A MULTI CRITERIA DECISION FRAMEWORK FOR “SMART” PRODUCT INTRODUCTION IN BEARING INDUSTRY THAT USES INTERNET OF THINGS

by

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ABSTRACT

MARKUS EFERDINGER. A multi criteria decision framework for "smart" product introduction in bearing industry that uses internet of things. (Under the direction of DR. ERTUNGA OZELKAN)

The digitalization changes products in almost every industry. Therefore, it is not surprising, that companies face challenges due to these new technological changes caused by Internet of Things (IoT). Especially for large corporations it could have a major impact if companies do not notice the quick and radical changes within the industry. As with many facets of the supply chain, IoT has been reshaping the product development process. Companies need to expand their portfolio and the way how they do business to keep up with increasing customer expectations. Developments within the Information Technology (IT) industry will impact other industries due to digitalization, and therefore, these changes need to be understood and applied. The purpose of this thesis is to develop a multi-criteria decision making framework for introducing a "smart" product that incorporates IoT into the market. After providing an overview and a literature review a decision framework is developed using the Analytical Hierarchical Process (AHP). The methodology is illustrated via a case study within the bearing industry. The case study shows that how a product like a bearing, that did not change its core technology, can become smarter through the incorporation of IoT. This example will further illustrate that even companies in a rigid industry, such as the bearing industry, must understand these technological changes in order to be successful on the market.

ACKNOWLEDGMENTS

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CHAPTER 1: INTRODUCTION

Our devices we use on a daily basis became smarter over the past years. We use our telephones for more tasks other than just messaging and calling. We are constantly connected to the internet and know immediately the breaking news, the current stock price of our investments and where a package currently is that we ordered from an online store. We are also able to track the location of our kids through our phone or call a taxi and track the current location until it arrives. Accordingly, we created a new terminology for that: “smartphone”.

All these new technological developments are not only happening in the telecommunication sector, but in every industry with the only difference being how fast the developments happen. Naturally, in the information technology industry, changes happen quicker than in more conservative industries (Bureau of Labor Statistics, 1997). For example, a few years ago when we used a phone, we visited the same internet websites that one can visit from a desktop computer. After a while, a mobile website was developed when it was recognized that the format and appearance of a desktop-oriented website is inconvenient on the small displays. This mobile technology was created for mobile devices to have a higher customer satisfaction factor. The next step was developing smaller-size software programs to install the mobile technology on each mobile device such as a smartphone.

This is not a trivial change or development because just a few years prior to this technological change, nobody assumed that Apple will be selling phones in the future, not at this scale for sure. A breakthrough happened on January 9, 2007 when Steve Jobs introduced on Apple's keynote the very first mobile computer, music library and phone in one device (Farber, 2014). Before 2007 several phone manufacturers sold products to the market with basically the same function, just in a different design and quality. The big change of the cell phone industry happened when the technology company Apple launched their product. Nowadays almost all of the former cell phone manufacturer like Nokia, Motorola, Sony Eriksson became irrelevant. In the year 2014 none of these companies had a significant share of the market anymore (Gartner, 2016) (Gartner.com, 2008). In a Gartner survey, it was indicated that Samsung, Apple, Microsoft, Lenovo, LG Electronics, Huawei and TCL Communications were the companies with the highest sales numbers globally (Gartner, 2016).

The cell phone industry is only one example of how quickly technological progress can happen, and clearly illustrates that if companies are not paying attention to the new market trends, they might not be capable to keep up with the global competition and soon become obsolete. These changes will happen to all the industries sooner or later. It depends how "smart" the industry actually is. That being said it is important to understand the "smart" terminology. Being smart means how much the industry works with the distribution of data and information. This is significantly different to all the industries. For example the banking and securities industry uses more data than the wholesale trade industry according to a presentation by Wilson Lucas (Gaitho, 2015).

Another example is how we use our television nowadays. Up until recently, we used it purely for receiving information. One was not able to choose what content they would like to see. The user depended on the broadcaster's program selection. The only option was to switch through the channels. This behavior has already changed since TVs are made "smarter". Smarter in that matter means that TVs can connect to the internet and are capable to install applications on it. The advantage in comparison to a conventional TV is that it allows the user to enable Web 2.0 features, like video streaming, interaction with others using social media, etc. The result is that the viewer has more freedom in how to use the TV set (Miller, 2015). One of the largest competitors of broadcasting stations are companies that offer video streaming on demand through the internet. For example Netflix is currently the market leader and has a usage of 40 percent in the United States of all streaming services, far ahead from Amazon Prime with 13 percent (Statista, 2016). Netflix was founded in 1997 and started out with DVD rental by mail and started streaming online in 2007. Per today the company is available in 190 countries, has reported over 83 million paid subscribers globally and with more than 47 million in the United States (Wikipedia, 2016). Netflix is just one example how the new technologies can provide new opportunities on how we consume or transport our goods. Large broadcasters, who needed to develop a very expensive infrastructure with their satellite dishes, were able to restrict the market for a long time to competitions. In contrast to the past the new technologies and the availability of the internet gives smaller companies therefore more opportunities than in the past. One fact is that the online TV and video market is developing very quickly and has a projected revenue of $15.5 billion by 2020 (Statista, 2016). These are the results of a change in the entertainment industry.

Customers nowadays are looking for more convenience and having the requested content available whenever the consumers want to watch it. These technological developments in the mobile phone industry and television industry are similar to the developments in the other industries and were presented here just as illustrative examples. The more important fact is to understand how these changes can be described. The focus of the business application of the thesis will be on the rail industry and an overview is given in the next chapter.

1.1. Rail Industry

The rail sector sees a tremendous growth rate in the United States of America. According to the Federal Railroad Administration each American requires the movement of approximately 40 tons of freight per year using rails (U.S. Department of Transportation, 2016). For the future, it means a 22 percent increase from 2010 to 2035 in regards to the moved tonnage via the railway network. The US has about 140,000 miles of rail tracks and moves more freight on the rain system compared to the rest of the world. While goods can be shipped by water, truck, through a pipeline or through the air, it is important to understand that the largest portion (about 40 percent) of all goods are still moved on rails in the U.S (U.S. Department of Transportation, 2016). Unlike to the majority of other countries, the U.S. freight railroads are owned by private organizations that are responsible to maintain and improve their network by themselves. Globally, this infrastructure is in general owned by the state or government and maintained through taxes. Forecasts suggested that the U.S. is becoming a more urbanized country and that about 75 percent of U.S. inhabitants will live in urban areas, where 80 percent of the growth will occur (United Nations, 2014). A result of this fact will be an increasing demand for alternatives to cars. One of the most effective transportation options are trains within or between cities. In order to enhance the quality of life for its citizens, the United States have passed several investments for infrastructure projects. In 2008, California approved a $9.95 billion bond to develop a high speed rail, and only one year later President Obama made high speed rail a priority in the 2009 stimulus and released $8 billion for various rail projects. The most ambitious infrastructure project is in California and will develop a high speed connection between San Francisco and Los Angeles, where trains will drive around 220 miles per hour. This 800-mile-long distance will be completed in 2029 and approximately 95 trains will be operated on this line. Currently, nine companies are proposing their high speed train solutions including companies such as Siemens, Bombardier, Alstom, CRRC Corporation and AnsaldoBreda.

As indicated earlier, the Schaeffler Group is also providing solutions for the trains and will be a supplier for the train manufacturers.

CHAPTER 2: SCOPE AND RESEARCH QUESTIONS

In the introduction section a brief overview was provided of the changes in the different industries and how drastic changes can be. The digitalization does not exclude any industry we know; the difference is the pace of changes how it is happening. Therefore, it is more important to precisely explain the focus of this work. This thesis covers three large topics to be researched and these are:

- Industry 4.0 / Internet of Things (IoT)
- Bearing Industry
- Product Development

The focus is on Industry 4.0 and IoT and how they impact the bearing industry and its products. The main research questions can be summarized as follows:

- How can IoT be used in the bearing Industry? What are the benefits of Internet of Things?
- How does IoT effect the bearing industry, its products and product development process?
- How do we make a decision to introduce a standard or a “smart” product incorporating IoT in the bearing industry?

In the next chapter a literature review is presented to summarize the related research. We then provide a more detailed overview of IoT, Bearing Industry and the Product Development Process in separate chapters. The thesis then proceeds with the methodology chapter where the multi-criteria decision framework using AHP is introduced. The proposed methodology is applied to the “smart” product selection in the bearing industry through an illustrative case study. The thesis is concluded with a summary of major findings and future research directions.

CHAPTER 3: LITERATURE REVIEW

The purpose of this section is to provide a concise literature review related to the three previously described topics, namely Industry 4.0, the bearing industry and the product development process. As illustrated in Figure 1, the proposed research is in the intersection of these three topical areas.

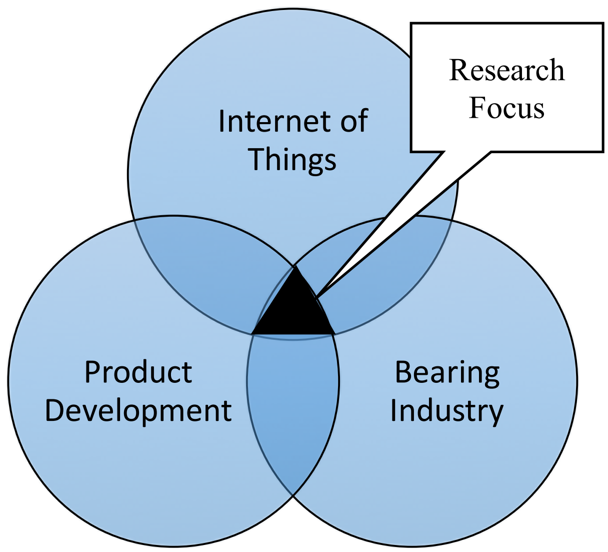


Figure 1: Research focus of the current study

3.1. Industry 4.0 and Internet of Things

The topic of Internet of Things is very broad since it has an effect on almost every industry and every size of company (Perera, Liu, & Jayawardena, 2015). One of the biggest challenges is to cover all the aspects for the Internet of things since it is used as a keyword for the widespread deployment of spatially distributed devices with embedded identification, sensing and/or actuation capabilities. Several studies have been performed to this topic and concluded the Internet of things as an innovation enabled by embedding electronics into everyday physical objects, making them “smarter” and letting them seamlessly integrate within the global resulting cyber physical infrastructure (Miorandi, Sicari, De Pellegrini, & Chlamtac, 2012).

Another fact that makes it more complicated to constrain the topic and literature is that the terminology is applied in so many ways. The reason for that is the manifold definitions and the apparent fuzziness around this terminology (Atzori, Iera, & Morabito, 2010). Another factor that increases the confusion around the terminology is the fact that stakeholders, businesses, research and standardization bodies approach the terminologies from different perspectives, either internet oriented or things oriented, depending on their specific interest and background (Atzori, Iera, & Morabito, 2010). Since the terminology Internet of Things is used in such a broad way it is more important to understand the concept of it.

A good overview is given by Gubbi and Buyya in their research work for Internet of Things. (Gubbi & Buyya, 2013). The work is based on literature research of the computer systems how they are currently used. Based on the influencing factors, the researchers draw a picture of the future how Internet of Things will change the IT technologies and how long it will take to develop fully in different markets. The conclusion of their work is that the evolution of the next generation mobile systems depend on creativity of users in designing new applications. IoT is an emerging technology that depends on the evolving data and computational resources in order to create revolutionary applications. In the future sensing and actuation functions seamlessly blend into the background and additional new capabilities can be developed through access of new information sources. The framework needs more standardization, especially with cloud based solution, which are currently already developing. Not only the technological challenges need to be considered, but also the privacy, security and data management issues. The consolidation of an international initiatives is clearly accelerating progress towards IoT and increases the successful integration and functions of elements.

In another report Goldman Sachs sees trends due to IoT and new businesses. Wearables, like fitness bands, smart watches, smart glasses, and other devices which will become smart will provide a better service for individuals and communities. For example, homes and cars will become safer due to improved security and the availability to communicate. Cars will be connected with each other and will drive more efficient and safer in heavy congested areas (Goldman Sachs, 2014)

3.2. Product Development

In regards of product development, a very broad literature exists already for every specific industry. Krishnan and Ulrich (Krishnan & Ulrich, 2001) from the University of Texas at Austin have researched fundamentally how product development is done and how the academic fields of marketing, operations management, and engineering design influence the decisions during that process. Their approach is that product development is a deliberate business process and shows, in contrast to previous to other survey papers, that their decision making model process can be fully supported by knowledge and tools. In their paper the researchers indicate that the majority of previous research depends too much on environmental and contextual variables, such as the market growth rate, the competitive environment, and the level of top management support.

Krishnan and Ulrich's methodology is based on in depth literature review of journals and citation rates to specific terms. Their research emphasized the importance the product development process within an organization, which was summarized as a general overview of decisions that need to be done for developing a new product. The conclusion was that in the different fields, the product development process has different levels of details. For example, in the case of industrial design, the academic research activities focus mainly on the form and the style of a product and lack of academic research in modeling relevant factors that contribute substantially to product development process. Both researchers also conclude that the product development must be tightly motivated by the needs of the industrial practice, because the product development is essentially a commercial function (Krishnan & Ulrich, 2001).

In other papers, researcher have also developed a model that shows the important stages of a new product development process (see e.g. (Ulrich & Eppinger, 2012), (Cooper & Kleinschmidt, 2002) and (Khan, 2005)). All researchers highlight the importance of following formal models in the product development process to be efficient and effective, and refer to studies that indicate the challenges and the low success rate of bringing a product to the market. An extensive research in that regard was performed by (Booz, Allen & Hamilton, 1982). In their research it was found that firms need to have a well communicated new product strategy in order to be successful. New product arenas along with long term trust, with clear goals and teams that have dedication towards the voice of the customer are needed to launch products successfully. Another critical point, where some firms are not successful, is the screening and business analysis. In their study it was indicated that too many products move from the idea stage right to development stage with little preparation with disastrous results. One important point to prevent such bad results is to implement continuous customer feedback stages during the development stage.

As indicated earlier, product development is closely related to some business environmental conditions such as the management and the organizational factors. Ian Barclay and Zoe Dann (Barclay & Dann, 2000)have researched how these factors influence the success rate in the new product development process. In their research they analyzed 12 British firms. In structured interviews the researchers verified and extended a complex set of criteria. Their conclusions were that the product development process is influenced by the structural and functional complexity, the product newness, project complexity and commercial constraints. They further indicate that in order to become better at new product development, it is required to invest in people, their skills and competencies. Their results showed that the process effectiveness and efficiency depend on how well trained and motivated the staff is, how the teams are led, on how appropriate organizational culture procedures and guidelines are.

3.3. Bearing Industry

The research within the bearing industry is done in many fields. In regards of understanding the bearing industry itself, many publications from consulting companies are available. For example, the company Business Wire, which belongs to Berkshire Hathaway, has performed an analysis of the industry and shows how bearings are used globally. Their report provides a trend analysis for the future of the industry and predicts growths for each product (Business Wire, 2014).

The research also showed that the bearing industry's main focus is on contact mechanics and life time calculation (Hartnett, 2010). The focus is on understanding the behavior of the mechanical parts during load cycles, considering friction and other influencing factors, like steel technologies. The research also includes new products, like magnetic bearings and its applications (Schweitzer & Maslen, 2009). Most of the research papers focus on special topics on mechanical properties of bearings since the fundamentals are understood very well already. One of the most investigated problem is the Hertzian pressure calculation and application. This pressure calculation is a fundamental part of the life time calculation according to ISO 281, and is explained in several research papers (Pipaniya & Lodwal, 2014). The differences are in most cases the applications, like airplanes. (Schaubhut, Suomi, & Espinosa, 2009). ISO 281 specifies the methods of calculation the basic dynamic load ratings or rolling bearings, which has a direct influence onto the statistically calculated life time. The standard does not influence anyhow the design of rolling elements and does not cover any wear, corrosion and electrical erosion of the bearing. In order to have a good overview of how the lubrication and tribology influences a bearing life time calculation several research papers are available for many different cases (Shah, Patel, & Trivedi, 2015)

Only a few papers where found during the research that consider Internet of things in the bearing industry. A few papers describe applications that can provide a monitoring system (Wang, 2014) and (Eliasson, Kyusakov, Martinsson, Eriksson, & Oeien, 2013). However, the bearing industry has not adapted yet the new technologies even though the foundation, like sensor and network technologies already exist.

CHAPTER 4: INTERNET OF THINGS

In regards of the digitalization, *Industry 4.0* and *Internet of Things* are the two main terminologies that are referred very often. In order to understand these terms and the differences it is important to know how the terminologies are applied and originated.

Industry 4.0

The terminology *Industry 4.0* was used the very first time at the Hannover fair in Germany (VDI Nachrichten, 2011). Henning Kagermann, Wolf-Dieter Lukas and Wolfgang Wahlster had influenced the terminology mainly due to their work in the German industry and politics. They recognized very early the opportunities of connecting the cyber-physical systems and the new business models that can be developed based on connectivity. The main part of Industry 4.0 is that processes become more automated due to sensor controlled and automatized development and decision processes. This terminology is mainly related to the industrial revolution and describes the trend of implementation of sensor and data systems in manufacturing technologies. Industry 4.0 is also described as the fourth industrial revolution (Schwab, 2016).

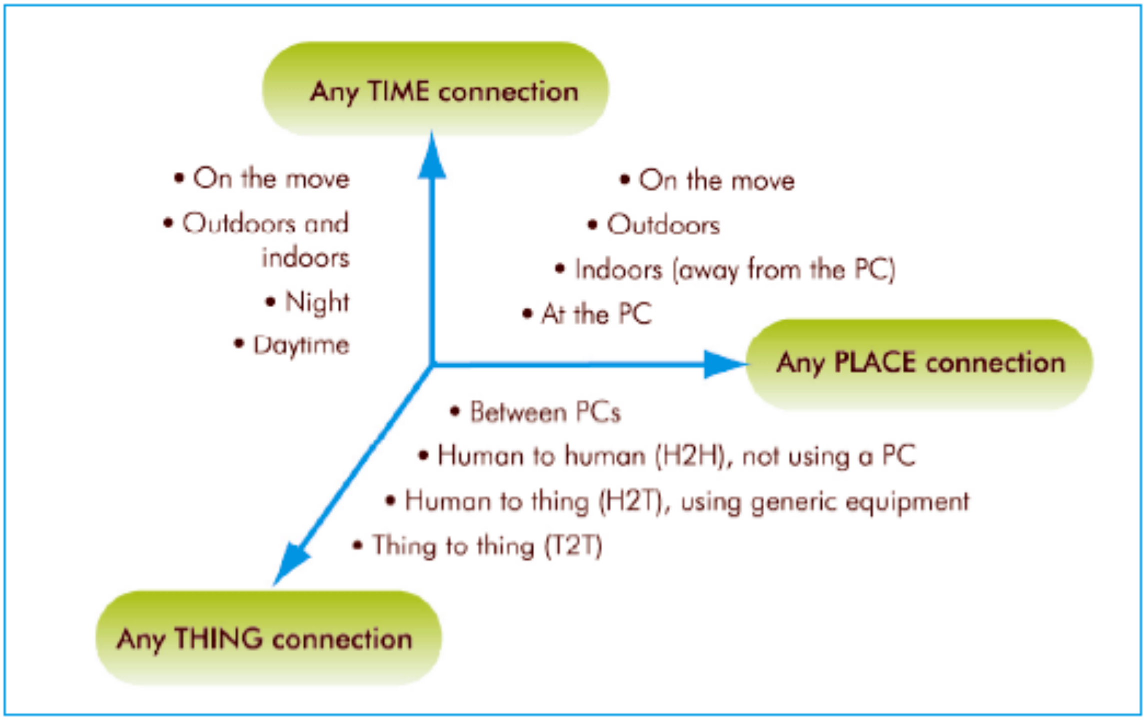
How important the changes are due to the fourth industrial revolution have been recognized by the German Government and therefore, the German leaders have put these important changes on their work agenda. For example, the Federal Ministry for Economic Affairs and Energy and the Federal Ministry of Education in Germany have created a program called *Plattform Industrie 4.0* that brings together stakeholders of the future changes due to Industry 4.0. The goal is to improve the value chain of the German Industrial Sector and develop new strategies and to be successful in the future (Federal Ministry for Economic Affairs and Energy, 2016).

Internet of Things

The terminology Internet of Things was originally created by former P & G brand manager Kevin Ashton in 1999. His vision was to connect sensors to the internet and the physical world. Even though it was only used for presentations, customers and coworkers liked this terminology and so it became socially accepted (Bainbridge, 2014).

The terminology is also used with the term Industrial. The concept of the Industrial Internet of Things refers to an industrial adaption of the Internet of Things. This term is used by several industrial companies in different versions, but mainly describes the usage of the internet in applications. One organization that uses the terminology Industrial Internet of Things is the Industrial Internet Consortium (IIC). It was founded by AT&T, Cisco, General Electric, IBM and Intel in 2014 and focus on industrial internet technologies. The goal of the work group is to help companies with the new challenges of the new developments (Industrial Internet Consortium, 2016)

In the past, the main communication was between people and humans made decisions. This will change with the technological leap of Internet of Things. The communication will be between a number of things and the smart devices will process information. A new dimension has been added to the world of information and communication: As illustrated in Figure 2, from anytime, anyplace connectivity for anyone, we will have connectivity for anything (International Telecommunication Union, 2005).



Source: ITU, adapted from Nomura Research Institute.

Figure 2: Internet of Things - A new dimension (Source: http://www.itu.int/itunews/images/2005/09/fig2-1.gif)

One of the main technologies of Internet of Things is establishing communication and identification. One example for that is radio frequency identification (RFID). RFID, which uses radio waves to identify items, can provide this function (Joung, 2009). In the past bar codes were used and RFID technology was seen as a replacement for that technology, but RFID can do much more. It allows the user to track items in real time about the location and status. As of today, RFID has already its application in the retail, health care and several other industries (Want, Nath, & Reynolds, 2006). The RFID chip is just one of the many examples, but the communication can also be enabled with other technologies, like Wi-Fi, LAN, 3G, UMTS, etc. (Tan & Wang, 2010).

This thesis does not focus on the different technologies rather it wants to provide an overview of what has been researched so far and describe a broad overview. In regards to the technology the following topics need to be covered to enable Internet of Things:

- *Standardization of communication*
- *Ambient Intelligence for Internet of Things Applications*
- *System characteristics for Internet of Things*
- *Cyber-Physical Systems (CPS)*
- *Company specific driven Terminologies*
- *Global usage of terminologies*

Next, we will elaborate on each of these topics.

Standardization of communication

A number of standardization activities have been performed on tag-based technologies in the recent years. These activities occurred mostly in the RF-lay and NFCIP (Near Field Communication Interface and Protocol) and have been standardized under various bodies like ISO 18092, 21481, 22536 and 23917; ECMA 340, 352, 356 and 365; ETSI TS 102 190.

In parallel, also the Global System for Mobile Communications Association (GMSA) established a NFC working group in 2006 and already derived guidelines for NFC services to be supported by cellular phones technologies. The main reason for the interest in the GSMA can be linked to the cellular technology, that is perceived as a potential enabler for the diffusion of a large number of services based on the use of embedded NFC devices (Miorandi, Sicari, De Pellegrini, & Chlamtac, 2012).

Ambient Intelligence for Internet of Things Applications

A number of characteristics are shared with the so called ambient intelligence (Aarts & Wichert, 2009). The Ambient Intelligence (AmI) is required to set up capabilities for sensing, computing and actuating in order to respond in a smart way and allowing to carry out specific tasks. This environment is also called an embedded system for the smart or computational devices. (Miorandi, Sicari, De Pellegrini, & Chlamtac, 2012).

System characteristics for Internet of Things

Internet of things can be summarized in three different levels from a system perspective. Every device is able to communicate with other devices through a shared network. Every device is individually identified through a digital name and/or digital domain and the relationships are defined within a network if a physical connection is not established. Last important key factor is that these smart devices can clearly interact within the local environment through sensing and actuating capabilities.

Cyber-Physical Systems (CPS)

The terminology Cyber-Physical System is used by the US National Science Foundation in NSF11-516 and refers to a system that connects computational and physical resources. It describes systems, which are using seamlessly integrated computational algorithms and physical components. The focus is to enhance capability, scalability, resiliency, safety, security, and usability for embedded systems that are used today in order to improve the data exchange. New smart CPS will also effect all industries as well (National Science Foundation, 2016).

Company specific driven Terminologies

The following terminologies were developed by companies in the past and are discussed here for sake of completeness. The terms relate to the above described concepts of Industry 4.0, but were developed by businesses internally. These are a few examples and cannot be considered as an exhaustive list. The list should be seen as an overview of how businesses develop their own brand name for Industry 4.0:

- Industrial Internet used by GE (General Electric, 2014)
- Internet of everything used by Cisco (Cisco, 2013)
- Smarter Planet used by IBM (IBM, 2016)
- M2M (machine to machine) used by several companies like AT&T (AT&T, 2016)
- Digital Life used by AT&T (AT&T Digital Life, 2016)
- Smartdust used by DARPA (Hoffman, 2003)

The most often used phrases in the industry are Internet of Things (IoT) and the Fourth Industrial Revolution (Industry 4.0). In this thesis the term Internet of Things will be used in order to make it easier for the reader.

Global usage of terminologies

The terminology *Industry 4.0* is commonly used in Germany and strongly supported by the German Government. It was originally a marketing terminology, but became more popular due to the efforts of the federal government in Germany as they decided to support business to overcome the challenges of Industry 4.0 (Springer Gabler, 2016).

The terminology *Internet of Things* is similar the terminology *Industry 4.0*. Both are used interchangeably and refer to similar technologies and applications, but have different origins and meanings. Industry 4.0 is mainly focused on the production and manufacturing industry whereas the Industrial Consortium focus more on the business opportunities due to new technologies.

"Industry 4.0 is focused specifically on the manufacturing industry ... the Industrial Internet Consortium is more focused on enabling and accelerating the adoption of Internet-connected technologies across industries." (De Bernardini, 2015)

IoT is not always focused only on software applications. A good example is the application of torque measuring bottom brackets for bicycles, which were developed to improve shifting. The system was invented by the Schaeffler Group and is used on electric bicycles, which carry a battery and provide additional torque when needed. The resulting benefit of the device it to allow the bicyclist to stay always in the right gear and therefore provide a more relaxing riding. The system calculates the optimum gearing and the perfect shifting point based on the cadence, force, wheel speed and gradient. The result of the IoT development is higher riding comfort with also flexibility compared to a regular manual gearshift. What it means for the industry is that manual shifting becomes obsolete if the rider decides to use the automatic setting only. Additionally, the system can be hooked up with a smartphone that gives the rider several more convenient features. For example, the user can see what current gear he uses, the generated torque, used energy and in addition to that, the rider gets information through his GPS system about the driven distances and current location through the application on the smartphone. The app also gives the rider more opportunities to set up his personal shifting program that suits his riding style. All parts of the gearshift system communicate wireless with each other and the system itself can be placed within the tube under the seat. Another example of IoT and how it creates an additional benefit compared to a conventional product. The interconnectivity and communication with other devices, like a smartphone, define additional created value through industry changing developments.

Figure 3: VELOMATIC by the Schaeffler Group (source: http://www.schaeffler.com/content.schaeffler.com/en/news_media/press_office/press_releases/press_releases_detail.jsp?id=70780481)

CHAPTER 5: PRODUCT DEVELOPMENT PROCESS

Organic growth is a desire and a challenge at the same time for most companies (Hamel-Green & Getz, 2004). In order to achieve profitable organic growth in dynamic industries companies need to focus on increasing innovation productivity, ensuring short lead times to release the product onto the markets and controlling development costs (Kim & Mauborgne , 2004). New Product Development processes involve a series of stages with the goal of providing a functional and financial benefit to costumers (Calantone, Vickery, & Droge, 1996).

In order to manage product development process effectively, it is recommended to use stepwise approaches such as stage-gate processes (Cooper & Kleinschmidt, 2002). What all different new product development processes have in common is providing a common language, facilitate action across functions and projects to enhance the communication (Engwall, Kling, & Werr, 2005). Therefore, it is not surprising that due to improvements in the product development phase, it results into more successful launches for an organization. (McDermott & O'Conner, 1999) indicates that stage gate processes often lead to lower-risk, immediate reward and incremental projects.

The stage gate process is described in the following section in more detail and should be seen as an example for a generic product development process. The following process has been adopted by leading companies and is the stage gate process by Robert G. Cooper (Castellion & Griffin, 2005).

The Stage-Gate® Process by Robert Cooper

According to Cooper (Product Development Institute, Inc., 2016) the Stage-Gate process consist of five gates for the product development, visible in the blue squares. These are:

Stage 0 - Discovery

During that stage new business ideas and products are discovered.

Stage 1 - Scoping

The scoping stage is defined through a quick investigation and sculpting of the project. A quick and inexpensive assessment of technical merits of the projects and potential market opportunities.

Stage 2 - Build Business Case

In this critical stage, the actions include a detailed market analysis and go no-go decision for the project. Technical, marketing and business feasibility are accessed in a business case, which has three main components: product and project definition; project justification; and the project plan.

Stage 3 - Development

During the development stage the project plan is transferred into deliverables. The actual design and development of the new product happens, the manufacturing plans are laid out and testing plans are developed.

Stage 4 - Testing and Validation

This stage is to provide validation of the entire project. The production process, customer acceptance and financial justification are required prior the next and last stage.

Stage 5 - Launch

Full commercialization of the product; this is the beginning of the full production of the product, and its commercial launch and selling.

Figure 4: Stage-Gate Process by Robert Cooper (Source: http://www.prod-dev.com/stage-gate.php)

The above described stage-gate process has been adapted in several different companies and will need to be considered in this thesis along with the multi-criteria smart product launch decision making tool that will be introduced under the Methodology chapter. It is important that the product development process is understood very well and can applied within an organization. In regards of this thesis it is not important to understand each single step, rather is more important to understand the whole process flow.

CHAPTER 6: BEARING INDUSTRY

The bearing industry has a long history. One of the earliest applications of a bearing was by Egyptian and Roman chariots to carry light load for short distances (Zebrowski, 2000). Also famous physicians like Leonardo da Vinci and Galileo Galilea performed investigations on the behavior of deformable bodies, that derived the theories on the bearing capacities (Gross, Hauger, Schroeder, Wall, & Bonet, 2011). The first breakthrough was in 1883, when the German company FAG started grinding balls of equal size and roundness the first time on their ball grinding machine. Due to this innovation, the foundation of the entire rolling industry was created (Schaeffler Technologies AG & Co. KG, 2016). Just a few years later, in 1898, the American company Timken was issued the first patent for a Tapered roller bearing (USA Patent No. US606635 A, 1898). In 1907 Sven Wingquist, who worked for the Swedish company SKF, invented a self-aligning ball bearing (Smith, 2016).

The bearing itself is always used in combination with other mechanical parts. The bearing itself consists of an inner ring, an outer ring, rolling elements that keep both rings separated, and often a cage that keeps the rolling elements separated. The rolling elements can be balls or rollers, depending on purpose and bearing type. The inner ring and outer ring are also called inner race or outer race, refereeing to the raceway where the rolling elements run. See figure 4.

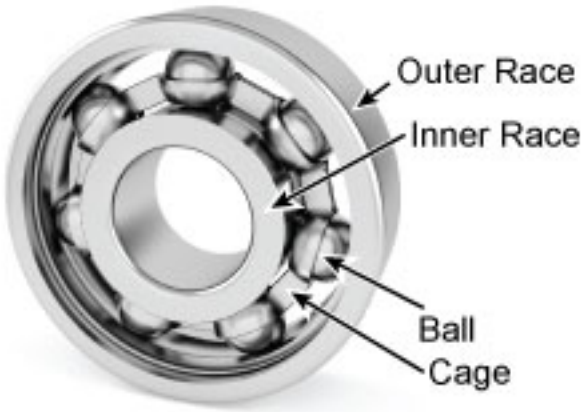


Figure 5: Components of bearing (source: http://www.lionprecision.com/tech-library/technotes/cap-0033-SEA-RPMvsBandwidth.html)

In order to characterize the supply chain of the bearing industry the 5P framework that is shown in Figure X is used below in figure 5 (Özelkan & Rajamani, 2006). The 5 P framework consist of the Products, Pain Points, Performance, Physical Structure and Processes. In addition to that the customers and Technology play an important role as well

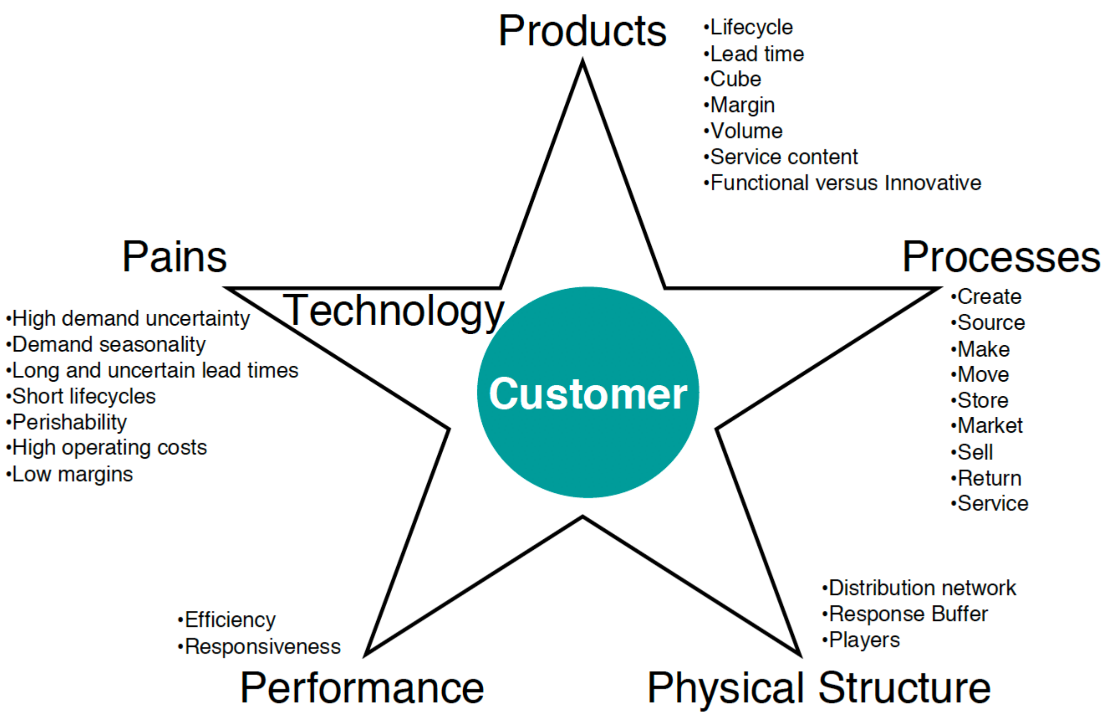


Figure 6: 5P Framework (Özelkan & Rajamani, 2006)

6.1. 5P Framework for the Bearing Industry

The customers in the bearing industry range from an individual end user to large multinational corporations. Depending on the bearing manufacturer, an average customer will be a bearing retailer, who sells standardized bearings to end-users and/or to companies that need bearings with a certain envelope for its application.

The technology that is used in the bearing industry range from any Enterprise Resource Planning (ERP) software solutions to specialized software solutions in manufacturing. Customers of bearing manufacturer send purchase orders electronically or even via fax to the manufacturer to place orders. In some cases, when a customer has a very good relationship with a bearing manufacturer, electronic portals are created for collaborative planning and purchasing. The advantage is that orders are instantly transmitted and can be planned in production sooner.

Products

The products of the bearing industry are available in many different types. In general, the bearings can be differentiated as plain or rolling bearing. The difference is plain bearings do not have rolling elements and rotate using a friction layer. The rolling bearings can be separated as ball or roller bearings with additional subtypes respectively, like Deep Groove Ball Bearing, Angular Contact Ball Bearing, etc. Lifecycle, lead time, profit margin, sales volume can tremendously vary based on the application. A bearing can last from just a few hours up to several years based on the customer requirements. Profit margin and sales volume are indirect proportional depending on the customer. In general, the lower the (sales) volume, the higher the profit margin per bearing is. The volume also impacts the lead time of the product: a small quantity can be acquired at local bearing retailers, whereas a few thousand pieces need to be ordered at a bearing manufacturer. Another fact is that bearings can be standardized or customized.

Pain Points

One of the biggest challenges are understanding the customer needs. The bearing has a calculated life time and can be calculated according to ISO 281. The capacities are provided by the bearing manufacturer, and the duty cycles for the specific application are defined by the bearing user. Having a good understanding of the calculated statistical life time is one of the few challenges in the bearing industry. Demand is very often forecasted if larger quantities are required and based on the quantity the lead time is determined. The larger the required amount, the longer it takes to ramp up production for the ball manufacturer. Another pain point within the industry is the competition between the bearing manufacturers, who compete in a highly fragmented multi-billion dollar market (RBC Bearings Inc. , 2007)

Performance

The performance can be measured in several different key performance indicators (KPI). One is the KPIs is the on-time delivery rate, which is an industrial standard. Another important factor is the product portfolio of a bearing manufacturer. Smaller companies tend to produce customized bearings, whereas large corporations produce high volumes, preferably standardized products, with very low costs per piece.

Physical Structure

The bearing manufacturer has a very special position within the supply chain. Every bearing manufacturer supplies raw materials like steel, balls and other parts for its product development from different vendors. The bearing manufacturer fabricates its products and sells it directly to other larger original equipment manufacturers (OEMs) or to retailers depending on the volume.

Processes

The processes within the bearing industry can be broken down into the business development process, the manufacturing process and the service process. The business development process aims to attract customers and create a strong business relationship with customers. The manufacturing process covers all aspects of producing the bearings either based on forecast or based on order. The service process covers all processes from transporting the finished goods to the customer of the bearing manufacturer and also after-market service, such as condition monitoring for bearings.

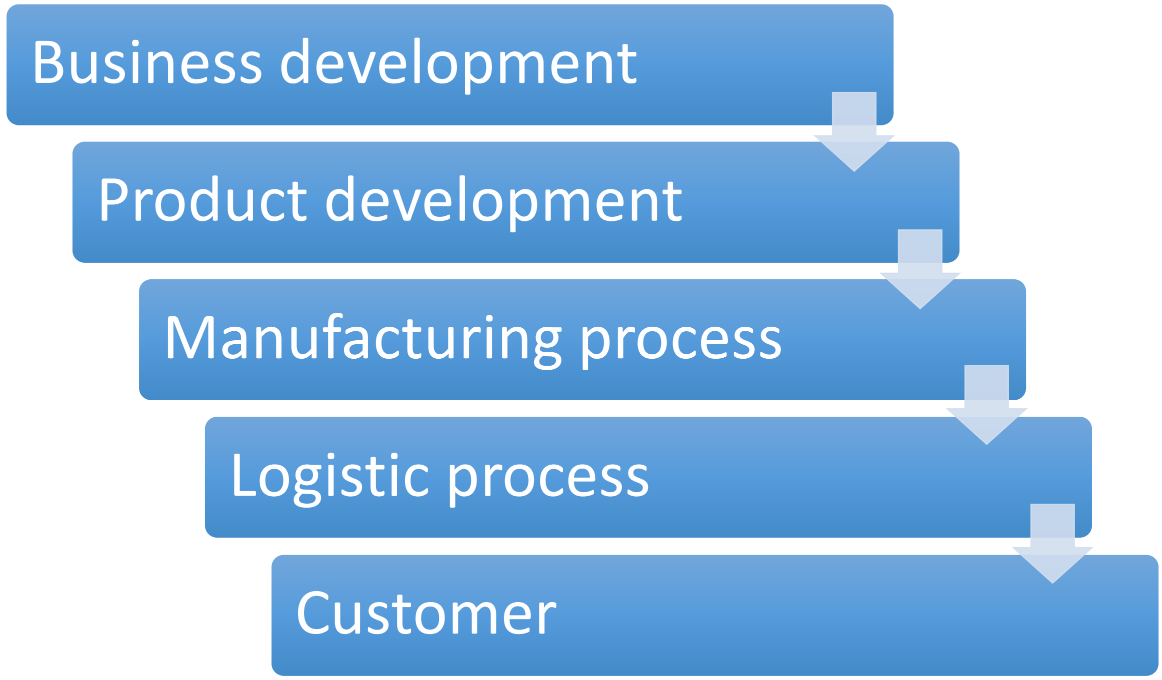


Figure 7: Bearing industry process (source: Schaeffler Group Management Handbook)

The global bearing market is a large competitive industry and expected to reach $117 billion by 2020 according to a study. The global bearing industry is dominated by six companies and control more than 60%. These companies are SKF, Schaeffler Group, Timken, NSK Global, NTN Corporation and JTEKT (Grand View Research, 2015). In January 2015 Global Industry Analysts have indicated that the fastest growing product segments are roller bearings with an approx. 7.5 % compound annual growth rate (CAGR). The largest and fastest growing market is by far Asia-Pacific at 9.2% CAGR. The drivers of the industry are:

- increase in heavy machinery manufacturing,
- increasing application of high capacity bearings in wind applications,
- growing use of light weight bearing in automotive sector,
- accelerated railway construction in developing countries, and

- rising use of hybrid bearings in aerospace and laboratory equipment (Global Industry Analysts, Inc., 2015).

CHAPTER 7: METHODOLOGY

In this section a multi-criteria decision model is developed to decide whether a standard product is preferred in the application or a "smart" product that incorporates IoT. The standard product is a regular bearing that the customer requested, whereas the smart bearing has sensor technologies that generates more benefits to the customer in general. For the bearing manufacturer the decision what product will be offered follows a relatively complex structure based on multiple criteria such as:

- Price,
- Production Risk,
- Operating Benefits,
- Quality.

The overall product development costs consider all costs associated with the product development process. The product quality is a very important factor since it directly relates back to the costs and the production challenges. It also considers the required quality when the bearing is in operation that it meets the minimum life time and can handle all loads during its operation. The development challenges consider risks during the product development process. This is a very important factor for manufacturing and design verification since the offered product is legally binding and must be provided to the customer. During the quoting process it is still possible to deny any quote if one of the risks seem to be too high or unpredictable. The operating risk must be understood in any cases since the bearing manufacturer is kept liable for any failures.

7.1. Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) was originally developed by Thomas L. Saaty and is a structured technique to make a concise decision based on mathematics and psychology (Saaty, 1987). AHP helps to make based on multiple criteria weighting factors and makes psychological factors quantifiable. In general, AHP involves four major steps for the decision making process:

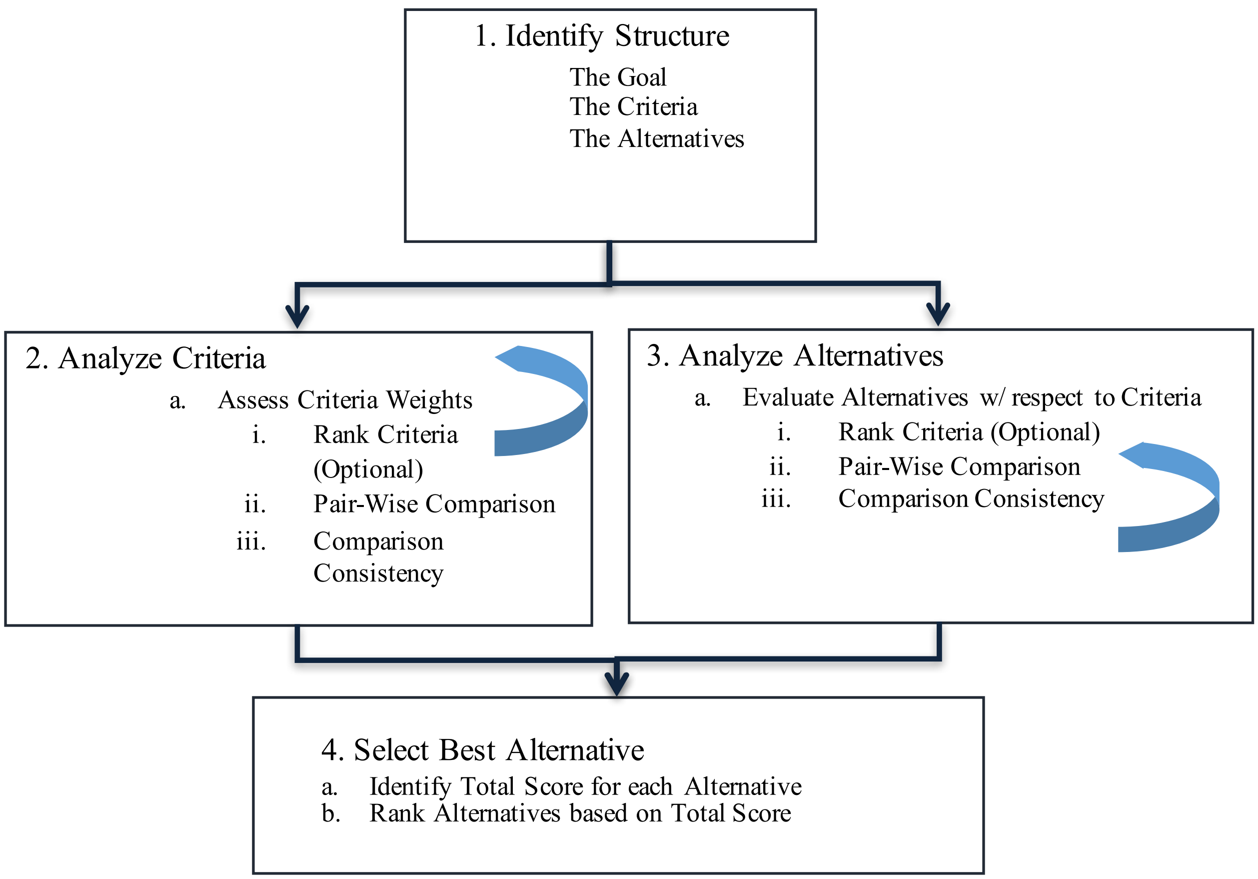


Figure 8: AHP Process (source: Ozelkan and Stephens, 2015)

The AHP process begins with a decomposition of the problem goal, criteria and alternatives. Then the criteria are analyzed using pairwise comparison tables to identify decision maker's preferences and weights on the criteria. Similarly, by using pairwise comparisons the different alternatives are scored for each criteria. For the pair-wise comparisons, a scale from 1 to 9 is used to explain the strength of the relationship as shown in Table 1.

Table 1: AHP scale (Ozelkan & Stephens, October 7-10, 2015)

Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over the other
5	Strong importance	Experience and judgment strongly favor one activity over the other
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of highest possible order of affirmation
2, 4, 6, 8	Intermediate values	

The comparison matrixes are then transformed into weights and scores for each criterion and alternatives, respectively. While the exact approach requires computing eigenvalues corresponding to the comparison matrices and well-recognized approximation is the geometric mean approach as shown in Table XX. In these comparisons, two criteria (or alternatives) are compared at a time to investigate how dominant or submissive these criteria (or alternatives) are. That means if criterion (or alternative) A is stronger than criterion (or alternative) B, it will receive the number higher than 1 and for the opposite case, it will receive the reciprocal value. When the matrix is filled with numbers the geometric mean is calculated for each row. Finally, the geometric means are normalized to obtain the criteria weights (or alternative scores).

Table 2: Weight calculation for criteria (Ozelkan & Stephens, October 7-10, 2015)

		Criteria			Geometric Mean	Criteria Weights
		A	B	C	$\left(\prod_{i=1}^{n} k_i\right)^{\frac{1}{n}}$	
Criteria	A	1	*a/b*	*a/c*	$A = \sqrt[3]{(1)\left(\frac{a}{b}\right)\left(\frac{a}{c}\right)}$	$W_A = (A \div T_w)$
	B	*b/a*	1	*b/c*	$B = \sqrt[3]{\left(\frac{b}{a}\right)(1)\left(\frac{b}{c}\right)}$	$W_B = (B \div T_w)$
	C	*c/a*	*c/b*	1	$C = \sqrt[3]{\left(\frac{c}{a}\right)\left(\frac{c}{b}\right)(1)}$	$W_C = (C \div T_w)$
					$T_w = \sum_{i=A,B,C} i$	

The final check is to review the logical consistency ratio. That means in a nutshell that when A>B and B>C, then A>C must be true. The consistency ratio needs to have a value less than 0.1 to be considered consistent.

In order to calculate the consistency, the following steps need to be performed:

- Multiply each column of the matrix by the corresponding weight
- Divide the sum of the row entries by the corresponding weight
- Compute the average of the values from the previous step (λ_{max})
- The approximate consistency index is calculated $CI = \frac{\lambda\text{max}-\text{n}}{n-1}$

n is the number of criteria; in our case n=4

- According to Saaty, the consistency ratio is calculated CR= CI/RI, whereas RI is a number from the random index (Saaty, 1987). In our case the consistency ratio is zero and considered good.

The same method is used for evaluating the criteria and alternatives as illustrated in Table XX. Each alternative is compared with each other for each criterion, and scored based on the normalized values.

Table 3: Calculation of alternative scores (Ozelkan & Stephens, October 7-10, 2015)

Criteria A		**Alternatives**			**Geometric Mean**	**Alternative Score**
		X	Y	Z	$\left(\prod_{i=1}^{n} k_i\right)^{\frac{1}{n}}$	
Alternatives	X	1	*x/y*	*x/z*	$X = \sqrt[3]{(1)\left(\frac{x}{y}\right)\left(\frac{x}{z}\right)}$	$S_X^A = (X \div T_s)$
	Y	*y/x*	1	*y/z*	$Y = \sqrt[3]{\left(\frac{y}{x}\right)(1)\left(\frac{y}{z}\right)}$	$S_Y^A = (Y \div T_s)$
	Z	*z/x*	*z/y*	1	$Z = \sqrt[3]{\left(\frac{z}{x}\right)\left(\frac{z}{y}\right)(1)}$	$S_Z^A = (Z \div T_s)$
					$T_s = \sum_{i=X,Y,Z} i$	

The last step is to select the best alternative. This is done based on the weighted score for each alternative. The Table XX, below shows the mathematical description for a three-alternative scenario:

Table 4: Calculation of best alternative (Ozelkan & Stephens, October 7-10, 2015)

	Criteria A	Criteria B	Criteria C	TOTAL
Alternative X	$WS_X^A = (W_A \times S_X^A)$	$WS_X^B = (W_A \times S_X^B)$	$WS_X^C = (W_A \times S_X^C)$	$\sum_{i=A,B,C} WS_X^i$
Alternative Y	$WS_Y^A = (W_A \times S_Y^A)$	$WS_Y^B = (W_A \times S_Y^B)$	$WS_Y^C = (W_A \times S_Y^C)$	$\sum_{i=A,B,C} WS_Y^i$
Alternative Z	$WS_Z^A = (W_A \times S_Z^A)$	$WS_Z^B = (W_A \times S_Z^B)$	$WS_Z^C = (W_A \times S_Z^C)$	$\sum_{i=A,B,C} WS_Z^i$

CHAPTER 8: BUSINESS CASE OF INDUSTRY 4.0 APPLICATION

The Schaeffler Group is specialized on the bogie housings, TAROL bearings (bearing on rail axles) and traction motor bearings that are used in the rail industry. In order to provide a higher value added than the competition, Schaeffler had developed using Industry 4.0 technology a new TAROL bearing for freight and high speed trains.

8.1. Condition Monitoring for Railway Applications

Every train needs to be serviced and go through regular maintenance like a car does (Figure 8). The difference is that when a train undergoes maintenance it takes longer and is more complex since the parts are heavier and require special equipment. One of the weaknesses in the rail industry are the “bogies”. A bogie, or often called railroad truck, is the unit under the train itself that connects the train with the rails. It contains the axles and the TAROL (bearing) in a special housing.

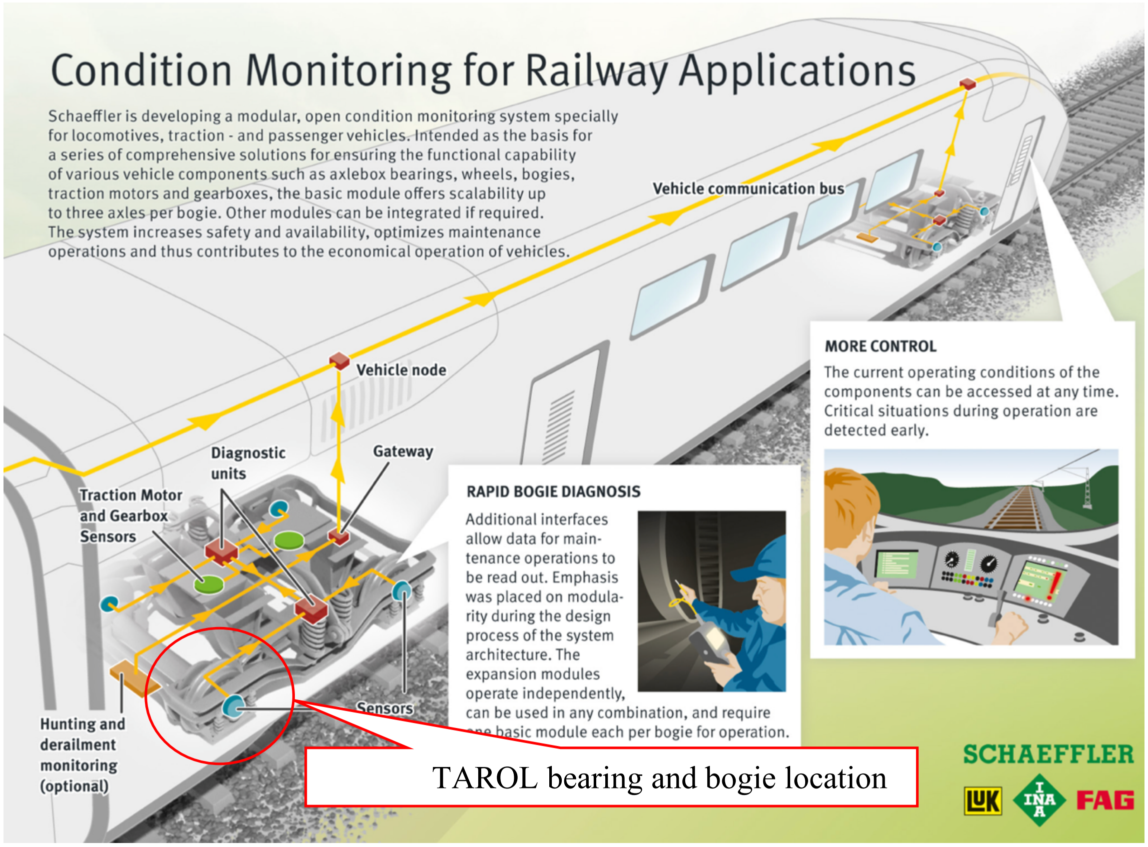


Figure 9: Condition monitoring application in train (Source: http://www.schaeffler.de/content.schaeffler.de/en/branches/industry/railway/products_railway/mechatronics_railway/mechatronics.jsp)

In order to maintain the train in a more efficient way it is necessary to understand the status of the bearings. Therefore, sensors are installed and measure constantly the condition of the bogies to prevent any failures and keep the train in service as long as needed. This allows customers avoid expensive premature replacements of bearings in order to use the units more efficiently. Figure 21 below illustrates how the bearing is build up. A generator creates electricity for the electronic module that measures the condition of the TAROL bearing through an intelligent system and sends it to a monitoring unit either wirelessly or with a cable. Consequently, the condition of each sensor can be reviewed in real time by the service personal and train provider through a graphical user interface.

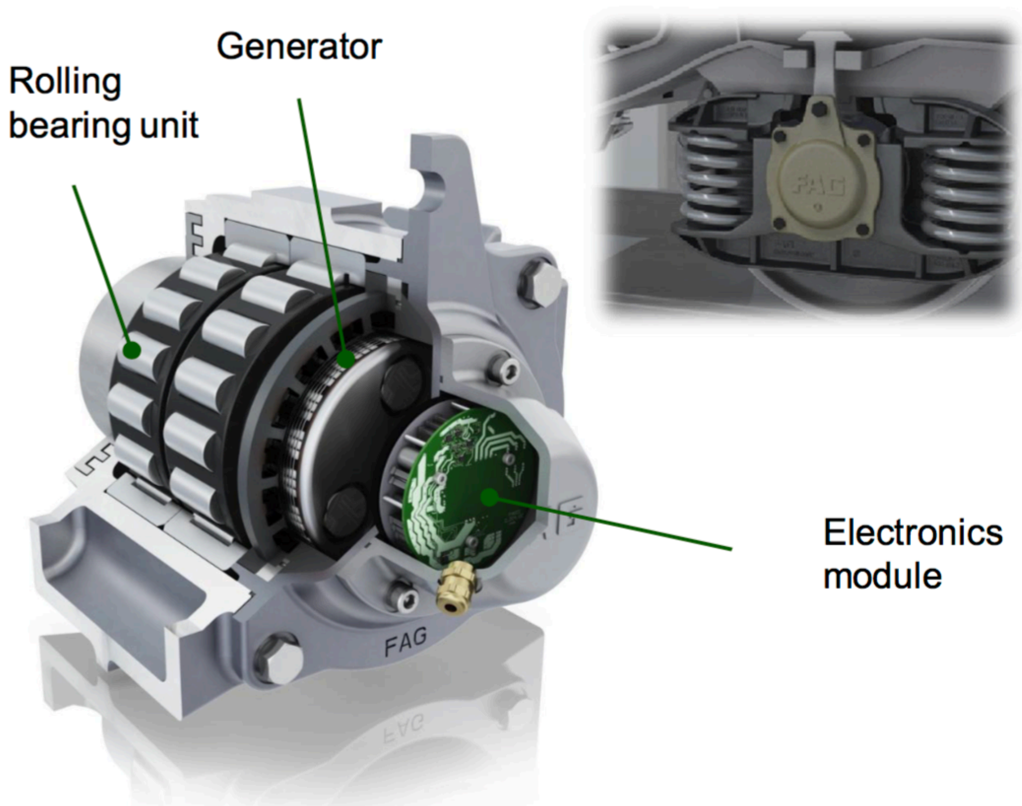


Figure 10: Mechatronics for freight train TAROL (Source: http://www.schaeffler.com/remotemedien/media/_shared_media/09_investor_relations/praesentetationen/capital_market_presentation/2015/Schaeffler_Capital_Market_Presentation_January_2015.pdf)

8.2. Business Opportunities

In order to understand the North American market a market analysis was performed. The largest TAROL bearing companies were investigated and a demand was estimated for the product. Each company was prioritized based on the revenue and on the number of locomotives, passenger wagons and freight cars.

- Amtrak
- BNSF Railway
- Canadian National Railway
- Canadian Pacific Railway

- CSX Transportation
- Kansas City Southern Railway
- Norfolk Southern Railway
- Union Pacific Railroad

Below, we will elaborate on each of these companies and related opportunities.

Amtrak

Amtrak owns 20 high speed Acela Express train sets, two Cascades Service train sets, 1,367 passenger cars, 403 locomotives, 80 Auto Train vehicle carries and 68 baggage cars. Additionally, Amtrak has ordered 130 single level cars and will receive new electric locomotives over the next years. In 2016, Amtrak will receive the next generation of the Acela Express and 40 percent more train sets.

BNSF

BNSF announced in 2015 a total operating revenue of $21.4 billion. For 2016 BNSF expects to invest 15% of its capital (approximately $600 million) into locomotives, freight cars and other equipment. BNSF lays out in its yearly financial statement that the company owns approximately 8,000 locomotives and 77,000 freight cars. In 2015 BNSF also laid out that it had costs of $2 billion in repairs and maintenance in the ordinary course of business.

Canadian National Railway

CN's property consist of about 430 locomotives, whereas 90 locomotives were new at the end of 2016. 50 percent of the railcars on CN's network are owned/leased by the customers in order to mitigate risk of market changes. In 2015 5,485,000 carloads were performed by CN.

Canadian Pacific Railway

Besides over 1,500 owned locomotives, CPR has several freight cars, like box cars, flat cars, etc. in its portfolio. The ownership of freight cars accumulates to 21,000 cars and over 18,000 cars that are currently leased. The average age of these railcars is around 28 years.

CSX Transportation

According to the financial report of 2015 CSX owned and long-termed leased 4,463 locomotives and 84,617 railcars with different purposes like Gondolas, covered hoppers, box cars, flat cars, etc. The operating expenses were $8.2 billion and partially allocated to reconditioning of the railcars (CSX Transportation, 2016).

Kansas City Southern Railway

50 new locomotives were purchased in 2015 and additional efforts were taken to increase the market share for railcar services. Additionally, KCS owned 12,950 railcars and 923 locomotives accumulated. The average age of locomotives is 18.7 years (Kansas City Southern, 2016).

Norfolk Southern Railway

The most common transported good is coal with a share of 17 percent and equals about 120 million tons or 1.1 million carloads. In 2015 the company owned 4,322 locomotives and over 70,600 railcars according to the financial report (Norfolk Southern, 2016).

Union Pacific Railroad

The largest share of railcars is used for agriculture products and generated a revenue of $3.6 billion. According to the annual report UP owned 6,260 locomotives and

34,299 railcars in 2015. The average age of the whole fleet was not indicated in the report but it might be around 25 years (Union Pacific Corporation, 2016).

8.2.1. Summary for North America Rail Industry:

Table 4 below provides a summary of the major railway companies indicating the type and quantity of railway equipment they own. In this table, the number of axles are estimated for each rail wagon type and per axle two bearings were considered. The sum of the total number of bearings provides a rough estimate of about 2.8 million bearings in operation. This large number indicates the magnitude of bearing industry business opportunities in the North American market. Note that in this thesis, our aim is not to have a detailed look into the different types of bearings that are used for each rail wagon type and estimate a prospective demand for each type.

Table 5: Overview of North American market (source: summary of annual financial reports; see appendix)

	Passenger Car	High Speed Train	Locomotive	Auto train	Baggage Cars	Freight Cars	
Amtrak	1,367	20	403	80	68		
BNSF			8,000			77,000	
CNR			430				
CPR			1,500			39,000	
CSX			4,463			84,617	
Kansas City			923			12,950	
Norfolk			4,322			70,600	
Union Pacific			6,260			34,299	
	1,367	20	26,301	80	68	318,466	
Axles	4	80	4	80	4	4	
Bearing	2	2	2	2	2	2	
Sum Bearing	10,936	3,200	210,408	12,800	544	2,547,728	**2,785,616**

The table gives an overview of how many bearings are for each rail wagon type and provides a rough estimate of about 2.8 million bearings in operation. This large number should indicate the business opportunities in the North American market. It is not focus of the thesis to have a closer look into the different types of bearings that are used for each rail wagon type and estimate a prospective demand for each type. Rather the thesis will provide the reader a number for further analysis.

8.3. A Multi-Criteria Decision Making Business Opportunity Indication Tool in the Bearing Industry

In this section the development of a business tool is presented to show how new business opportunities in the bearing industry can be indicated following a multi-criteria decision making process.

8.3.1. Analytical Hierarchy Process (AHP) for Bearing Application

In this section, we will discuss how AHP can be applied to the decision-making process to offer a bearing product in the rail industry, where the options are to offer either a standard bearing, a smart bearing, or both or make no offer.

Step 1: Identify Structure

In order to make a reliable offer four different criteria need to be considered. These are price, production risk, operating benefits and quality and create the foundation for the decision making process. In order to come up with the criteria for the bearing industry, a survey was performed with four specialists in the product development department at the Schaeffler Group. These four people were asked for criteria that are required to develop, launch and sell successfully a bearing to the market. The conclusion was the four criteria price, production risk, operating benefits and quality. See figure 10. Every expert had a different understanding of the importance of each influencing factor on the alternatives, which lead to a high value for the consistency ratio. It was important to bring all experts together and discuss the deviations. The result was after some iterations that the consistency ratio could be significantly improved, which also lead to a better understanding of the decision-making process of the product development process. A detailed analysis of the survey responses can be found in the Appendix.

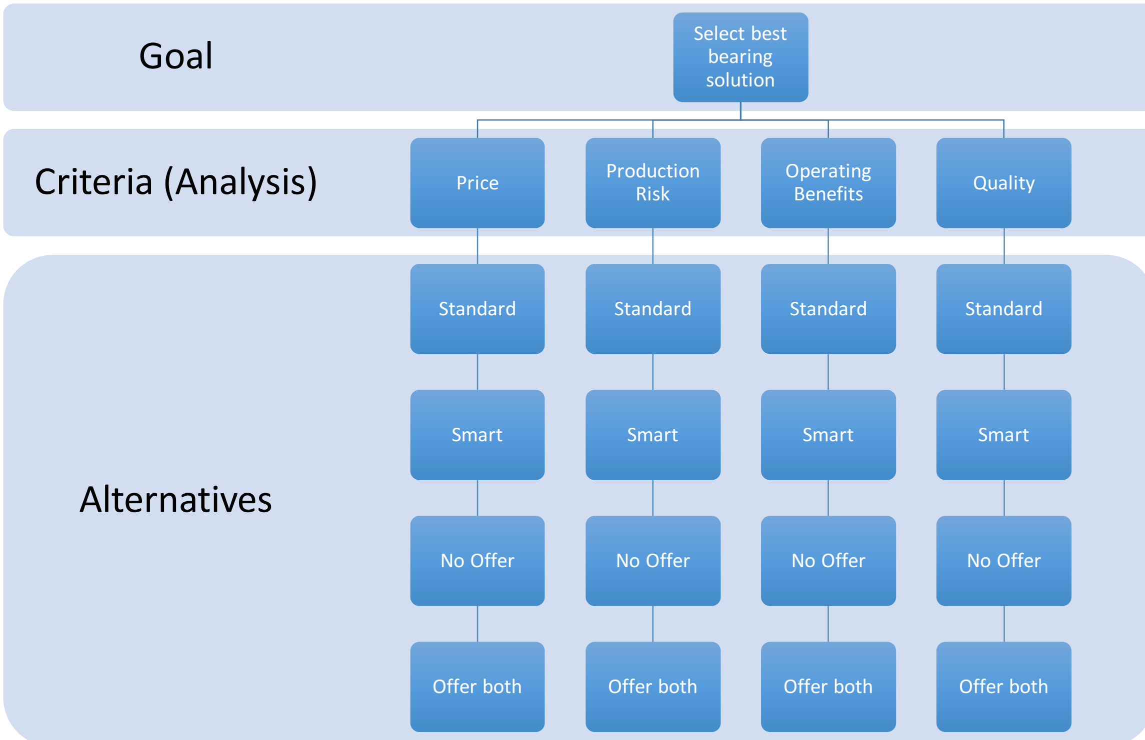


Figure 11: AHP Structure

Step 2: Analyze Criteria

At first a comparison is performed between the criteria. In order to use every respondent's opinion equally for the AHP, a geometric mean value was calculated for each comparison. The summary pairwise comparison table is shown in Table 6. Individual pairwise comparison tables obtained from each respondent can be found in the Appendix.

Table 6: Summary Table for Pairwise Comparison of Criteria for all Respondents

	1	2	3	4	**Geometric Mean**	**Criteria Weights**
	Price	Production Risk	Operating Benefits	Quality		
Price	1	0.61	1.32	0.58	0.83	19%
Production Risk	1.63	1	1.32	1	1.21	29%
Operating Benefits	0.76	0.76	1	0.29	0.64	15%
Quality	1.73	1	3.41	1	1.56	37%
				Total:	4.24	100%

In the pairwise comparison matrix, it was indicated that the price has a weight of 19 percent and the production risk has a risk of 29 percent. This seems to be confusing at first since the bearing industry is a heavily price driven industry, focused on a high quality with consideration of the production risk. On the other hand, the operating benefits were weighted with 15 percent and the quality with 37 percent. One reason can be that the influencing factors of price, production risk, operating benefits and quality could not be clearly defined. We would like to remark that the interviewees indicated that the factor price has several influencing factors (see appendix) and also depends on the industry branch how large the impact of the price is at the end. Another point is that the operating benefit has a lower value since it does not influence the product during the development process.

Step 3: Analyze Alternatives

The next step is to make a comparison of the alternatives for each criterion to identify corresponding alternative scores. The first criterion is price and the corresponding pairwise comparison table is shown in Table 7.

Table 7: Price Comparison of price for all alternatives

Price Comparison	1	2	3	4	Geometric Mean	Alternative Scores
	Standard	Smart	No Offer	Offer both		
Standard	1.00	3.87	1.00	1.00	1.40	34%
Smart	0.26	1.00	1.32	1.00	0.76	19%
No Offer	1.00	0.76	1.00	1.00	0.93	23%
Offer both	1.00	1.00	1.00	1.00	1.00	24%
				Total:	4.10	100%

The comparison in table 7 shows that the standard product in comparison to the smart product has a moderate to strong impact considering the price. This needs to be interpreted as the standard product having an advantage compared to the smart product from an overall product development cost perspective. The price for a smart product is in general higher than for a standard product. The reason for that is that the smart product involves more parts and is more complex to develop. Therefore, it is not surprising that the standard product has a higher score than the smarter product. Another interesting fact is that the scores for no offer and offer both options are even higher than for the smart product itself. A reason for that could not be clearly determined during the survey with the specialists. The logical consistency ratio was calculated with 0.11 indicating only some minor inconsistencies (See Appendix for details).

The next step is to perform a comparison of product development alternatives with respect to the next criterion, the production risk (Table 8). The production risk is mainly driven by the manufacturing challenges of the parts. A summary of all influencing factors can be found in the Appendix. In the pairwise comparison matrix below, we see a large difference between the smart and the standard product. The standard product has the lowest risk for production, whereas the smart product is on the other side of the evaluation spectrum. The challenges during the manufacturing process are more challenging for the smart product than for the standard product. The reason is the implementation of the sensor unit and the generator that make the product smart. However, due to a distinct differentiation of product development between the Research and Development and standard product development these risks are very well considered, and lead to the fact that the smart product is the most favorable solution. The worst solution of course is to offer nothing. The logical consistency ratio was very good with a value of 0.08.

Table 8: Production Risk comparison for all alternatives

Production Risk Comparison	1 Standard	2 Smart	3 No Offer	4 Offer both	Geometric Mean	Alternative Scores
Standard	1.00	0.26	1.00	1.00	0.71	16%
Smart	3.85	1.00	3.41	1.00	1.90	44%
No Offer	1.00	0.29	1.00	1.00	0.74	17%
Offer both	1.00	1.00	1.00	1.00	1.00	23%
				Total:	4.35	100%

The next criterion that needs to be investigated is the operating benefits for the customer (Table 9). This criterion considers all factors that a customer can benefit from. A full list of all benefits can be found in the Appendix. All benefits for both product types are summarized within one factor in order to make it easier to develop a decision model. The biggest benefit of the smart product for the customer is the fact that the bearing is permanently under surveillance and information of the condition can be controlled in real time. The table below indicates that the standard bearing offers moderate to strongly more benefits than the smart bearing. This was discussed with specialists in the rail industry and the ratio can be seen as realistic since the smart bearing has also a higher likelihood to fail during operation than the standard bearing. In this regard it can be said that the standard bearing has a lower likelihood to fail during operations in comparison to the smart product. The consistency ratio was calculated with a value of 0.12, indicating minor logical inconsistencies throughout the evaluation.

Table 9: Operating benefits comparison for all alternatives

Operating Benefits Comparison	1 Standard	2 Smart	3 No Offer	4 Offer both	Geometric Mean	Alternative Scores
Standard	1.00	4.21	1.00	1.00	1.43	35%
Smart	0.24	1.00	1.32	1.00	0.75	18%
No Offer	1.00	0.76	1.00	1.00	0.93	23%
Offer both	1.00	1.00	1.00	1.00	1.00	24%
				Total:	4.11	100%

The last but not least important criterion is quality. This criterion was quite difficult to describe since it is a very broad terminology and was difficult to define for the pairwise comparison. The most important influencing factors are definitely the process know-how throughout the product development process, but also the complexity of the product. A very interesting factor that has a significant impact on quality is the lead time. For the specialists, lead time indicates the time that is required from receiving the order to shipping the finished good to the customer. The lead time indicates how much time can be spent for each single process step and it can sometimes create a challenge if a product is very complex. The result below shows a similar pattern that was already indicated before. The smart and the standard product have relatively close and high scores and that can only be reasoned due to the product development processes of the smart and standard product. The Schaeffler Group performs a risk level assessment before a product is launched in a plant in order to understand the product development risk for each phase. If a product is considered a higher risk, a different stage gate model is used with a more in depth risk evaluation and preventative and corrective actions. Therefore, it does not a surprise that both products have the same score. The results for no offer was very low since it is the worst case not to offer anything. The alternative to offer both options has the third highest score since it would be a compromise of the standard and smart product. Also the consistency ratio had a value of 0.1, indicating consistence throughout the comparison process.

Table 10: Quality pairwise comparison for all alternatives

Quality	1	2	3	4	Geometric Mean	Alternative Scores
Comparison	Standard	Smart	No Offer	Offer both		
Standard	1.00	1.50	3.87	1.00	1.55	36%
Smart	0.67	1.00	4.21	1.00	1.29	30%
No Offer	0.26	0.24	1.00	1.00	0.50	11%
Offer both	1.00	1.00	1.00	1.00	1.00	23%
				Total:	4.34	100%

Step 4: Select the Best Alternative

To select the best alternative, a weighted score for each product development alternative has been computed as shown in Table 11. For example, the final score for the standard product was calculated as a sum of the product of the weight factor for price (19%) multiplied the standard product score (34%) plus the weight score for the production risk (29%) times score for the product (16%) and so on.

Table 11: Result of decision making process

			Criteria				
			1	2	3	4	
			Price	Production Risk	Operating Benefits	Quality	
		Weights	19%	29%	15%	37%	Final Score
Alternatives	1	Standard	34%	16%	35%	36%	0.298
	2	Smart	19%	44%	18%	30%	0.299
	3	No Offer	23%	17%	23%	11%	0.169
	4	Offer both	24%	23%	24%	23%	0.235

The result is that basically the standard product and the smart product have almost the same final score. Interesting point is how the values were accomplished. On one hand the standard product has the highest ratings on price, operating benefits and quality. Therefore, the accumulated value results in a high overall score. On the other hand, the smart product has a high value on production risk and on the option of quality. This is a result of a specific product development process that is in place for smart products. Due to the complexity a more in depth project management tool is in place to reduce potential risks to a minimum. The relatively high weight on production risk along with a high score for smart product with respect to the production risk results in a high score for the smart product as well.

The largest benefit of the result is the knowledge that both products are similar if the whole picture is taken into account. The quantification of the production risk and operating benefits is in most cases difficult to evaluate. This fact also occurred during the survey with the specialists from each department. The final weights and values might be different for other products, but overall the result was discussed and approved by the interviewee.

The least favorable option is to make no offer. The case that the smart product, nor the standard product is offered should be avoided. A very low score of 17 percent reflects the expected opinion of all participants of the survey. The case that both products are offered seems to be biased but in most cases a customer expects from a supplier to receive just one final product and not a product selection.

Several assumptions within this analysis were made that the implementation of the sensor is flawless, and that the customer is trained on using the sensor technologies. Another aspect is the fact that no potential risks were considered for production, and therefore, a best case scenario was assumed. In real life the smart products have more parts and need a closer control throughout the product development process. The reason why these factors were able to be left out is the fact that these risks are considered in a different tool of the product development process. As mentioned previously, at the beginning of the product development process a risk level assessment is performed to understand the risk of the product development. Therefore, any potential failures that can occur during the process were assumed will be captured by the corrective and preventive action plan. In this business case scenario, the focus is on the decision-making tool only.

8.4. Sensitivity Analysis with Respect to the Criteria Weights

Increase in Price:

A point that led to discussion was the fact that the price had a weight of only 19 percent. In the bearing industry, especially for standard products, the price is the most dominating factor when a business decision is done. Therefore, a sensitivity analysis is made to have a better understanding of the final result, when the price becomes more important for the decision process. See table 12.

Table 12: Sensitivity Analysis with changed weight for price

			Criteria				
			1	2	3	4	
			Price	Production Risk	Operating Benefits	Quality	
		Weights	28%	26%	12%	34%	Final Score
Alternatives	1	Standard	34%	16%	35%	36%	0.302
	2	Smart	19%	44%	18%	30%	0.289
	3	No Offer	23%	17%	23%	11%	0.174
	4	Offer both	24%	23%	24%	23%	0.235

The weight for price has changed from originally 19 percent to 28 percent. That seems to be very realistic or even still underestimated depending on the industry branch. The increase by 9 percent points lead to a decrease of three percent points for the remaining three criteria. The resulting final scores indicate that more emphasis on price will push the decision towards the standard product, which is slightly more favorable in this case compared to the smart product. This is a significant change from the original scores and indicates that the criteria weights have a large impact on the decision making process. Therefore, it is essential to have a good understanding of the perception of the market. All over the results did not change in any surprising manner.

Increase in Production risk

If the change of 9 percent points is increased for the production risk and reduced by three percent points for the remaining three factors, the results strengthens the decision for the smart product. See table 13. This can be understood due to the strong influence of the criterial production risk in favor for the smart product. See table 13.

Table 13: Sensitivity Analysis with changed weight for Production Risk

			Criteria				
			1	2	3	4	
			Price	Production Risk	Operating Benefits	Quality	
		Weights	16%	38%	12%	34%	Final Score
Alternatives	1	Standard	34%	16%	35%	36%	0.280
	2	Smart	19%	44%	18%	30%	0.319
	3	No Offer	23%	17%	23%	11%	0.167
	4	Offer both	24%	23%	24%	23%	0.234

Increase in Operating Benefits

If the weight is shift in the same way as above, it will result in the fact that the standard bearing is the most favorable solution. The contributing factors for that are the high values for price operating benefits and quality. The product sum for these factors lead to an overall score of 30.2 percent and slightly more favorable than the smart product. See table 14.

Table 14: Sensitivity Analysis with changed weight for Operating Benefits

			Criteria				
			1	2	3	4	
			Price	**Production Risk**	**Operating Benefits**	**Quality**	
		Weights	16%	26%	24%	34%	**Final Score**
Alternatives	**1**	**Standard**	34%	16%	35%	36%	0.302
	2	**Smart**	19%	44%	18%	30%	0.288
	3	**No Offer**	23%	17%	23%	11%	0.174
	4	**Offer both**	24%	23%	24%	23%	0.235

Increase in Quality

The last option that will be review, is the increase for quality in the same way. The result is similar to the change in operating benefits. The most favorable product is the standard product with even a closer score to the smart product. See table 15.

Table 15: Sensitivity Analysis with changed weight for Quality

			Criteria 1	Criteria 2	Criteria 3	Criteria 4	
			Price	**Production Risk**	**Operating Benefits**	**Quality**	
		Weights	16%	26%	12%	46%	**Final Score**
Alternatives	**1**	**Standard**	34%	16%	35%	36%	0.304
	2	**Smart**	19%	44%	18%	30%	0.302
	3	**No Offer**	23%	17%	23%	11%	0.160
	4	**Offer both**	24%	23%	24%	23%	0.234

Allover, the sensitivity has shown that either the standard product or the smart product are the most favorable solution. No offer or offer both options was never a solution due to the low scores for these alternatives. It could not be verified any case where either alternative with no offer or offer both had the highest value. Therefore, a more in depth analysis was not provided in this work. Other scenarios of changing weights were considered but did not lead to significant findings.

CHAPTER 9: SUMMARY AND CONCLUSION

In this thesis research in the field of IoT, product development and the bearing industry was performed to understand how these fields relate to each other. The conclusion was that IoT is not necessarily a globally used terminology, even though it is difficult to define since the terminology is used very loosely. For example, in Germany the terminology Industry 4.0 is more common. It was indicated that the developments of IoT do not exclude any industry and therefore companies need to make preparation to be able to meet future customer requirements.

The research focused on a general understanding of IoT, whereas the research focus in the bearing industry was specifically to determine what research in regards of IoT was performed so far. The conclusion was the bearing industry offers very limited research to this topic. Scope of the thesis was to answer the following questions: 1) How can IoT be used in the bearing Industry and what are the benefits of Internet of Things? 2) How does IoT effect the bearing industry, its products and product development process? 3) How do we make a decision to introduce a standard or a "smart" product incorporating IoT in the bearing industry? To answer these questions, we performed a literature review, proposed a decision-making framework and presented an application case study.

Another key point of the thesis of the research was that even in more conservative industries, where product development happened only in mechanical optimized steps, like machining with a higher precision, IoT will allow companies to create products with a higher value. These new products can generate more benefits for customers than previous products. The trend is that products will be more effectively used and calculation with regression models will not be necessary anymore. The opportunities, which are available due to the digitalization, allow using cross functional benefits to create better and more accurate products.

Part of the thesis was developing a multi criteria decision model to compare two significant products. One product was a conventional bearing for the rail industry and the other product was an IoT influenced smart product. In order to compare these products, it was necessary to develop a decision model and understand the criteria. Within the organization, where the bearing is manufactured, it was difficult to come up with specific criteria to compare these products. The approach was to come up with at least four criteria and make a pairwise discussion. A list of criteria was defined and it was not possible to break it down to only four criteria. The result was that all these factors are summarized under the criteria: Price, Production Risk, Operating Benefit and Quality. See in appendix B, table 47. The terminology might be biased, but the bearing manufacture specialists agreed on using these terms. The alternatives are either a smart product, a standard product, both product or no product will be offered to a customer in a specific business case. All alternatives are realistic.

Additionally, a sensitivity analyze was performed to have a better understanding of the results if the weights change. It has shown that the focus product, standard or smart, can change based on the criteria weight. Both products, the smart and the standard product, are the most favorable for specific cases. For example, the standard product was more favorable when the decision is based on price and operating benefits. The smart product is selected when the production risk has a higher priority. Another case was that the quality criterion was increased and either smart or standard product are most favorable. The least recommendation was to offer no product or both products in each single case.

The general result of the decision-making process also indicated that the proposed decision model needs to be customized for each product in each industry to reflect associated priorities. The new product development alternatives that are used herein are fairly generic and can be applied across industries and products assuming there is always a standard product option without the consideration of IoT. Thus, if the decision-making model is implemented in the product development process, the decision-making model must be performed from the very beginning and cannot rely on previous developments. During the survey, it was indicated that several criteria were found and therefore it is recommended to consider a second criteria level to in increase the model precision.

The result of the business application was that the smart and standard product had almost the same score. This can only be explained if the product development process is understood behind each product. The smart product is more complex to develop and therefore a more in depth risk management is performed, which increases the quality and mitigates the risks of the product development process. The conclusion is to offer either the smart or the standard product. The results indicate that the final decision must be made on the basis of the customer requirements since both products generate similar value for the manufacturer.

Another outcome of the decision-making process is that it is not favorable to offer both products to the customer. The reason for that is that each product has a different focus and benefits a customer in different ways. A customer might not be interested in the smart product features or may prefer just a standard bearing that suits their requirements in a better way. These factors also need to be evaluated for each application and might differ for each customer. The least favorable option is to offer no product. This can be an option, if the margin is too low or the production risk is too high or alternatively, if the management decides not to offer any quote, which happens occasionally. The reason is that in many cases the cost/benefit ratio is not favorable for the company and the management does not want to spend resources on these projects.

Within the decision-making model several assumptions were made. The flawless implementation of the sensor, and that the customer is trained on using the sensor technologies are just two of them. The fact that no interruptions occurs during production might not be realistic, but needed to assumed as well since the variation of possible risks is countless. In this business case scenario, the focus is on the decision-making tool only.

Future research and development can be performed in regards of implementing a model in an organization that covers different industries and applications. This will allow us to see how the new product development criteria change across different products and industries. Additionally, as indicated earlier conducting a two-level criteria analysis may help increasing the model precision.

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APPENDIX A: SURVEY OF SPECIALISTS

Person 1:

Table 16: Pairwise comparison of Criteria of Person 1

	Price	Production Risk	Operating Benefits	Quality
Price	1.00	0.20	3.00	1.00
Production Risk	5.00	1.00	3.00	1.00
Operating Benefits	0.33	0.33	1.00	0.33
Quality	1.00	1.00	3.00	1.00

Table 17: Price pairwise comparison of Person 1

Price	Standard	Smart	No Offer	Offer Both
Standard	1.00	5.00	1.00	1.00
Smart	0.20	1.00	1.00	1.00
No Offer	1.00	1.00	1.00	1.00
Offer Both	1.00	1.00	1.00	1.00

Table 18: Production Risk pairwise comparison of Person 1

Production Risk	Standard	Smart	No Offer	Offer Both
Standard	1.00	0.20	1.00	1.00
Smart	5.00	1.00	3.00	1.00
No Offer	1.00	0.33	1.00	1.00
Offer Both	1.00	1.00	1.00	1.00

Table 19: Operating Benefits pairwise comparison of Person 1

Operating Benefits	Standard	Smart	No Offer	Offer Both
Standard	1.00	3.00	1.00	1.00
Smart	5.00	1.00	1.00	1.00
No Offer	1.00	1.00	1.00	1.00
Offer Both	1.00	1.00	1.00	1.00

Table 20: Pairwise comparison of Criteria of Person 1

Quality	Standard	Smart	No Offer	Offer Both
Standard	1.00	1.00	5.00	1.00
Smart	5.00	1.00	5.00	1.00
No Offer	0.2	0.2	1	1
Offer Both	1	1	1	1

Person 2:

Table 21: Pairwise comparison of Criteria of Person 2

	Price	Production Risk	Operating Benefits	Quality
Price	1.00	5.00	3.00	1.00
Production Risk	0.20	1.00	1.00	1.00
Operating Benefits	0.33	1.00	1.00	0.33
Quality	1.00	1.00	3.00	1.00

Table 22: Price pairwise comparison of Person 2

Price	Standard	Smart	No Offer	Offer Both
Standard	1.00	3.00	1.00	1.00
Smart	0.33	1.00	1.00	1.00
No Offer	1.00	1.00	1.00	1.00
Offer Both	1.00	1.00	1.00	1.00

Table 23: Production Risk pairwise comparison of Person 2

Production Risk	Standard	Smart	No Offer	Offer Both
Standard	1.00	0.33	1.00	1.00
Smart	3.00	1.00	5.00	1.00
No Offer	1.00	0.20	1.00	1.00
Offer Both	1.00	1.00	1.00	1.00

Table 24: Operating Benefits pairwise comparison of Person 2

Operating Benefits	Standard	Smart	No Offer	Offer Both
Standard	1.00	5.00	1.00	1.00
Smart	0.20	1.00	1.00	1.00
No Offer	1.00	1.00	1.00	1.00
Offer Both	1.00	1.00	1.00	1.00

Table 25: Quality pairwise comparison of Person 2

Quality	Standard	Smart	No Offer	Offer Both
Standard	1.00	3.00	3.00	1.00
Smart	0.33	1.00	3.00	1.00
No Offer	0.33	0.33	1.00	1.00
Offer Both	1.00	1.00	1.00	1.00

Person 3:

Table 26: Pairwise comparison of Criteria of Person 3

	Price	Production Risk	Operating Benefits	Quality
Price	1.00	1.00	3.00	1.00
Production Risk	1.00	1.00	3.00	3.00
Operating Benefits	0.33	0.33	1.00	0.20
Quality	1.00	0.33	5.00	1.00

Table 27: Price pairwise comparison of Person 3

Price	Standard	Smart	No Offer	Offer Both
Standard	1.00	3.00	1.00	1.00
Smart	0.33	1.00	1.00	1.00
No Offer	1.00	1.00	1.00	1.00
Offer Both	1.00	1.00	1.00	1.00

Table 28: Production Risk pairwise comparison of Person 3

Production Risk	Standard	Smart	No Offer	Offer Both
Standard	1.00	0.33	1.00	1.00
Smart	3.00	1.00	3.00	1.00
No Offer	1.00	0.33	1.00	1.00
Offer Both	1.00	1.00	1.00	1.00

Table 29: Operating Benefits pairwise comparison of Person 3

Operating Benefits	Standard	Smart	No Offer	Offer Both
Standard	1.00	3.00	1.00	1.00
Smart	0.33	1.00	3.00	1.00
No Offer	1.00	0.33	1.00	1.00
Offer Both	1.00	1.00	1.00	1.00

Table 30: Quality pairwise comparison of Person 3

Quality	Standard	Smart	No Offer	Offer Both
Standard	1.00	0.33	3.00	1.00
Smart	3.00	1.00	3.00	1.00
No Offer	0.33	0.33	1.00	1.00
Offer Both	1.00	1.00	1.00	1.00

Person 4:

Table 31: Pairwise comparison of Criteria of Person 4

	Price	Production Risk	Operating Benefits	Quality
Price	1.00	0.14	0.11	0.11
Production Risk	7.00	1.00	0.33	0.33
Operating Benefits	9.00	3.00	1.00	0.33
Quality	9.00	3.00	3.00	1.00

Table 32: Price pairwise comparison of Person 4

Price	Standard	Smart	No Offer	Offer Both
Standard	1.00	5.00	1.00	1.00
Smart	0.20	1.00	1.00	1.00
No Offer	1.00	0.33	1.00	1.00
Offer Both	1.00	1.00	1.00	1.00

Table 33: Production Risk pairwise comparison of Person 4

Production Risk	Standard	Smart	No Offer	Offer Both
Standard	1.00	0.20	1.00	1.00
Smart	5.00	1.00	3.00	1.00
No Offer	1.00	0.33	1.00	1.00
Offer Both	1.00	1.00	1.00	1.00

Table 34: Operating Benefits pairwise comparison of Person 4

Operating Benefits	Standard	Smart	No Offer	Offer Both
Standard	1.00	7.00	1.00	1.00
Smart	0.14	1.00	1.00	1.00
No Offer	1.00	1.00	1.00	1.00
Offer Both	1.00	1.00	1.00	1.00

Table 35: Quality pairwise comparison of Person 4

Quality	Standard	Smart	No Offer	Offer Both
Standard	1.00	5.00	5.00	1.00
Smart	0.20	1.00	7.00	1.00
No Offer	0.20	0.14	1.00	1.00
Offer Both	1.00	1.00	1.00	1.00

Summary for all people (Geometric Mean):

Table 36: Consolidated pairwise comparison of Criteria

	Price	Production Ris	Operating Benefi	quality
Price	1.00	0.61	1.32	0.58
Production Risk	1.63	1.00	1.32	1.00
Operating Benefits	0.76	0.76	1.00	0.29
Quality	1.73	1.00	3.41	1.00

Table 37:Consolidated Price pairwise comparison

Price	Standard	Smart	No Offer	Offer Both
Standard	1.00	3.87	1.00	1.00
Smart	0.26	1.00	1.32	1.00
No Offer	1.00	0.76	1.00	1.00
Offer Both	1.00	1.00	1.00	1.00

Table 38: Consolidated Price pairwise comparison

Production Risk	Standard	Smart	No Offer	Offer Both
Standard	1.00	0.26	1.00	1.00
Smart	3.87	1.00	3.41	1.00
No Offer	1.00	0.29	1.00	1.00
Offer Both	1.00	1.00	1.00	1.00

Table 39: Consolidated Price pairwise comparison

Operating Benefits	Standard	Smart	No Offer	Offer Both
Standard	1.00	4.21	1.00	1.00
Smart	0.24	1.00	1.32	1.00
No Offer	1.00	0.76	1.00	1.00
Offer Both	1.00	1.00	1.00	1.00

Table 40: Consolidated Price pairwise comparison

Quality	Standard	Smart	No Offer	Offer Both
Standard	1.00	1.50	3.87	1.00
Smart	0.67	1.00	4.21	1.00
No Offer	0.26	0.24	1.00	1.00
Offer Both	1.00	1.00	1.00	1.00

APPENDIX B: AHP

Table 41: Pairwise comparison of Criteria

	1	2	3	4	Geometric Mean	Criteria Weights
	Price	Production Risk	Operating Benefits	Quality		
Price	1.00	0.61	1.32	0.58	0.83	19%
Production Risk	1.64	1.00	1.32	1.00	1.21	29%
Operating Benefits	0.76	0.76	1.00	0.29	0.64	15%
Quality	1.72	1.00	3.45	1.00	1.56	37%
				Total:	4.24	100%

Consistency Ratio 0.03
Very Good

Table 42: Price pairwise comparison

Price	1	2	3	4	Geometric Mean	Alternative Scores
Comparison	Standard	Smart	No Offer	Offer both		
Standard	1.00	3.87	1.00	1.00	1.40	34%
Smart	0.26	1.00	1.32	1.00	0.76	19%
No Offer	1.00	0.76	1.00	1.00	0.93	23%
Offer both	1.00	1.00	1.00	1.00	1.00	24%
				Total:	4.10	100%

Consistency Ratio 0.11

Good: has some minor inconsistencies!

Table 43: Production Risk pairwise comparison

Production Risk	1	2	3	4	Geometric Mean	Alternative Scores
Comparison	Standard	Smart	No Offer	Offer both		
Standard	1.00	0.26	1.00	1.00	0.71	16%
Smart	3.85	1.00	3.41	1.00	1.90	44%
No Offer	1.00	0.29	1.00	1.00	0.74	17%
Offer both	1.00	1.00	1.00	1.00	1.00	23%
				Total:	4.35	100%

Notes:

Consistency Ratio 0.08

Very Good

Table 44: Operating Benefits pairwise comparison

Operating Benefits Comparison	1	2	3	4	Geometric Mean	Alternative Scores
	Standard	Smart	No Offer	Offer both		
Standard	1.00	4.21	1.00	1.00	1.43	35%
Smart	0.24	1.00	1.32	1.00	0.75	18%
No Offer	1.00	0.76	1.00	1.00	0.93	23%
Offer both	1.00	1.00	1.00	1.00	1.00	24%
				Total:	4.11	100%

Notes:

Consistency Ratio 0.12

Good: has some minor inconsistencies!

Table 45: Quality pairwise comparison

Quality Comparison	1	2	3	4	Geometric Mean	Alternative Scores
	Standard	Smart	No Offer	Offer both		
Standard	1.00	1.50	3.87	1.00	1.55	36%
Smart	0.67	1.00	4.21	1.00	1.29	30%
No Offer	0.26	0.24	1.00	1.00	0.50	11%
Offer both	1.00	1.00	1.00	1.00	1.00	23%
				Total:	4.34	100%

Notes:

Consistency Ratio 0.10

Good: has some minor inconsistencies!

Table 46: Summary of AHP

			Criteria 1	Criteria 2	Criteria 3	Criteria 4	
			Price	**Production Risk**	**Operating Benefits**	**Quality**	
		Weights	19%	29%	15%	37%	**Final Score**
Alternatives	**1**	**Standard**	34%	16%	35%	36%	0.298
	2	**Smart**	19%	44%	18%	30%	0.299
	3	**No Offer**	23%	17%	23%	11%	0.169
	4	**Offer both**	24%	23%	24%	23%	0.235

Selected Alternative	**Worst Alternative**
Smart	
	No Offer

Table 47: Influencing factors for price, production risk, operating benefits and quality provided by four specialists at Schaeffler Group

Criterion	**Price**			
Specialist 1	Market value	Customer expectation	Competitive Price	Costs
Specialist 2	Quantity	Production Location	Complexity	market value
Specialist 3	Costs	Quantity	Business Relationship	Type of product vs Standard
Specialist 4	Costs	Perceived Quality	Margin	market value
Criterion	**Production Risk**			
Specialist 1	Complexity	Size of Product	Lead time/ development time	Suppliers
Specialist 2	Process know how	Suppliers	Product type	Production Planning
Specialist 3	Process know how	Quality	Type of product	Suppliers
Specialist 4	Maturity of Production Line	Volume of Product	Production Day	Lead time
Criterion	**Operating Benefits**			
Specialist 1	Reliability	Quality	Unique Selling Proposition	Life time
Specialist 2	High capacity	Standard products/ interchangeability	low maintenance	Customer service
Specialist 3	Engineering Expertise	Quality	Costs	Business Relationship
Specialist 4	Understand of Application	understanding Product line	Life Time	Good Design of Bearing
Criterion	**Quality**			
Specialist 1	Complexity	Quantity	Lead time	Manufacturing Know-how/ Processes
Specialist 2	Repeatability	Reproducibility	Production Planning	Product Complexity
Specialist 3	Country of Origin	Raw materials	Level of Expertise	Process Know how
Specialist 4	Amount of Information of Application	Lead Time	Business Relationship	Sales volume of product

APPENDIX C: DESCRIPTION OF RAIL COMPANIES

Amtrak

Amtrak is the business name for the National Railroad Passenger Corporation and partially government funded passenger railroad service in the United States. The name Amtrak is a result of blending the words “America” and “track”. It was created by the U.S. Congress in 1970 and began operations on May 1, 1971. Today Amtrak is a federally chartered corporation with the federal government as a majority stockholder. The board is appointed by the President of the United States and confirmed by the U.S. Senate. Amtrak operates more as a for-profit company instead of a public authority (AMTRAK, 2016). In 2015, Amtrak announced that 30.8 million passengers were transported, which means that on an average day over 84,600 passengers used more than the 300 Amtrak trains. This lead to an annual revenue of $3.2 million and an expense of over $4.3 million. The annual operating loss was announced with over $306 million. As another fact it is highlighted that Amtrak carried more riders between New York City and Boston than all air carriers combined (AMTRAK, 2016).

BNSF

Is one of the largest freight railroad networks in the North America. The company employs 44,000 employees and has over 32,500 miles rail tracks in over 28 states in the USA and three Canadian provinces. The company was created on September 22, 1995 from the merger of Burlington Northern, Inc. and Santa Fe Pacific Corporation (BNSF). On February 12, 2010 BNSF became a subsidiary of Berkshire Hathaway. Beside the rolling stock BNSF owns over 13,000 bridges and 89 tunnels (BNSF, 2016).

Canadian National Railway (CN)

CN is a Canadian Class I Railway Company and is headquartered in Montreal, Quebec. CN is the largest railway in Canada and the only transcontinental railway company. CN owns about 20,400 miles of rail tracks in 8 provinces. The market capitalization is about CAD 60 billion and CN's Stocks are traded on the stock exchanges at New York and Toronto. In 2015 the total revenue has reached CAD 12.6 million and employed 23,172 employees (Canadian National Railway Company, 2016).

Canadian Pacific Railway

CPR is a Canadian Class I Railway company and was incorporated in 1881. The company is owned by Canadian Pacific Railway Limited and is headquartered in Calgary, Alberta. The company owns approximately 18,800 miles of rail tracks across Canada and into the United States. In 2015 CPR announced to acquire all shares of Norfolk Southern Railway that will excess a market capitalization of over $26 billion. If the merger is successful CPR will become the largest single railway company in North America.

CSX Transportation

CSX stands for Chessie and Seaboard System and is a Class I railroad company in the United States. The CSX Corporation is headquartered in Jacksonville, FL and owns approximately 21,000 miles of rail tracks, which are mainly located on the east coast from Montreal to Miami. In 2015 CSX generated a revenue of $11.8 billion, an operating income of $3.6 billion and employed around 29,000 employees.

Kansas City Southern Railway

KCS is owned by Kansas City Southern and is the smallest third-oldest Class I railroad in North America and was founded in 1887. The company operates in the central U.S. region and in Mexico. The company is headquartered in Kansas City, Missouri and owns over 6,600 miles of rail tracks. In 2015 a revenue $2.4 billion was generated with an operating income of $804 million. The operating expenses were outlined with $1.6 billion. Most of the revenue stems from shipping industrial and consumer products (23%), chemical and petroleum (20%), Agriculture and minerals (18%), intermodal (16%), energy (10%), automotive (9%) and other products (4%).

Norfolk Southern Railway

NS is a Class I railroad company in the United States with headquarter in Norfolk, Virginia. The company is responsible to maintain over 36,000 miles in over 22 of the eastern states and was founded in 1982 after the Norfolk Southern Corporation was established. NS is a direct competitor of CSX on the east coast and generated a revenue of $10.5 billion in 2015. The operating revenue was $2.9 billion

Union Pacific Railroad

UP is likewise the other companies a freight hauling Railroad Company. It employs over 47,500 employees and maintains over 32,100 miles of rail tracks. UP has its headquarter in Omaha, Nebraska and generates $21.8 billion revenue, whereas $8 billion were generated from operations. Approximately 9 million carloads were shipped and generated and operation ratio of 63.1 percent (operation expenses divided by operation revenue).