stage, so they can be introduced straight into production, having an increased level of performance compared to ones developed using conventional methods.

An overview of the vQM concept is depicted in Figure 1, with interactions between its elements.

Figure 1: Elements of virtual Quality Management



Source: (Bookjans & Weckenmann, 2011, p. 17)

Figure 1 shows that starting from the information that describes ideal processes (process knowledge) and taking into consideration factors that are environment related or come up due to other external influences, which make the process not to behave in an ideal way (quality knowledge), through simulations, highly accurate, close to real-life scenarios can be obtained, as well as prognosis regarding the stability, capability and predictability of a modelled process (Bookjans & Weckenmann, 2011).

The main advantage of this concept is that by increasing the accuracy of the process models there will be no surprises when implementing them into production. This way highly precise resource allocation can be made, which in term reduces overall costs.

Keeping this in mind, the proposed framework is based on the architecture of vQM, having three main stages: “Acquiring and ranking customer knowledge” (e.g. Voice of the Customer Table (VOCT) and Analytical Hierarchy Process (AHP) in identifying customer requirements and their degree of importance); “Turning requirements into characteristics” (e.g. cascaded QFD is translating successively customer requirements into technical characteristics of product and its components) and “Product optimization” (e.g. genetic algorithm optimizes the component characteristics), corresponding to the stages of vQM.

VOCT is a broadly used and simple method for identifying the needs or preferences of the customer. (Roman, 2010) It can also be deployed for better understanding how the customer perceives the product (Hanjun, JinYoung, & Yongmoo, 2014, p. 207). In the field of product development, the VOCT is applied to improve the fitness of the product that is developed to the customer needs for which it is intended.

The VOC analysis is mainly deployed either by subjecting each formulated customer requirement to a 5W1H analysis (Bradlow, 2010) or by determining relationships between complaints and requirements (Pyon, Woo, & Sang, 2010). When dealing with small scale applications the first one is more convenient, as it does not require data mining and huge amount of data processing.

The VOCT is followed by the ranking of identified customer requirements, regardless if they are intrinsic or expressed. For this purpose the authors propose the use of the AHP method, which ranks and weighs criteria in a systematic way, by pair wise comparison (Guo-Niu, Jie, & Jin, 2015). The scale attribution to each comparison integrates not only qualitative, but quantitative aspects as well (Yanlai, Jiafu, Xinggang, & Jie, 2009) for determining the relative importance.

The outputs (the ranked customer requirements) from the first stage, which constitute the "Quality knowledge", enter the next phase, where they will be analyzed and transformed into product characteristics through a cascaded QFD deployment. The two QFD matrices are formed out of Ranked *Customer Requirements*, *Technical Characteristics (CTQs)* and Individual *Components* of the product.

It has to be noted that QFD is a powerful tool for "continuous product improvement" bringing forth innovation (Cor, 2001) and creative ways for solving conflicts between the technical characteristics.

Another advantage and argument for incorporating QFD in the proposed framework is that this method keeps in focus what the customer wants throughout the development process (Bouchereau & Rowlands, 2000). In its extended form the QFD process involves 4 steps: Product planning: house of quality; Product design: parts deployment; Process planning; Process control (Bouchereau & Rowlands, 2000). Because the authors focused mainly on product development, the framework will include the deployment's extent only to the first two matrices.

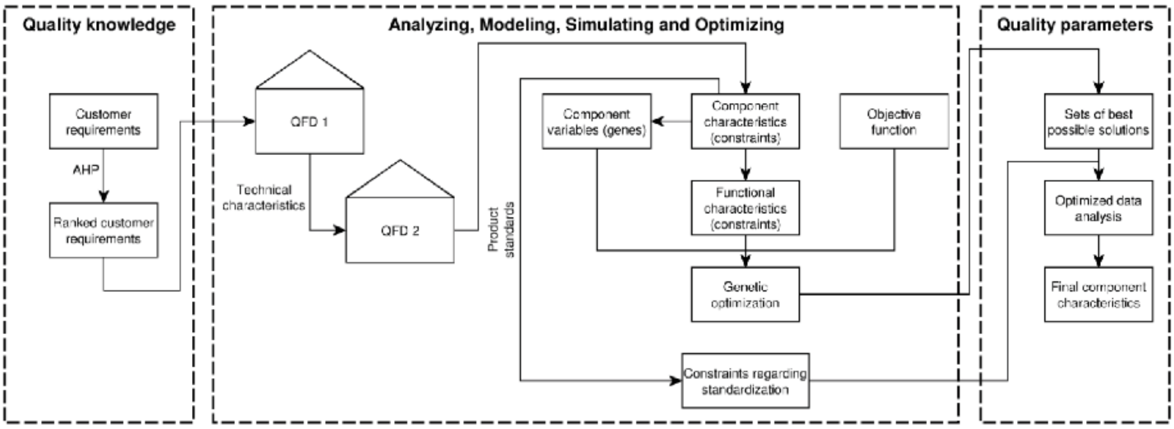
After verifying the correlations in the second QFD and obtaining the importance of each component their optimization can begin. At this point each component can be described by its characteristics (each with its own value interval), which are consistent with the customer's requirements. The optimization is done through evolutionary algorithms, by defining a single objective function (fitness function), which is either minimized or maximized, depending on the product in question and the desired outcome. First, individuals (values) are selected randomly from the defined value intervals. By applying the two fundamental evolutionary operators, which will affect those individuals and genes, the crossover and mutation (Chan, Kwong, & Wong, 2011), new possible solutions are obtained. A solution is found to be suitable, if all defined constraints are satisfied. That solution is returned and for it, it is calculated the value of the objective function. It will also serve as parent for the next generation. After re-iteration, the value of the objective function is recalculated and it is compared to the previous iteration. If the value is smaller (or greater – depending on the defined objective function) than the previously obtained one the new value is returned. It can be stated that it has a better fitness than the last one (Syberfeldt & Gustavsson, 2014). This cycle continues until the minimum (or maximum) value of the objective function is reached (Chan, Kwong, & Wong, 2011). It has to be noted that during a single objective optimization multiple values can be optimized concurrently.

3. RESEARCH

3.1. Methodology

An overview of the methodology is depicted in Figure 2:

Figure 2: Proposed framework for optimized product development



The proposed methodology begins with the customer requirements collected from potential customers by deploying numerous virtual tools such as: online surveys and questionnaires, VOCT or by analyzing trending features for the product in question, identified with the help of the internet.

The collected set of customer requirements have to undergo further finishing within established brainstorming sessions to which members from the product development team participate. This way, redundant requirements are eliminated and the remaining ones are grouped into categories for making it easy to keep track of them. This step also facilitates knowledge sharing between members and further understanding of the requirements by those that are directly connected to the product development process, thus ensuring that all ambiguity is lifted and the formulated requirements by the customer are not vague.

After this process, the final and concise set of requirements are obtained, which can undergo the prioritization process. There are lots of ways for ordering the requirements by importance, starting from traditional conjoint analysis to fuzzy logic ranking. However, arguably, the most widely used tool for prioritization is the Analytical Hierarchy Process (AHP). For this reason the presented methodology will also rely on this solution, but it can be replaced with more sophisticated tools, depending on the product in question and its complexity.

The next step is the Quality Function Deployment (QFD). The proposed methodology contains two QFD matrices interlinked in a cascaded way. The first matrix brings together the customer needs with the technical attributes. The second one verifies the correlation between technical attributes or specifications and components. This way, starting from the customer requirements we obtain technical specification for each component.

Before entering the optimization stage a few crucial steps have to be made in order to ensure the smooth running of the optimization process. This is called also as defining the optimization problem. Firstly, it is imperative to define the objective function. Depending on the application and the desired outcomes the objective function lays out the path through which the optimization is made. Secondly, the genes (variables) that are optimized in the light of the objective function have to be stated, so it is clear, which are the critical areas upon which the optimization is performed. These genes are the actual information that describes each component (length, width, height, etc.). It should also be noted that the genes have to be present as variables in the mathematical form of the objective function. It is also accepted if a new variable is used, that was earlier defined with the help of the gene in question.

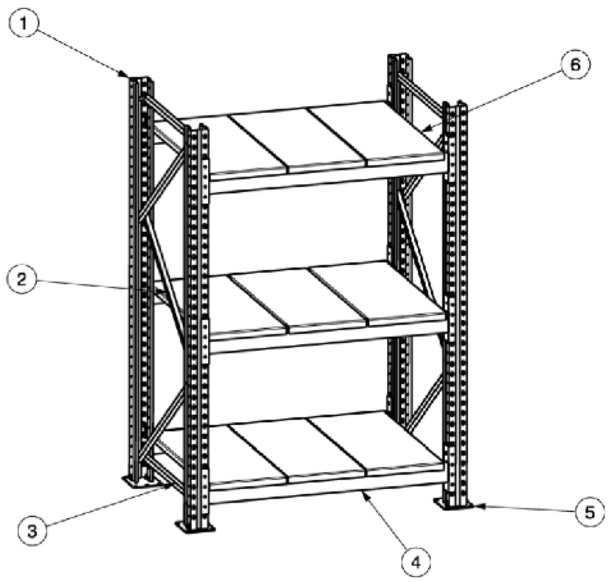
Finally, it is important to define the constraints, which are given by the component and functional characteristics of the product.

Next, the genetic algorithm can be easily deployed for each component of the product with its own objective function, constraints and genes. By deploying the genetic algorithm we obtain an optimized set of genes (i.e. component characteristics) or set of best possible solution. This set of data has to be further analyzed and compared to product standards that contain standardized information regarding the shape, size, or even form of the product. This is done because even if an “optimized variable” is obtained, incorporating it in the product could prove more costly than to use a standardized dimension.

3.2. Illustrative case study

The methodology described above is illustrated on a simple example. The product in question (modelled using a 3D CAD solution – Figure 3) is a common household shelf that was optimized regarding its mass. It was desired that the product should serve the same needs in the same way or better, but with less material consumption. Thus, the objective function was formulated taking account the weight of each product component.

Figure 3: The modelled optimized product (Note: part denomination can be seen in the second QFD matrix)



The first step was the requirement identification and hierarchization, which was possible using a specialized software tool called "Qualica QFD":

Figure 4: Ranked customer requirements

Group: **Top Level ITEMS** | Output | Completed: ☑

AHP Toplevel Matrix

- 9 9,00 an order of magnitude more important
- 8 8,00 absolutely more important (8x as important)
- 7 7,00 demonstrated more important
- 6 6,00 demonstrated more important (6x as important)
- 5 5,00 essentially more important
- 4 4,00 essentially more important (4x as important)
- 3 3,00 considerably more important
- 2 2,00 twice as important
- \+ 1,50 somewhat more important
- ○ 1,00 Equally important
- \- 0,67 somewhat less important
- ½ 0,50 half as important
- ⅓ 0,33 clearly less important
- ¼ 0,25 essentially less important (other item 4x as important)
- ⅕ 0,20 essentially less important
- ⅙ 0,17 demonstrated less important (other item 6x as important)
- ⅐ 0,14 demonstrated less important
- ⅛ 0,13 absolutely less important (other item 8x as important)
- ⅑ 0,11 an order of magnitude less important

Input	1 the shelf should be modular	2 open access to every item on the shelf	3 easy and fast assembly	4 it should bear a weight of 60 kg/ stand	5 it should be made out of steel	6 it should fit into a space with a volume of 1200x600x2000 mm	7 it should be light	8 it should have minimum two stands	9 the stands should be at least 500 mm apart	Importance in group
1 the shelf should be modular		3	3	¼	½	¼	⅓	2	4	8,8%
2 open access to every item on the shelf			½	⅙	⅕	⅙	½	½	-	3,6%
3 easy and fast assembly				¼	½	¼	-	○	2	5,7%
4 it should bear a weight of 60 kg/ stand					3	-	4	4	5	25,1%
5 it should be made out of steel						-	⅓	3	3	11,1%
6 it should fit into a space with a volume of 1200x600x2000 mm							3	4	4	23,7%
7 it should be light								2	2	12,5%
8 it should have minimum two stands									2	5,5%
9 the stands should be at least 500 mm apart										3,9%

Importances / Sorted ITEMS 1	Calculated Importance %	Final Importance %
4 it should bear a weight of 60 kg/ stand	25,1%	23,1%
6 it should fit into a space with a volu...	23,7%	22,0%
7 it should be light	12,5%	12,3%
5 it should be made out of steel	11,1%	11,1%
1 the shelf should be modular	8,8%	9,2%
3 easy and fast assembly	5,7%	6,5%
8 it should have minimum two stands	5,5%	6,3%
9 the stands should be at least 500 m...	3,9%	4,9%
2 open access to every item on the shelf	3,6%	4,6%
Most important item:	25,1%	
Least important item:	3,6%	

After the pair wise comparison between the requirements (Figure 4 – left) the ranked customer needs are obtained (Figure 4 – right). As it can be seen in the above figure the two most important needs are related to the dimensions of the shelf and its load capability.

The information obtained after the AHP constitute inputs for the phase, for the cascaded QFD deployment.

In Figure 5 it is depicted the first QFD matrix, which analyzes correlation between needs and technical characteristics (which constitute the CTQs). This is the first step in transforming customer requirements into component characteristics. Based on the calculated importance of the needs, by verifying correlation between needs and CTQs, one can calculate the importance of the later ones. In this sense, as expected, the most important two CTQs describe the top two customer requirements, ranked during the AHP.

The second QFD matrix (Figure 6), which is interlinked with the first one (calculated CTQ values are the same), analyzes correlations between CTQs and product components. Thus, alongside the importance of each component we also obtain information about their characteristics (dimensions, load that it should withstand, etc.). For a simple illustration the authors focused only on optimizing the top two most important components (i.e. the *shelf* – no. (6) and the *shelf support beam* – no. (4))

When it is established which components are suitable for optimization, the problem must first be formulated. In our case the most suitable components that should undergo optimization are the shelf and the support beams upon which the shelf is placed. This selection is based on data obtained from the QFD process, thus, in a broader sense, based on customer requirements.

Next, it has to be established which variables, that characterize the component, will serve as genes. In the case of the first component we are looking for the thickness of the metal sheet and the height of the shelf's side reinforcement. After that the objective function is formulated: in this case it is the mass of the shelf, which is expressed by multiplying height, width, length and material density. It is imperative that the objective function has to contain all of the genes (optimized variables) or other variables that are expressed with the help of them. Finally, the restrictions have to be expressed by inequations, that will serve as limits for the optimization.

Figure 5: First QFD matrix

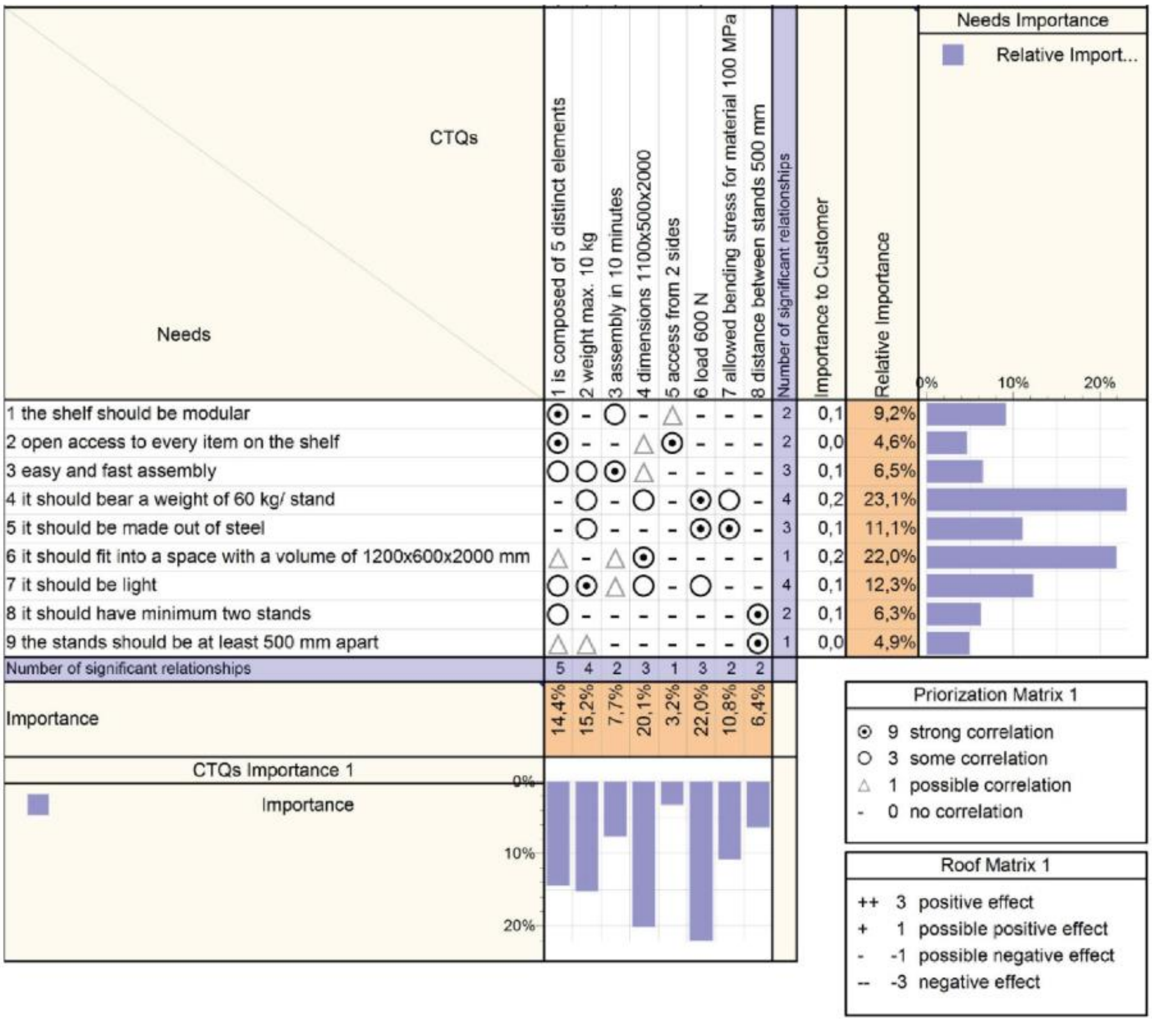
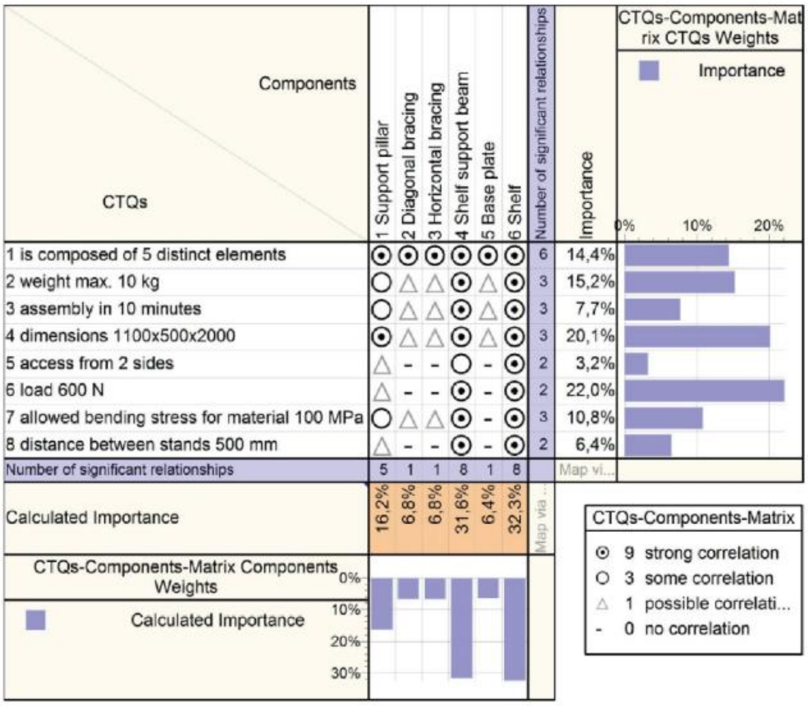


Figure 6: Second QFD matrix



The main concern when designing a product is dimensioning of components. When employing classic methods a "pre-dimensioning" is done, which will make sure that the component will withstand the stress that is subjected to. In many cases the allowable bending stress for the material is not optimally used because the component is oversized (more material is put into the component without need). In the case of optimal design the "pre-dimensioning" is replaced with iterations, meaning that the solution is not calculated exactly, but looked for within an interval. This way the obtained solutions are closer to an ideal case, because they are found according only to the established restrictions.

Keeping all this in mind, the input data for optimizing the top two components are presented in table 1 and 2:

Table 1: Entry data for the optimization for the "*shelf*" component

Known variables		Searched variables (genes)	Objective function	Restrictions
Load: F=600 N (≈60 kg)	Material density: r=7.87*10^{-6} kg/mm^3	Metal sheet thickness: t	Mass: M=r*(h*t+w*t)*l	1. Bending verification: $\sigma_i \leq \sigma_{ia} \rightarrow R_1 = \frac{\sigma_i}{\sigma_{ia}} - 1 \leq 0$
Length: l=1000 mm	Allowed bending stress: σ_a=100 MPa	Height of the shelf reinforcement: h		2. Metal sheet thickness should be at least 0.7 mm: $t \geq 0.7$ mm $\rightarrow R_2 = \frac{0.7}{t} - 1 < 0$
Width: w=400 mm				3. The height of reinforcement should be at least 20 mm; $h \geq 20$ mm $\rightarrow R_3 = \frac{20}{h} - 1 < 0$

Table 2: Entry data for the optimization of the "support beam" component

Known variables	Searched variables (genes)	Objective function	Restrictions
Load: F=650 N (≈65 kg)	Height of the beam: H	Mass: M=r*(H*B-h*b)*l	1. Bending verification: $\sigma_i \le \sigma_{ia} \rightarrow R_1 = \frac{\sigma_i}{\sigma_{ia}} - 1 \le 0$
Length: l=1200 mm	Width of the beam: B		2. Wall thickness should be at least 2 mm: $t \ge 2$ mm $\rightarrow R_2 = \frac{2}{t} - 1 < 0$
Material density: $r=7.87*10^{-6}$ kg/mm^3	Wall thickness: t		3. The width should be smaller than the height $B < H \rightarrow R_3 = \frac{B}{H} - 1 < 0$
Allowed bending stress: σ_a=100 MPa			4. The width should be at least 2 times smaller than the height: $B \ge H/2 \rightarrow R_4 = \frac{H}{2*B} - 1 \le 0$

All this information obtained until this point is introduced in a specialized software tool, called Genesis, which will perform the actual optimization in the manner described in the previous chapter (the information is transformed into a C++ code).

As outputs we obtained a set of solution, which was then compared to product standards for both components (i.e. standardized thickness, standardized width, standardized length, etc.), according to (EN 10025, 2004), (EN 10219, 2006), (EN 10305-5, 2010).

For better illustrating the effectiveness of the described framework the authors also calculated the values for the component characteristics using classic design methods. A comparison between the two is shown in Table 3.

Table 3: Obtained results

<table>
<tr><th colspan="6">Classic product development</th><th colspan="6">Optimized product development</th></tr>
<tr><td colspan="3">t – 1 mm</td><td colspan="3">h – 20 mm</td><td colspan="3">t – 0.7 mm</td><td colspan="3">h – 28 mm</td></tr>
<tr><td colspan="6">Mass: 3.305 kg</td><td colspan="6">Mass: 2.358 kg</td></tr>
<tr><td colspan="2">H – 50 mm</td><td colspan="2">B – 40 mm</td><td colspan="2">t – 3 mm</td><td colspan="2">H – 70 mm</td><td colspan="2">B – 30 mm</td><td colspan="2">t – 2 mm</td></tr>
<tr><td colspan="6">Mass: 3.966 kg</td><td colspan="6">Mass: 3.022 kg</td></tr>
</table>

In the case of both components significant reduction of mass is obtained: 29% and 24% respectively.

4. CONCLUSIONS

The purpose of the vQM concept is to generate resilient knowledge either for product or processes by deploying tools and instruments used in the virtual environment. The end scope is to develop the necessary information for those products/processes that will enable implementation into production with an increased performance and with a higher degree of predictability. The concept of vQM was slightly adapted for the product development process, thus obtaining a new framework that relies on customer requirements throughout the entire process and it offers optimized data for the component characteristics of the products' constitutive elements.

By deploying instruments that are simple to use (e.g. VOCT, AHP and cascaded QFD) and more advanced ones (e.g. genetic algorithms) in the structure described within the framework, product optimization can be achieved without compromising or neglecting the initial customer requirements.

The framework was subject to a common household item, which was optimized from its mass perspective, but it can also be applied to more complex products, with a different optimization perspective. For the optimized product an overall 27% mass reduction was obtained.

Future work can go as far as the extent of process modelling.

ACKNOWLEDGEMENTS

This work was partially supported by the strategic grant POSDRU/159/1.5/S/137070 (2014) of the Ministry of National Education, Romania, co-financed by the European Social Fund – Investing in People, within the Sectoral Operational Programme Human Resources Development 2007-2013.

The present paper benefited also from the scientific and academic support of Prof. Dr.-Ing. Prof. h.c. mult. Dr.-Ing. E.h. Dr. h.c. mult. Albert Weckenmann, who provided valuable assistance for the undertaking of the research summarized here and for the overall doctoral progress.

REFERENCE LIST

1. Bookjans, M., & Weckenmann, A. (2010). Virtual Quality Management - Validation of measurement systems by the use of simulation technologies. *Laser Assisted Net Shape Engineering 6(5), Part 2 - Proceedings of the LANE 2010* , 745-752.
2. Bookjans, M., & Weckenmann, A. (2011). Virtual Quality Management: A holistic approach for the set-up of true-to-life process models and according virtual quality management tools. *Proceedings of 1st International Conference on Quality and Innovation in Engineering and Management* , 17-22.
3. Bouchereau, V., & Rowlands, H. (2000). Methods and techniques to help quality function deployment (QFD). *Benchmarking: An International Journal* 7(*1*), 8-19.
4. Bradlow, E. (2010). User-generated content: The "voice of the customer" in the 21st century. *Marketing Intelligent Systems using Soft Computing 258* , 27-29.
5. Chan, K. Y., Kwong, C. K., & Wong, T. C. (2011). Modelling customer satisfaction for product development using genetic algorithms. *Journal of Engineering Design 22(1)*, 55-68.
6. Cor, P. M. (2001). QFD not just a tool but a way of quality management. *International Journal of Production Economics 69(2*), 151-159.
7. European Committee for Standardization. (2004). EN 10025.
8. European Committee for Standardization. (2006). EN 10219.
9. European Committee for Standardization. (2010). EN 10305-5.
10. Guo-Niu, Z., Jie, H., & Jin, Q. (2015). An integrated AHP and VIKOR for design concept evaluation based on rough number. *Advanced Engineering Informatics* , Article in Press.
11. Hanjun, L., JinYoung, H., & Yongmoo, S. (2014). Gift or threat? An examination of voice of the customer: The case of MyStarbucksIdea.com. *Electronic Commerce Research and Applications 13* , 205-219.
12. Lee, J., Bagheri, B., & Kao, H.-A. (2015). A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters 3* , 18–23.
13. Pyon, C., Woo, J., & Sang, C. (2010). Intelligent service quality management system based on analysis and forecast of VOC. *Expert Systems with Applications 37* , 1056-1064.
14. Roman, E. (2010). *Voice-of-the-Customer Marketing: A Revolutionary 5-Step Process to Create Customers Who Care, Spend, and Stay.* McGraw-Hill.
15. Syberfeldt, A., & Gustavsson, P. (2014). Increased robustness of Product Sequencing using Multi-Objective Optimization. *Procedia CIRP 17* , 434-439.
16. Yanlai, L., Jiafu, T., Xinggang, L., & Jie, X. (2009). An integrated method of rough set, Kano's model and AHP for rating customer requirements' final importance. *Expert Systems with Applications 36(3), Part 2* , 7045-7053.

2016 International Conference on Production Research – Africa, Europe and the Middle East
4th International Conference on Quality and Innovation in Engineering and Management

ASSISTIVE AUGMENTED ENVIRONMENT IN QUALITY INSPECTION AND STATISTICAL PROCESS CONTROL

Ș. Bodi[1], R. Comes[2], A. Weckenmann[3], S. Popescu[4]

[1,2,4] Department of Design Engineering and Robotics, Technical University of Cluj-Napoca,
103-105 Muncii Blvd., 400641 Cluj-Napoca, Cluj, Romania

[3] Quality Management and Manufacturing Metrology, University Erlangen-Nürnberg,
25 Naegelsbachstr., 91052 Erlangen, Germany

[1] stefan.bodi@muri.utcluj.ro, [2] radu.comes@muri.utcluj.ro, [3] albert.weckenmann@qfm.uni-erlangen.de,
[4] sorin.popescu@muri.utcluj.ro

Abstract
Advancements in ICT systems brought forward progress in many fields. In production engineering, for example, facilitated the emergence of the fourth Industrial Revolution or Industry 4.0, which, among others, promotes the use of virtual or augmented environments in various industrial processes. Thus, it creates a new branch in the quality approach that tackles the virtual aspects of quality management, entitled Virtual Quality Management (vQM). In this context, this paper presents the implementation of an augmented reality (AR) application linked to a web platform, both developed to aid the workers on the factory floor and supervisors, to monitor and control different manufacturing processes. The workers are assisted throughout the measurement of workpieces by the application providing them with relevant information about the measured dimensions. The values of the latter ones are recorded into a database with the help of an online, easy to use and intuitive platform. Users with special access credentials can login to the web platform and generate control charts, histograms or bar charts that are constructed based on the values from the database. The purpose of these charts is to assist the supervisors in monitoring the processes, aiding them with information for taking the proper corrective or preventive actions. This approach is in line with the currently trending Industry 4.0 concept by making use of smart devices on the factory floor.

Keywords:
Assistive Inspection, Augmented Reality, Statistical Process Control, Virtual Quality Control

1 INTRODUCTION

Today's manufacturing processes have multiple layers of quality control steps that ensure that the product quality meet the required specifications. Quality control technologies are controlling multiple fabrication processes in an active way [1] and newly developed IT instruments are increasingly present in today's manufacturing [2], [3], [4].

Augmented reality, for example, is a technology that is more and more appealing to operators working on the factory floor as it combines real world elements acquired using different computer vision techniques with computer generated elements. Natural features of different real world elements are being used in order to register and trigger the computer generated elements. Mobile devices that are capable to operate AR applications have increased during the last years therefore the number of developers and researchers has increased by a vast amount.

The subject of this paper is the development and use of virtual type instruments that support the quality approach, but at the same time bridge the gap between currently employed industrial solutions and practices promoted by Industry 4.0. In this sense, advantages offered by smart devices alongside augmented reality (AR) mobile applications and web platforms are proposed to be introduced straight into production and used on the factory floor to empower the workers and boost the organization's quality capabilities through the virtual environment.

2 PURPOSE AND PRELIMINARY INFORMATION

This paper introduces a package of two solutions used concurrently for both quality inspection and statistical process control (an AR mobile application and a web platform) and illustrates their combined effectiveness and importance in different manufacturing environments. This synergy is highlighted in scenarios when complex operations are carried out and the part dimensional validation is primordial for future actions.

The AR mobile application assists the operator eliminating any ambiguities about the required dimensional values, providing him with access to all essential information. This kind of application reduces the need for expert supervision in the manufacturing plant. One common issue regarding the manufacturing and quality control systems is that they make use of 2D CAD layouts and only some employees have the required expertise to fully understand these layouts especially when they are for complex assemblies.

In recent years many companies have started to use 3D CAD representations, however their visualisation system uses only digital representation limited to complex assemblies and data sheets without any real-life inclusion.

The proposed application makes use of real parts and adds an extra layer of visualization to these real parts using computer vision offered by the tablet or smartphone camera. The technology and hardware capabilities of these devices have a great potential for real time visualisation and processing due to their speed, accuracy and ease of use.

The web platform used alongside the application was designed to be a safe, simple and reliable method for inputting, storing, analysing and retrieving workpiece information

3 AUGMENTED REALITY APPLICATION DESCRIPTION

The developed application is capable of identifying real life manufacturing parts based on their 3D shape. This system is capable of positioning different computer generated elements such as annotations and tolerances directly in their correct position using computer vision and edge tracking techniques.

The application developed for this paper is an enhanced version of the augmented reality application that enables real time dimensional annotations directly on real life components. The application workflow and development process is presented in [5]. The enhanced version of this application has added another computer vision layer that enables dimensional tolerances along the standard geometrical values.

The workpiece (Figure 1) used for illustrating the functioning of the above mentioned instruments is cube-shaped and it's made out of aluminium with plenty of dimensions to measure on each side. The AR mobile application detects the side of the workpiece and it virtually overlays information about the nominal values of the dimensions and their tolerances. Each side and dimension was numbered so that the operator knows exactly which is the dimension that he refers to and where he has to input the uploaded values to the web platform's database.

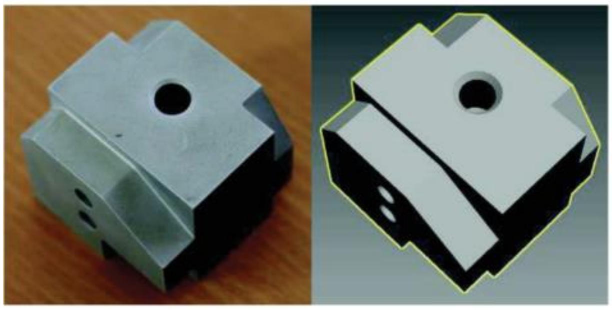


Figure 1. The workpiece part and it`s CAD 3D model

All the dimensional values and their tolerances have been created and linked to each facet of the workpiece thus reducing the time required for the edge detection system to superimpose in real time the correct annotation.

Each facet of the workpiece has been assigned a number therefore the person that will input the values in the database will be able to assign these values with ease. Figure 2 illustrates two facets of the workpiece, the image is a perspective view and it has been taken within the CAD software (3ds Max) used to create them.

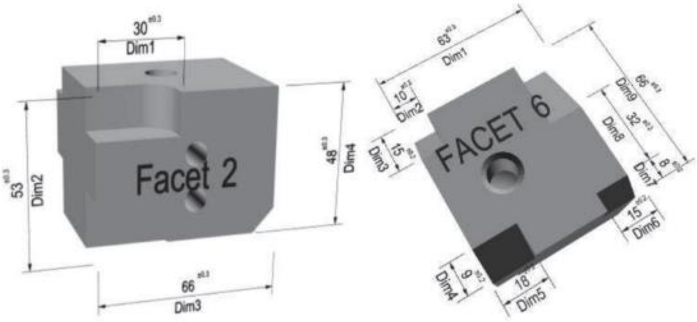


Figure 2. The dimension values and their tolerances of two facets of the workpiece

From the end user's point of view, the proper handling of the augmented reality application and the linked web database is summed up in the following steps:

1. Start the AR application;

   On his smartphone or tablet the user starts the augmented reality application. In order to speed up the application edge detection system the user is required to input the ID number of the workpiece. This process will enhance the augmented reality speed since it will only have to compare a limited amount of edges from its database with the edges obtained using the device camera.

2. Position the camera over a facet of the workpiece;

   When the application is started it will process the image offered by the camera and overlay the correct annotation on top of the part (see Figure 3). In the current system the application is set to a delay of 2 seconds, this delay has a main purpose in improving the detection speed by limiting the input images that the system analyzes.

Figure 3. Visualizing the annotations in AR

3. Read the nominal value and the dimension number of the geometrical dimension that will be measured on the workpiece;

   The user only has to see the workpiece through the mobile device screen in order to display the proper nominal values. In the meantime, he is also able to manipulate and inspect the workpiece while observing different values on the screen. After the user knows exactly what dimension he is going to measure and has acknowledged the nominal value and tolerance he can proceeded to the actual measurement of the dimension using a measuring device, for example a caliper.

4. After measuring the dimension, open the web platform using a standard web browser and log in with provided credentials;

   This step requires the user to access the web platform in order to input the measured values obtained in the previous step (Figure 4).

5. Select the measured dimension of the workpiece and the dimension number corresponding to it from the two dropdown menus;

   As presented in Figure 5 the user has to select interactively the side of the workpiece and the dimension number to link the entered value in the textbox with the proper dimension. The "Record dimension" button will upload the value into the database.

If the measured dimension value is within tolerances a message will appear advising the user that the "Dimension was recorded successfully", otherwise he will be warned that the "Measured dimension is out of tolerance" (See Figure 8 for example).

The last two steps can be repeated as many times as there are workpieces that need to be measured.

4 WEB PLATFORM'S DESCRIPTION

It was decided that the platform should be independently developed from the application for security, reliability and user traceability issues using the simple and robust html programming language. It was brought online by a free hosting service and can be accessed at the http://vqmapplication.comxa.com/ address. Developing the two instruments separately brought forth another advantage and made it possible for the web platform to be accessed from any device (mobile or stationary) without being strictly tied to the Android operating system.

The design of the platform is quite simple and it was kept this way in order to avoid bugs or other failures (which are very undesirable in an industrial environment) and to be as user-friendly as possible. Its simplicity makes it appealing to both experienced and unexperienced users and makes it ready to use without a long training session. Actual screenshots of the web platform's layout were captured and are provided below. They represent it performs on a mobile device's screen:

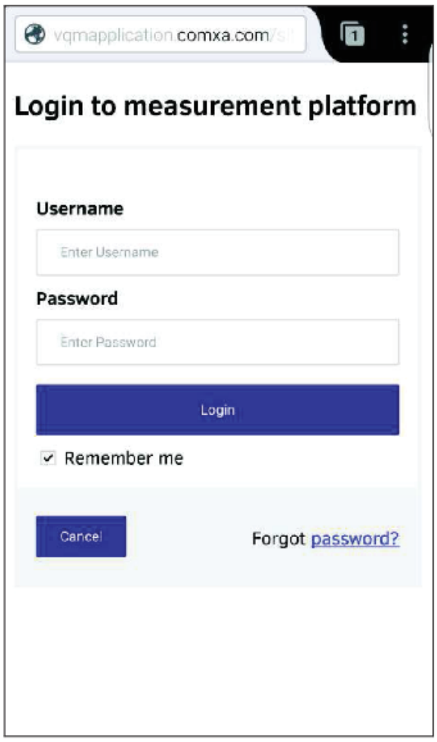


Figure 4. Login screen

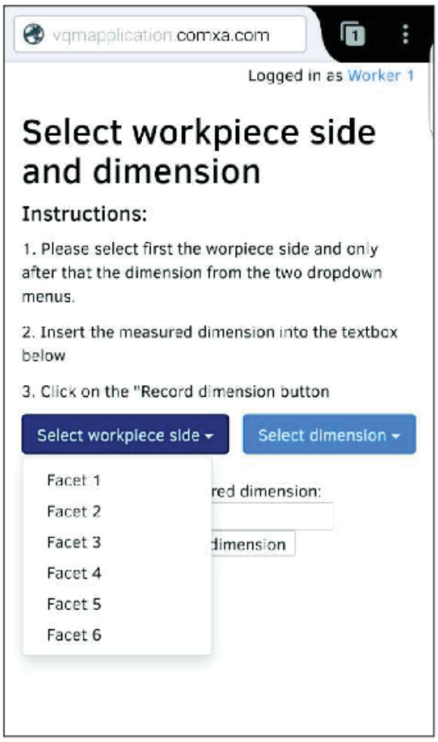


Figure 5. Side and dimension selection

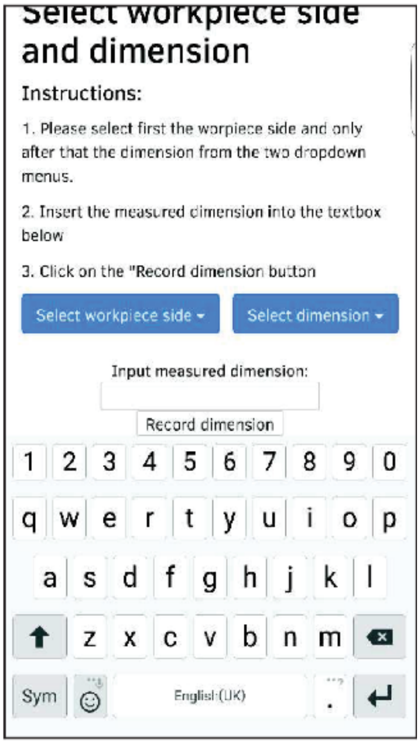


Figure 6. Recording the dimension

The first image (Figure 4) appears on screen when accessing the web platform's address and it asks the user to log in. Depending on the rights that the user has he is capable to view reports of previously recorded values in the form of bar or control charts or just enter values into the database. These features, however, will be detailed later on in section 4.1 of the current paper.

The second image (Figure 5) presents the home screen for an operator that logged in with basic rights. In this example, it can be seen on the top right corner of the screen that the logged in user is "Worker 1". The operator is reminded about the steps he needs to take in order to record a value into the database. By tapping on a dropdown menu it unfolds, making it available for the user to select the facet of the workpiece. The second dropdown menu works in the same way, but it refers to the dimension number.

In the third image (Figure 6) the keyboard appears after taping the textbox, below the "Input measured dimension:" label and the user is able to input the measured value. The inputted value is uploaded when the "Record dimension" button is tapped.

Apart from verifying that dimensions are within tolerances or not, additional control rules were added, which take into consideration the eight Nelson rules [6] used for detecting “out-of-control” values. This set of rules is among the most used ones in interpreting control charts and it establishes whether or not a process needs intervention (corrective actions), based on final or intermediate results. The values of all measured dimensions are recorded online and disposed into control charts and when a new dimension is entered into the database it's verified if it's not in conflict with the following eight conditions (Nelson rules):

Table 1: Nelson rules

Rule no.	Description
1	One or more points are disposed at more than 3 times the standard deviation (or 3σ) from the mean.
2	Nine or more consecutive points are situated only on one side of the mean.
3	Six or more consecutive points are on the same ascending or descending curve.
4	Fourteen or more consecutive points oscillate shifting their domain from one point to another, ascending then descending suddenly.
5	Two (or three) of three consecutive points are situated at more than two times the standard deviation from the mean, in the same domain.
6	Four (or five) of five consecutive points are situated at more than one standard deviation from the mean, in the same domain.
7	Fifteen or more consecutive points are situated within the first standard deviation limit, on both sides of the mean.
8	Eight or more consecutive points are situated on both sides of the mean, all exceeding the first standard deviation limit.

Each time one of these conditions is broken a warning will appear (such as in Figure 7) and it will advise the operator in real-time to take measures to prevent such issues to reappear in the future.

For example, let's presume that the operator is about to measure the x dimension on side x, which has a nominal value of 53 mm with a tolerance limit of ±0.2 mm, which complies with ISO 2768 standard requirements [7]. After obtaining workpiece information with the help of the AR application the operator logs into the web platform using provided credentials.

For illustration purposes only the last 20 values of this dimension are taken into account. They are disposed in the following control chart:

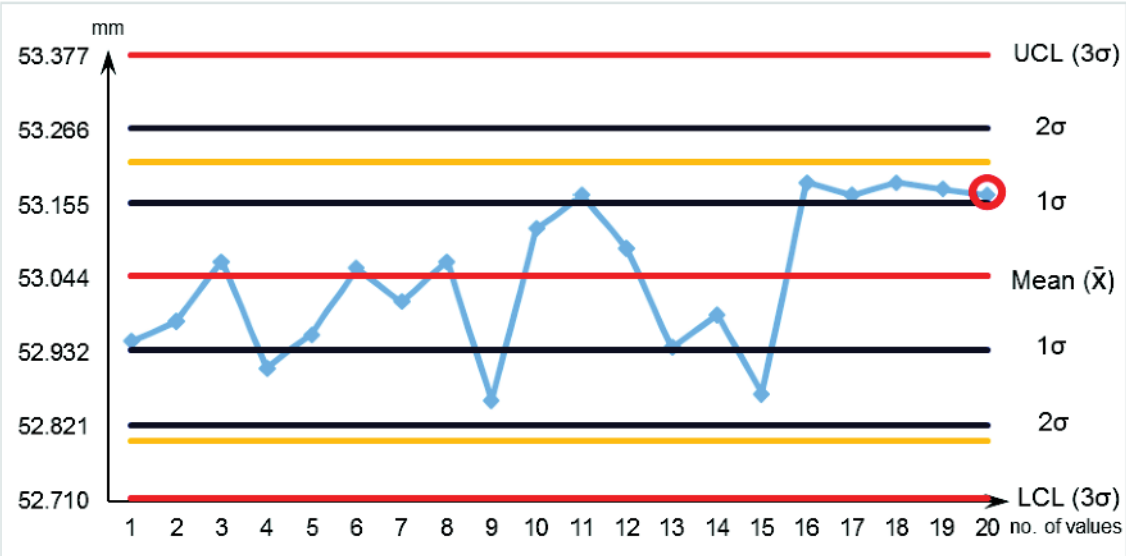


Figure 7: Control chart for Dim 2 on facet 2

If the measured dimensions are within tolerances, represented values on the chart range from 52.8 mm to 53.2 mm, disposed between the two orange lines on the graph (which are the upper and lower tolerance limits). When a new value is entered in the database the algorithm behind the web platform firstly calculates the mean (represented on the chart as x̄), which is the average of all collected values and secondly the standard deviation (represented on the chart as σ). The charts are divided into 3 zones on both sides of the mean by two dark blue lines (one and two times the standard deviation) and one red line (representing three times the standard deviation – coinciding also with the upper and lower control limits). The measured value (which is entered into the textbox on the web platform) is compared to previous values for making sure that the eight rules are respected. In the example from Figure 7 the final value entered is 53.17 (circled in red on), which is within tolerances, but as it can be seen the 6th rule is broken stating that four (or five) of five consecutive points are situated at more than one standard deviation from the mean, in the same domain. Although the tolerances are respected, this is a clear indication that there is something wrong with the manufacturing process and the operator at that point is advised that further investigation is needed. A warning will pop-up relating him this issue:

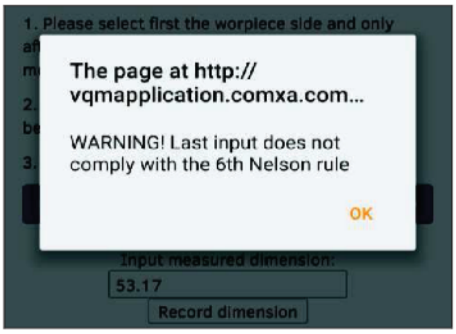


Figure 8: Screen capture with error

4.1 Generating quality control charts

An additional feature of the web platform is that it can generate a number of charts based on recorded values, thus helping the user to monitor and control the manufacturing processes. They provide accurate information about how the processes function in time and whether or not they are stable and centred. Currently, the platform is capable of arranging recorded values into three types of charts, control chart, histogram and bar chart, but further development actions will focus on including other commonly used quality control charts as well, such as the Pareto diagram or correlation diagram.

To access this feature on the platform the user must log in with credentials that offer him administrator rights. The login form is the same as in Figure 4, but once logged in an additional instruction and button will appear on screen, just as in Figure 9.

By pressing the “Generate charts” button another page will load with additional instructions on how to display the required chart on screen. In essence, the user has to select chart type, how many values to display, workpiece side and dimension number from the four dropdown menus appearing on the screen (Figure 10). Once all of these are selected and the “Display chart” button is tapped the required chart will appear on screen. Figure 11, for example, displays a histogram for the last 50 recorded values of dimension 2 from side 2 of the workpiece. The nominal value of this dimension is 53 mm with a tolerance of ±0.2. The user can then interpret this information and take the recommend or proper actions for the processes.

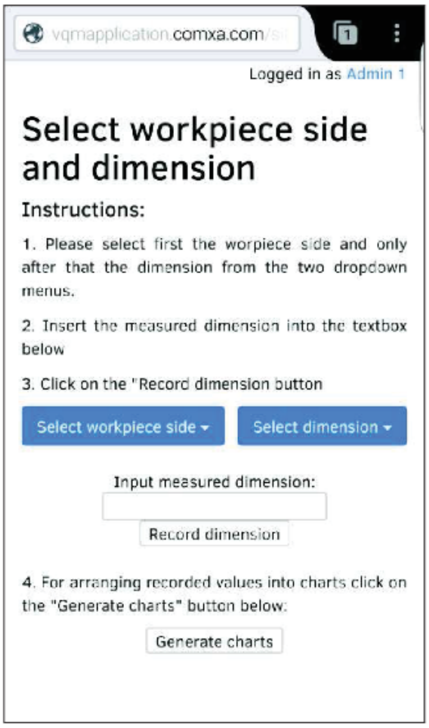


Figure 9. Supervisor UI

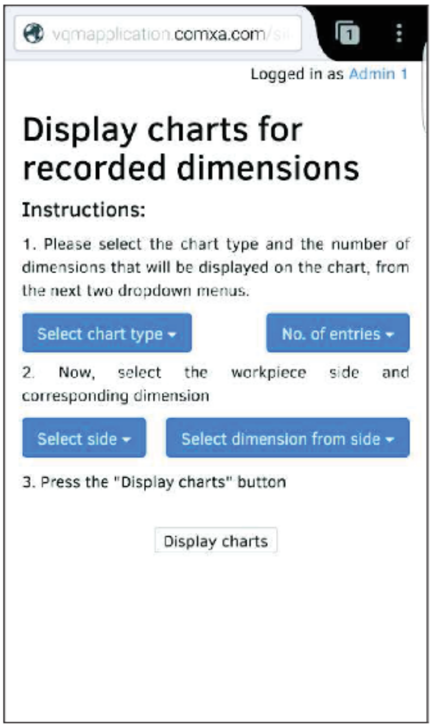


Figure 10. Chart generation

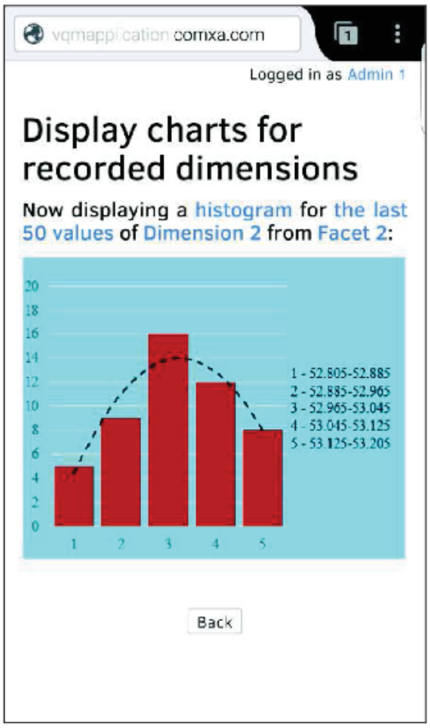


Figure 11. Chart display

5 ADVANTAGES, LIMITATIONS AND FUTURE VIEWS

By introducing the augmented reality application in a manufacturing system using mobile devices enables the operator to have a better understanding and functioning of the processes by measuring their provided outputs (such as workpiece information). It also warns the operator about imminent problems that the processes might encounter, providing him with information for proper corrective or preventive actions.

The combination of the two instruments not only allows the inspection of individual parts, by verifying whether or not their dimensions are within tolerances, but provides an additional level of control essential for reacting in due time to possible process changes.

The large number of values from the web platform’s database can be further analysed to make forecasts and predictions about the overall manufacturing process.

Alongside the above mentioned advantages there are also some limitations regarding AR applications. One of the most constant challenge that still hasn’t been properly addressed is related to the illumination of the environments. These types of applications require excellent lighting condition in order to function properly.

Another disadvantage of the proposed system is the fact that a constant internet connection is required in order to upload the value to the web platform’s database.

The creation of the digital dimensional values and tolerances that will be superimposed over the real parts in the augmented reality application is time-consuming and tedious. Currently this step is done manually within a CAD software, but it could be automated using different scripts.

For further development of the application a feature that would increase the measuring input speed is presented below. This feature allows the user to highlight a certain geometrical dimensional on the tablet screen by double tapping it. Doing so, the mobile device application will change the color of that value. Later on, when the user accesses the web platform, the side and dimension number will be automatically selected and he just has to input the measured value into the textbox.

Another approach would require that all the data will be saved locally within the app and only upload the final report with all the values when the user will connect the mobile device to the internet. One possible solution to this would require the development of a more complex mobile device application that can store the input values locally and only upload them to the database when the mobile device has an internet connection. However, this approach does not offer real-time processes monitoring.

The proposed concept is not limited to a specific quality control operation. The application is flexible and has an architecture that allows further changes and improvements. The web platform can also be extended so that it will generate other charts as well, such as Pareto diagram or correlation diagram used frequently in the quality approach.

6 CONCLUSIONS

The approach described in this paper has shown that an augmented reality application paired with a web database can deliver good results regarding the quality control of manufactured workpieces and related processes.

Using this system, the workers that are employed to measure the parts don't require advance training and qualification, thus reducing the overall quality control costs.

The future goal and vision of this system is to develop augmented reality applications and web databases into a support tool that can be used for almost any manufacturing and quality control system.

The proposed assistive system comes to eliminate error possibilities within the measuring process, thus reducing the execution time and automatically storing all the required information in the web database. This way supervisors can analyse the automatically generated control charts for a better monitoring of the whole fabrication process.

This application also notifies operators in real-time about errors, thus allows the deployment of different correction measures for reducing the overall production costs.

7 REFERENCES

1. Segovia, D., Ramírez, H., Mendoza, M., Mendoza, M., Mendoza, E., González, E., Machining and dimensional validation training using augmented reality for a lean process, Procedia Computer Science, Vol. 75, pp. 195-204, (2015).
2. Newman, R., Chang, V., Walters, R.J., Wills, G.B., Web 2.0 – The past and the future, International Journal of Information Management, Vol. 36, pp. 591-598, (2016)
3. Colledani, M., Pedrielli, G., Terkaj, W., Urgo, M., Integrated virtual platform for manufacturing systems design, 46th CIRP Conference on Manufacturing Systems 2013, Procedia CIRP, Vol. 7, pp. 425-430, (2013).
4. Ghinea, R.A., Popescu, D., Neamțu, C., Hurgoiu, D., Popișter, F., Using DELMIA V5 for human activity improvement in an assembly line production, Applied Mechanics and Materials, Vol. 657, pp. 353-358, (2014)
5. Popescu, D., Comes, R., Neamțu, C., Popișter, F., Using augmented reality in metrology for technical drawings and CAD data management, Proceedings of the 11th International Scientific Conference on "Coordinate Measuring Technique", Bielsko-Biała, Poland, (2014)
6. Nelson, L.S., "Technical Aids" Journal of Quality Technology Vol. 16, No. 4, pp. 238-239, (1989)
7. International Organization for Standardization, ISO 2768-1:1989, last revised on February 10th 2012, (2012)