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OPPORTUNITIES OF INDUSTRY 4.0 FOR SMES IN THE AREA OF REBAR STEEL DISTRIBUTION WITHIN THE CONSTRUCTION INDUSTRY – A PPC POTENTIAL ANALYSIS

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I. Abstract

Industry 4.0 coins a global trend towards applying digital technologies to manufacturing. However, the openness towards related innovations varies among different industries. Whilst for instance many manufacturers within automotive or logistics industries have optimized their factories already, the German construction sector falls back regarding adaptation. Reinforcement steel distributors reflect a fundamental part of this sector and are broadly hesitant to initiate their factory transformation. This research provides an overview of the opportunities of Industry 4.0 in the area of reinforcement steel trade and processing. It analyzes how to derive an innovative factory design leveraging on state-of-the-art production planning methods, by aggregating market information and technology.

Keywords

Industry 4.0 | **SME** | **Steel Trade** | **Manufacturing**

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II. Agenda

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V. List of Abbreviations

I4.0	–	Industrie 4.0
ST&P	–	Steel Trader and Processor
RQ	–	Research Question
H1 – 3	–	Hypotheses 1-3
CPS	–	Cyber Physical Systems
IIoT	–	Industrial Internet of Things
GmbH	–	Gesellschaft mit beschränkter Haftung (Limited Liability Company)
D2D	–	Device to Device Communication
M2M	–	Machine to Machine Communication
LP	–	Lennerts & Partner GmbH
SE	–	Schilt Engineering BV
PPC	–	Production Planning and Control
PdM	–	Predictive Maintenance
R1 – 10	–	Respondent 1-10

1 Introduction

Digitalization and Industrie 4.0 (I4.0) are considered the major drivers to overcome new challenges in the modern business world. The vision of the fourth industrial revolution is described as a highly reconfigurable, customized and autonomous manufacturing (Ivanov et al. 2020, 1-5). Organizations within different manufacturing industries face issues including demographic changes and demands, streamlining business processes, productivity and process stability as well as quality assurance, while aiming to save overall costs (Schumpp et al. 2019, 34). The degree to which companies integrate I4.0 applications to address changing economic and social environments varies. According to surveys, 48% consider the automotive industry as leader when it comes to the implementation of I4.0 concepts, followed by the logistics and distribution industry with 24%. In contrast, 52% state that the construction sector has the highest backlog demand (Handelsblatt 2017). Steel distributors, also termed steel traders and processors (ST&P), operate in a commoditized sector within the construction industry, highly sensitive to fluctuations in steel prices and slow to embrace new technologies and business methods (London Metal Exchange 2020). Different barriers regarding the introduction of I4.0 technologies decrease the number of overall factory transformations. Relevant hurdles comprise the integration of existing machines, software interface issues, upfront investments and lack of know-how as well as missing acceptancy across all company-levels (Schumpp et al. 2019, 29-34). However, when cumulating the information provided by other surveys with ST&Ps the need and pressure for change becomes apparent. Being sellers of a commodity, steel distributors share a very low margin business – prices from distributors are non-transparent, strongly negotiated and jeopardized by commodity price shifts. Thus, there is no differentiation to any other competitor, despite putting emphasis on decreasing costs for manufacturing and logistics. This research outlines concrete opportunities for ST&Ps to upgrade their factory according to the I4.0 principles to enhance manufacturing processes and become competitive.

1.1 Scope of the Analysis

This study focuses on linking I4.0 to German ST&Ps. These organizations are placed in between steel producers and customers in the value chain and create value by sawing, drilling, cutting, threading, bending or refining the raw steel. The overall German steel industry is seen as the backbone of the national economy. Around 84.000 employees produced almost 42.4 million tons of raw steel in 2018 making Germany the largest steel producer in Europe. The most critical customer segments in the steel industry are the automotive and construction industry. (Wirtschaftsvereinigung Stahl 2019, 2-34). The majority of ST&Ps offer their customers a diversified product portfolio, ranging from sectional steel, tools and machines via building components and services to reinforcement steel. Within the different areas of activity, this research will depict the opportunities of I4.0 with a view on the processing of reinforcement steel in bending plants. Regarding value chain classification, the chosen topic deals with the primary activity 'Productions and Operations' as well as the supporting activity 'Technological Development'. Information Communication Technology (ICT) as sub-component of 'Technological Development' is considered the enabler of digitalized bending plants (BP). Thus, the implications on this supporting activity will also be examined (Porter 1985, 11-15).

1.2 Structure

First, the existing literature is reviewed to approach the research question (RQ) and to deduct the underlying hypotheses. The structure of the work derives generic I4.0 applications to the German steel trading and processing sector. The first part of the research concentrates on the theoretical findings from academic research relevant to the fourth industrial revolution. In addition, the status quo within the steel distribution industry is examined and the shared views are discussed. Finally, a two-folded use-case approach towards the production and manufacturing of rebar steel processors is elaborated. The areas analyzed in the use-cases are derived from the literature review. The use cases provide an exemplary approach for the application of I4.0 fundamentals – from designing a unique connected BP 4.0 to the decentralized software-based production planning and control.

2 Literature Review

This chapter investigates the existing academic literature and its implications for I4.0 within the area of steel trading and processing. First, I4.0 is described in terms of relevant factors regarding origin, properties and implementation. The second part presents an appropriate status quo analysis of ST&Ps with respect to I4.0 from existing literature, which together serve as basis for the development of the hypotheses and use cases.

2.1 Origin of Industry 4.0

I4.0 was launched by the German government as a long-term high-tech strategy, determined by the German government through the Ministry of Education and Research (BMBF) and the Ministry for Economic Affairs and Energy (BMWI) to advance digital technologies in industrial production in 2011 (European Commission 2017, 3).

I4.0 reflects a global concept – However the scope regarding its perception varies. While Europe connects I4.0 to the field of production and manufacturing, the United States have a more holistic perspective embedding the related technologies in their overall supply- and value chain (Mehta et. al 2020, 7). As the term I4.0 indicates, there have been three prior revolutions that are summarized in figure 1 below.

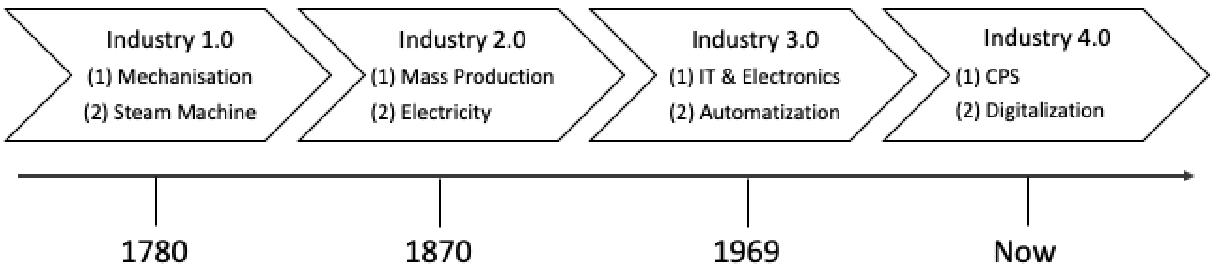

Figure 1. Timeframe of the four industrial revolutions (Skilton and Hovsepian 2018, 6)

2.2 Properties and Implications

While the 3rd industrial revolution, launched 1969, was coined by automatization and the involvement of computer and electronic systems in the production process, I4.0 is characterized by additional automation and the bridging of the physical and digital world through Cyber Physical Systems (CPS). These systems work through the integration of ICT, such as Cloud or Industrial Internet of Things (IIoT) and play a fundamental role (Zhou et al. 2015, 2147-52). Before proceeding with the properties and implications of I4.0, CPS and IIoT are explained:

- **CPS** can be described as innovative technologies that enable the management of interconnected systems through the integration of their physical and computational environments (Lee et al. 2014, 18). A CPS consists of three levels. At the top, a service system in which intelligence is allocated and where the actual logical networking takes place. Second, a level where mainly process data about conditions are stored - the data memory. And a level, where physical objects, machines and production facilities are connected. The use of CPS allows real-time data generation and the decentralization of process control (Drath 2014, 3-5).
- The term **IIoT** has been introduced to describe the application of IoT within the industry. IIoT applies technology such as sensors, actuators, control systems, machine-to-machine communication, data analytics, and security mechanisms to improve modern industrial systems (Mourtzis et al. 2016, 290-295). Satyavolu et al. (2014) defines IoT as „a scenario in which every object or 'thing' is embedded with a sensor and is capable of automatically communicating its state with other objects and automated systems within the environment. Each object represents a node in a virtual network, continuously transmitting a large volume of data about itself and its surroundings." Thus, IIoT reflects a communication network connecting production-related objects which have naming, sensing and processing abilities. The

interconnectivity among objects, including devices, actuators, sensors, embedded computers and RFID tags, is in most cases based on standard communication protocols such as Bluetooth and ZigBee (Al-Sarawi et al. 2017, 685-687).

Generally, I4.0 connects products, machines and people with each other, and combines information technology with manufacturing and the internet (Kagermann et al. 2013). Even though I4.0 reflects autonomous manufacturing, complex processes remain and stipulate Human-to-Machine tasks and information exchange (Rojko 2017, 77-82). Manufacturers are becoming capable of masscustomization and flexible reconfiguration of productlines regarding product type and quantity (Federal Ministry for Economic Affairs and Energy 2019, 2). To remain competitive in a global market, especially high-wage countries can take advantage of implementing I4.0 within their factories by opening more domestic production hubs due to the increased efficiency (Smit et al. 2016, 32). The implications of realizing I4.0 cover different areas. Each of them embraces additional value, as described in the table 1.

Area	Implications
Customer	▪ Customizable products ▪ Real Time production status access and punctual delivery ▪ Decrease in prices
Supply Chain	▪ Connected system ▪ Seamless information flow ▪ Decrease in inventory due to just-in-time production
Manufacturer	▪ Decentralized control and access to machines ▪ Interconnected machines for M2M communication ▪ Increased machine productivity leads to lower production costs ▪ Collect, store and analyze huge amounts of process data

Table 1. Implications of I4.0 on different factors (Own Representation based on Mehta et al. 2020, 9-11)

2.3 The 3-Layer Principle of Industry 4.0

I4.0 out of a technically lens is built on three major layers, comprising the upgrade to smart physical resources, the set-up of an integrated network to enable device to device (D2D) communication and finally the data application layer to autonomously control and plan the production of an organization. Each layer requires the integration of different digital technologies (IEEE Access 2018, 6505-6513). The first layer is related to the production assets.

Entire production plants and their components are becoming smart systems, capable to make decisions based on machine learning algorithms, real-time data capture and historical action analysis (Kagermann et al. 2013, 19-23). This is achieved by embedding software into hardware, for instance sensors or processors, adding intelligence to the production-related devices (Rojko 2017, 82). The second layer enables the interoperability and connectivity of the production components using integrated networks as communication channels. The network layer involves the standardization of communication in terms of a uniform data format. As such information can constantly flow between the different machines, devices and components (Zezulka et al. 2016, 8-9). Finally, the data application layer connects the factory to the back-office. Through a cloud platform with business intelligence raw data can be converted to useful information supporting a continuous self-improvement of the production process and its underlying components. Production control and planning is decentral and monitoring, intervention as well as decision-making becomes data driven. This layer contains very sensitive and oftentimes confidential information, raising the claim for a holistic approach to cybersecurity (Rojko 2017, 84-86). By applying the three layers, I4.0 creates smart processes with digitalized production networks and the least human involvement, while adopting the operations depending on environmental dynamics (Pereira 2017, 3-4).

2.4 Industry 4.0 in the Area of Reinforcement Steel Trading and Processing

Reinforcement steel bars or coils are heavy-weight products of circular or nearly circular cross-section design, used for the reinforcement of concrete at construction sites (see Appendix 11). ST&P process the material in BP factories before it is later embedded in concrete at construction sites (Marriam Webster 2020). By incorporating the steel, the concrete, which otherwise can only be loaded in compression, can also be loaded in tension. (Concrete Reinforcement Steel Institute 2020). Logistics are complex and long-distance delivery for smaller projects is expensive. The competitive landscape is divided into two segments – a few large-scale project

ST&Ps delivering products nationally and smaller regional enterprises taking care of small and mid-sized construction sites. Overall, the market is highly fragmented with 165 different enterprises in 2019 (Statistisches Bundesamt 2020). For 73% of all surveyed companies, digitalization within the steel trading and processing industry is still considered as 'dreams of the future'. Over half of those surveyed state that automatized processes and machines are not of any importance, committing that they do not plan any implementations of I4.0 applications in the future (Günther and Schramm 2017, 10-11). However, a relevant portion of 40% are announcing that they will begin transforming within the next three years (Schumpp et al. 2019, 49). The Suelzle Group has set the first benchmark in 2019, completing the construction of their first connected and digitalized BP 4.0 in Germany (Suelzle 2020). The reasons for implementing I4.0 are diverse and depending on the prioritization of each enterprise. In sum, there are five factors that are especially relevant for ST&Ps, summarized in table 2.

Property	Insights
Real-Time Data	Real-time data through the continuous communication between systems serves to: ▪ Avoidance of accidents at work through real time video analysis and sensors that intervene if workers are in danger ▪ Condition monitoring of the process, for instance in case of automatic material un-and loading ▪ Assure machine access anytime ▪ Allow to intervene right at the spot whenever problems occur
Data Collection	Data Collection: ▪ Steel traders and processors expect the highest advantage of data collection in the area of production (76%) and production planning (74%). ▪ Enables the best possible capacity utilization and the avoidance of machine breakdowns through predictive maintenance systems. ▪ Data serves to avoid scrap material and downtimes with regards to tools and machine components, such as saw blades
Data Analysis	Data Analysis: ▪ is the result of data collection andtransforms raw information into true value for an organization. ▪ Its scope depends on an organization's metrics, KPIs and individual needs. ▪ The evaluation of gathered data is the key driver for steel traders and processors to decision making and its accuracy depends on the data quality. Examples include configurable scoring systems to evaluate factors including offcut weight, cycle weight, number of varieties.
Transparency	Data information and gathering leverages the level of transparency along many different dimensions. Steel traders and processors are especially concerned about clarity when it comes to: ▪ Cost transparency with respect to material usage, energy consumption and labor costs ▪ Machine downtimes and performance monitoring – Replace machine components before they cause costly machine breakdowns ▪ Process stability & monitoring ▪ Quality monitoring to assure customer satisfaction and popularity
Standardization	Standardization has always played an important role, however in the context of industry 4.0 new needs are created, such as: ▪ Establishing standardized transmission interfaces ▪ Enable standardized protocol information ▪ Determine standards with regards to units of measurement

Table 2. Most relevant I4.0 properties for ST&Ps (Own Representation based on Schumpp et al. 2019, 27-32)

The other three characteristics, still assessed as medium relevant comprise decentralization, flexibility and connectivity. According to Schumpp et al. (2019), as of today, 20% of the surveyed organizations have made any experiences with I4.0 and its applications. The most frequent implemented building block of I4.0 is considered to be the digital and human-independent collection of data and the connection of administrative systems to the factory. A development towards a broad roll-out of fully connected and digitalized steel distribution is currently not foreseeable according to surveys.

2.5 Challenges and Benefits of Industry 4.0 for Steel Traders and Processors

In sum, ST&Ps anticipate four major challenges and benefits when it comes to the implementation of I4.0 related technologies.

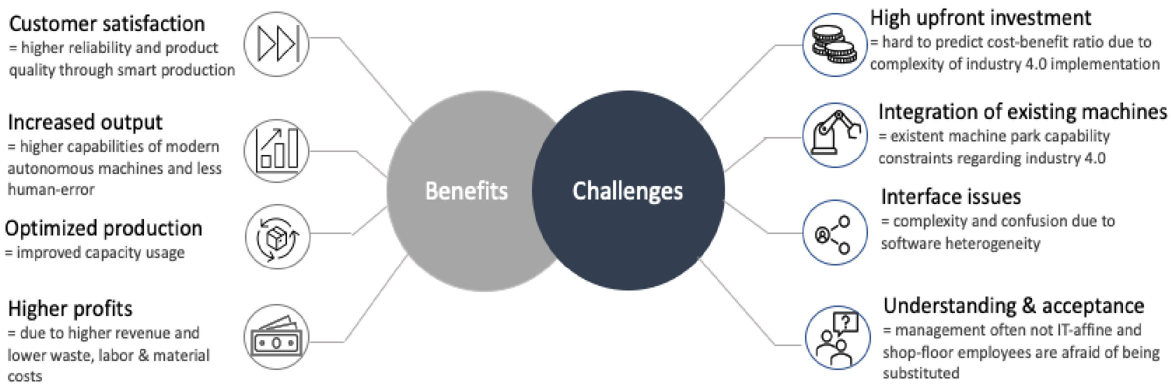

Figure 2. Benefits and challenges regarding the implementation of I4.0 for ST&Ps (Own Representation based on Schumpp et al. 2019, 27-35; Kempermann 2019, 46-47)

2.6 Research Question and Hypotheses

This work project answers the RQ of how small-and mid-sized rebar steel trading and processing organizations within the construction industry can adapt and integrate I4.0 applications to leverage their production planning and control as well as overall manufacturing efficiency. Lagging behind regarding digitalization results in two major implications for organizations. First, a window of opportunity, as there is still a lot of untapped land to gain competitive advantage, second, a sense of urgency as organizations will be externally forced by customers to catch up in order to continue as a going concern. In sum there are three hypotheses (H) derived from the literature review that led to the major RQ and aim to justify applying state-of-the art technology within the area of steel trade and processing:

H 1: *Integrating the underlying technologies of I4.0 (CPS, IIoT) in a BP assures a seamless production flow, positively impacting the productivity level. I4.0 strengthens the overall business model by significantly cutting labor and waste costs, decreasing an organization's exposure to market volatility.*

H 2: *The implementation will provide process transparency and real-time data to managers, enabling a smart and connected production planning and control system. Complex and time-consuming data analytics regarding the optimal usage of machines, different material or varying batch sizes will be adopted by smart and automatized planning systems.*

H 3: *The current amount of I4.0 BPs within German is still low, due to the high efforts related to the implementation. One major driver is the large upfront investment for replacing most parts of the machine park. The investment exceeds the capabilities of most small-and medium sized enterprises. However, if ST&P encounter company growth, the revenue increase might outbalance the costs of the investment, leading to long-term higher profits.*

3 Methodology

An empirical approach has been chosen to address the RQ, with the objective to gain experience by means of a methodical-systematic collection of data. Limited amounts of published knowledge on the topic requires a complementary qualitative research design in order to derive potential opportunities for the area of steel trading and processing (Reinders and Ditton 2011, 49-50).

3.1 Primary research

I4.0 has just begun to enter the steel distribution sector and the know-how and experiences are still constrained to a handful of non-public organizations within Germany. As a consequence, this research focuses on data gathered from qualitative interviews. In order to assure a reasonable sample, respondents from three different steel distributors and two service enterprises have been selected. The expert interviews have been conducted to get first-hand insights into the industry to elaborate the different use cases of I4.0 applications for ST&Ps. To generate comprehensive results, ST&Ps in different maturity stages regarding I4.0 and digitalization have been interviewed. The included small-and medium enterprises (SME) range from 20 to above 500 million EUR in revenue, employing between 70 and 2,000 people (for more detailed information about the surveyed companies and respondents see Appendix 1-10). Each interview contains a different set of questions with a low number of overlaps, tailored to the field of expertise of the respondent. Two interviews have been complemented by field trips to the respective BPs. The visual insights of these trips highly contributed to the machine park design of the first use case. As only semi-structured interviews have been used, this research is based on a mono-method qualitative study (Saunders et al. 2019, 187).

3.2 Secondary research

Considering the increasing relevance of I4.0 to most manufacturing industries since its origin in 2011, there is sufficient scientific and technical literature on generic aspects. Having investigated the status quo of German ST&Ps, research has shown that there is some scientific journals and magazines that deduct most insights from surveys. Nonetheless, these sources primarily discuss the construction or steel and metal industry in general. The concrete topic related to the processing of reinforcement steel represents a niche in the scope of I4.0, which simultaneously leads to a low quantity of scientific literature. Up to now, first-mover companies within this industry held back the publication of their applications and experience. For the literature search the databases of EBSCO, Science Direct, Research Gate, B-On and Google Scholar were searched. The literature analysis focuses on generic I4.0 properties and structure in order to derive an implementation strategy for BP manufacturing. Across the literature, the impression is created that there is consensus on the disruptive potential of I4.0 for the lagging ST&Ps.

4 Bending Plant 4.0

Being a traded commodity, the purchasing price of rebar is volatile and volume-independent, resulting in a low economics of scale leverage with respect to procurement. As such, ST&Ps focus on the optimization of manufacturing processes to reduce the claim for human labor, while becoming more efficient with regards to factory productivity rates (R3). This chapter includes two use cases outlining how ST&Ps can reach this objective by adjusting their manufacturing to I4.0 based on interviews conducted with experts. The case structure is related to the 3-layer principle of I4.0 (see chapter 2.3). The physical asset and network layer are addressed in the first use case. The second use case deals with the data application layer and examines the interconnection of physical assets to back-office to enable decentralized autonomous production planning and control. For simplification and unification of the findings and results both cases assume that the underlying steel distributor generates an annual sales volume of ~10 million EUR, solely with rebar steel and prior to implementing I4.0.

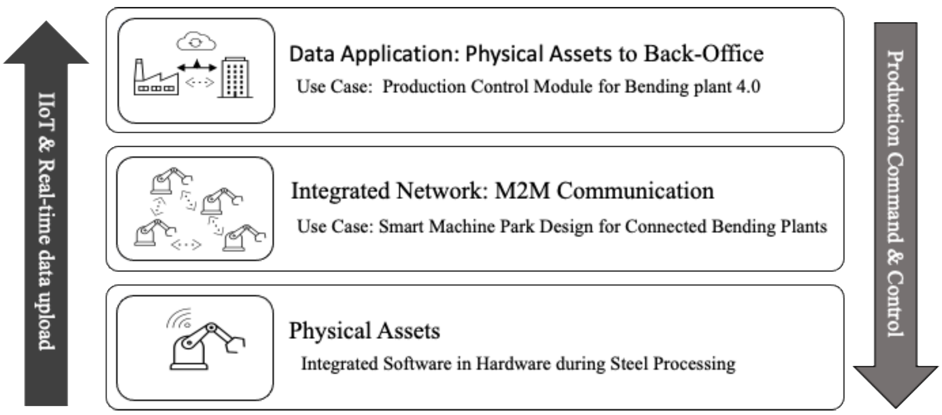

Figure 3. Two-folded use case approach for industry 4.0 introduction (Own representation based on IEEE Access 2018, 6505-6513)

4.1 Integrated Network: Machine to Machine communication

M2M communication describes a technology whereby a large number of smart physicals resources can autonomously interact with each other to make collaborative decisions without direct human intervention. The objective is to increase efficiency with respect to costs and time management (Chen and Li 2012; Igarashi et al., 2012). As of today, BPs consists of a variety of different machines and systems – the production process is divided into different working stations and the interoperability and frictionless process flow is depending on the coordination capabilities of factory location managers.

4.1.1 Use Case 1: Smart Machine Park Design for Connected Bending Plants

The shift from traditional BPs to I4.0 comes with a whole new set of complex machine systems that are capable of being connected to wireless networks to communicate with each other. This use case portrays how innovative manufacturing resources can be combined to realize a smart steel trading factory, based on IIoT. The conducted interviews have revealed information about the devices as well as their constellation needed to set up such plant. Experts advise to look out for three value creating dimensions, when choosing a machine park supplier.

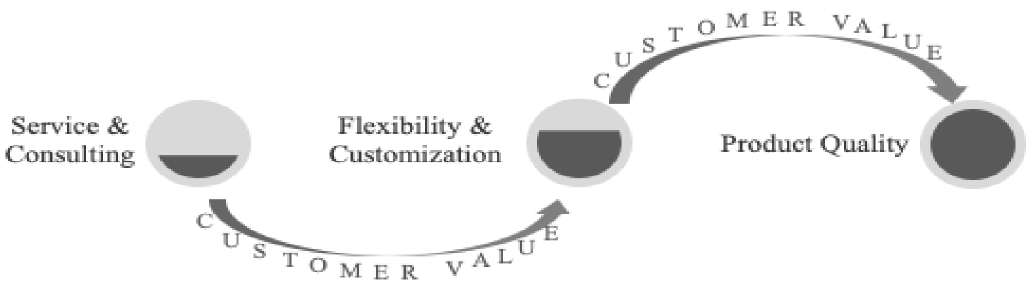

Figure 4. Value Creation Path out of a steel trader's CEO perspective (Own representation based on R4)

According to the opinion of different interviewed experts Schilt Engineering (SE) meets the criteria (R1;R2;R4). The innovative machine engineer and supplier is based in the Netherlands and has become a leader in developing I4.0-based BPs delivering its products to customers around the globe – from Germany to Australia. Supplemented with parts and machines from other German suppliers, a state-of-the-art machine park can be designed. For the purposes of this research a sketch of an I4.0 BP has been developed by the author as depicted in figure 6. The operations flow in the scenario is from left to right.

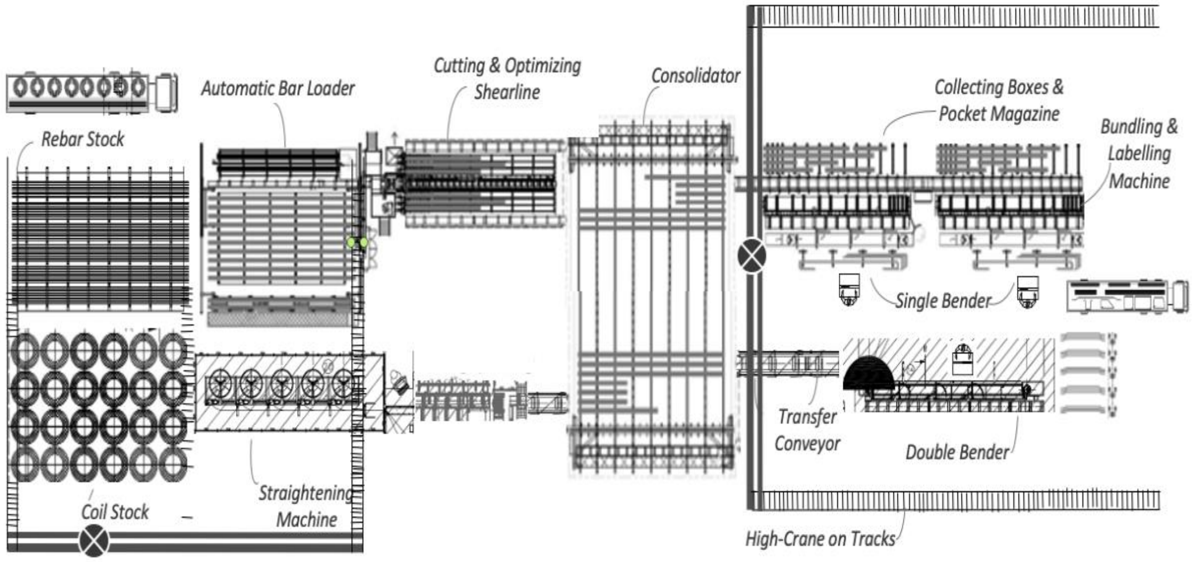

Figure 5. Bending Plant Sketch (Own Representation based on PEDAX 2020 and Schilt Engineering 2020)

The left side shows the edge of the reinforcement steel bar inventory. Here the suppliers unload the different types of bars and coils. A manually controlled crane with magnet crossbeams places the delivered raw material in the respective inventory rack. The crane must be able to carry at least six tons and is mounted to the ceiling moving along fixed tracks.

As soon as the processing of an order initiates, the crane moves the bars from the inventory to the Automatic Bar Loader's (ABL). Embedded sensors of the machine trigger the integrated computer system to pick up the raw steel bundle from the pre-processing rack and place it into a new compartment closer to the shearline. The compartment is pre-defined and selected based on the queue position by the production control software. Wireless networks enable a continuous data exchange between the production control software and the ABL. Every step, from compartment box selection to gripping, counting and extracting the steel bars happens fully autonomous (R5). The ABL is a highly sophisticated production system, equipped with hundreds of sensors that control its actions and send alerts to the location manager, if problems occur. To assure timely intervention the location manager monitors the activity on his control screen. Each product line and order have their pre-calculated schedule that will be further discussed in the second use case (R5). As soon as the material is requested by the production planning system the ABL proceeds by picking up the rebars again from the compartment and dropping them on a roller conveyor. Pressure-sensitive chain conveyors are automatically activated and transport the material to the rebar cutting shearline. Due to the flexibility of its cutting mechanics, it can be fed with various types of rebars within short time (R3). The integrated cutting technology enables accurate measuring and quick processing. ST&Ps without the ABL and connected shearline must employ people for the described loading and cutting tasks – the number of workers correlates with the volume of processed rebars.

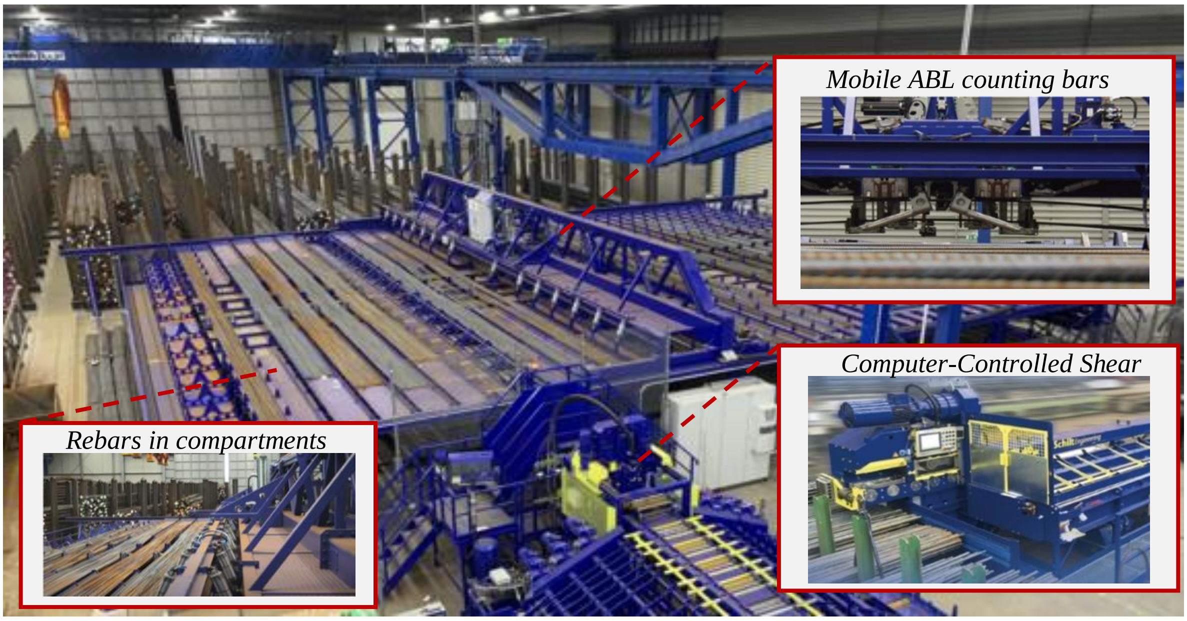

Figure 6. Automatic Bar Loader (Schilt Engineering 2020)

The overall production process is dichotomous. As illustrated in figure 6, the raw material comes from two different sources – the coils and the rebar inventory. On average, coils require a cost premium of around 20 EUR per ton (for further information regarding rebar steel prices see Appendix 12). However, ST&Ps have to use it, because the unroll process is much faster than separately picking the bars. On top, waste is minimized as the occurrence of residual length is much lower (R3). Next to the shearline is the straightening machine with hyperbolic rollers.

Instead of bars, the reinforcement steel is unreeled from 3-5-ton coils and cut after being flattened. Among different straightening machines, the Polycut PCX from the supplier EVG is a state-of-the-art automatic machine for straightening and cutting heavy-duty reinforcing steel from coils. The patented feed system incorporating a motorized roller straightening unit as well as a water-cooled electric servo drive guarantee highest output rates with minimum maintenance and best dimensional accuracy of the products. Material changes with regards to wire diameter or quality can be performed quickly due to the integrated motorized straightening roll adjustment in the roller-type straightening units (R4).

Figure 7. Polycut PCX from EVG - a heavy duty rebar straightening machine (EVG 2020)

Similar to the ABL, through implementing CPS, a digital twin of the machine is created, allowing to monitor and retrieve data regarding capacity utilizations, variations, malfunction and progress.

Coming either from the ABL shearline or the straightening machine the material is further transported via transfer conveyors to the consolidator, capable to effectively coordinate multiple incoming production lines. The consolidator is an intermediate buffer station with robotized pick and place systems, equipped with sensors to count and measure the bars, providing feedback to the production managers control system. Similar to the ABL the interim storage system is operating autonomously and is connected to the organization’s production control system (R4). It equalizes any time constraints and assures a structured and ongoing workflow in the factory. The consolidator further gives the manufacturer flexibility and the opportunity to form production units within the interim storage for optimized bundling and labelling later in the process. It solves the bottleneck of production breakdown due to the time-consuming loading of trucks with finished products, as operations can continue seamlessly. The consolidator has at least two exits. The first output-way is comprising a chain conveyor to transport the material to a bundle and labelling machine. Alternatively, the material is further processed at the single and double benders according to the customer's needs before transferred to the loading zones. Once again, according to experts, SE's automated bundling and labeling machine system is the leading technology on the global market (R1;R4;R5). The bundling machine can be connected to existing or new straightening machines as well as cutting machines providing the opportunity to be integrated into an existing machine park. The bundling and labelling activity happens simultaneously and eliminates two more time-consuming and error-prone steps that have been completed by people before (Schilt Engineering 2020). If the bars are required to be further processed, roller conveyors transfer the material from the consolidator to the bending machines. These conveyors are self-configurable and adjust their speed according to the worker's pace. Depending on the specific item configurations, defined on the digital positioning list, either a single bender or double bending machine completes the job. The names of the two machines already indicate their duties – the double bender has full mobility to flexible react to changing lengths or diameters and twists the rebars on both sides simultaneously while the single bender is capable to cover just one side at a time. So far, the processes have been computer-driven, solely involving human monitoring and supervision. However, this step additionally requires human-to-machine interaction., in terms of manually picking-up the bended steel from the anchorage of the machine to put it aside. It is a remnant of prior BPs that could be substituted by complex robotics (R1). Although the physical motion seems simple, the robotic arm would need to repetitively identify the changing centers of gravity depending on lengths and angles. As the combinations of these two factors are close to infinite, robotics cannot support with this operational step yet (R4). The success of the development of an innovation concerning autonomous robotics primarily depends on the willingness to value and invest into research and development of ST&Ps.

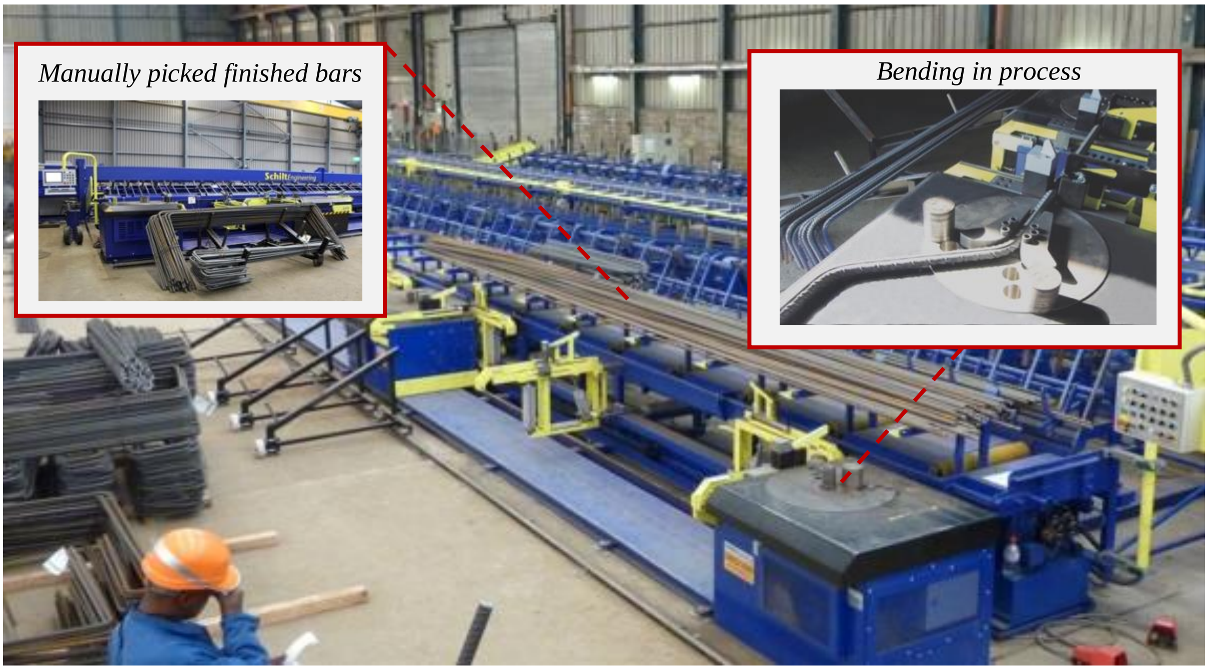

Figure 8. Semi-Automatic Double Bender (Schilt Engineering 2020)

Surrounded by optical sensors, photo-electric barriers take care of the remaining workers' safety. As soon as a human comes too close to any of the machine systems, the sensors trigger an immediate interruption. Besides establishing a safe environment for people, sensors are embedded in the different machine systems to track material movements and provide data about the variations, speed and current location to the digital control board of the BP (R4). Different types of sensors are applied to measure the change in positions, angles and distances of the material. The assortment includes ultrasonic sensors, indoor GPS, optical sensors and image sensors (VDMA and KIT 2018, 9-11). To avoid errors when loading the trucks, a computer near the loading zone provides information about the location and type of finished products that need to be loaded. By scanning the material, the truck driver provides feedback to the system.

As soon as all items have been scanned and loaded the truck driver receives the delivery note and is authorized to leave the factory (R5).

4.2 Physical Assets to Back-Office Connection

The back office bolsters the factory and vice versa, creating an inevitable interdependency. I4.0 has identified the huge potential of a rigor connection, blurs the lines and brings these organizational components together by integrating CPS (Rojas et al. 2017, 1-4). As of today, it is common that within steel trading organizations, information and data gets from A to B in paper-form, manually carried by a human employee. Same applies to the storage of gathered data – according to a survey, 47% of the German ST&Ps still store data in paper-form. In corporation with innovative consultancies, a handful of ST&Ps have recently begun to transform the conventional style and digitalize the process (Schumpp et al. 2019, 46). The following use case sheds light on how the back office can effectively control and manage the production planning and control (PPC) by incorporating smart modular software.

4.2.1 Use case 2: Production Control Module for Data Application & Machine Activation

By conducting expert interviews, a structured approach to a smart back office to machine park connection has been deducted, based on IIoT technology, CPS and cloud. As discussed above (chapter 4.1.1) the involved machine systems range from ABLs, consolidators, semi-autonomous bending machines to autonomous straightening and cutting systems – everything connected digitally via the internet and physically with transfer conveyors. Lennerts & Partner (LP) supports businesses with their expertise by embedding a digital production planning and control tool into the existent software infrastructure. The product is described as a software that can automatically import the data of a customer's order with a multi-import module and processes it in the back office of the steel trader autonomously – from the order, via the whole manufacturing process to the delivery note (R1). To successfully transform a BP, ST&Ps can introduce this Production Control Module (PCM) levering the degree of autonomation and smart factory from zero to almost one. As soon as a new order is received from a customer the module covers the steps shown in Figure 9 below. Although the PCM is the German leading tool within the steel trading industry, LP is still on a journey, trying to feed their software with maximum data to learn more about best-practices. The current bottleneck is primarily the small number of innovation-oriented ST&Ps, thus actual customers of LP (R1). This underscores the mentioned broad reluctance of ST&Ps towards change within this industry (see chapter 2.4).

Figure 9. The 6-step-based PCM (Own representation based on personal interview with R1)

After the structural engineer has transferred the order, in form of a bending list (for a detailed example see Appendix 13) including the configurations of each position as an absolute database file, the interface imports the plan to the steel traders PCM in the first step. The Federal Association for Building Software provides the guideline for the exchange of reinforcement data to assure format alignment across the value chain. The concept is defined by construction software houses, bending machine manufacturers, steel bending companies, and steel suppliers.

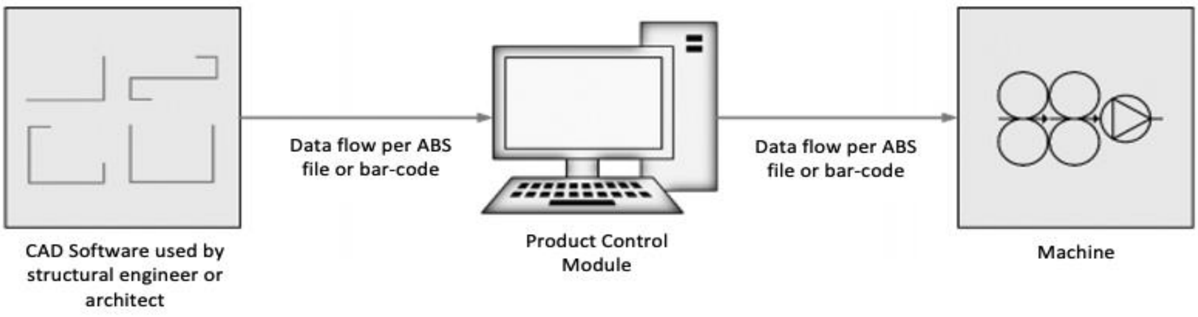

Figure 10. Organizational Process. Each data supplier/recipient has to set up a converter software (Bundesverband Bausoftware e.V. 2019, 2-5)

As a first step the module allocates the machines to the order and performs an inventory check of the required material, for instance coil, bar, diameter and thickness. In the background, CPS transmit the condition and capacity status of each involved physical asset to its digital twin in the cloud and analyzes the data (R4). In case of machine failure or maintenance, the positions are automatically reallocated to the appropriate production line. The PCM assigns the machines and checks all priorities while calculating the production time for each product line. The fully autonomous smart module also allocates appropriate positions within the bending lists to the rest length machine, avoiding and controlling waste. Now, the system provides an integrated digital machine utilization and load distribution schedule to the production manager for final approval (see Appendix 14). The second step moves deeper into each order and is called prioritization. Typically, a bending list comprises between 50 and 300 positions, containing the concrete measures, angles, diameters, etc. of the required rebars (R3). The PCM prioritizes the orders and sorts the numerous embedded positions based on configurable parameters, such as loading date, delivery date, planned production date and others. This step takes into consideration any dependencies among machines, for instance if rebars need to be bend, the cutting and bending happens in two subsequent steps on different machines. To assure punctual product delivery to customers the module is applying a backward calculation (see Appendix 15) determining the latest production start and end for each individual item (R1).

The third step aims to put the individually listed positions together and determine production units for the manufacturing process. As such multiple orders can be combined and processed simultaneously. This step serves to avoid production downtimes caused by full consolidators. Consolidators represent the smart interim storage of the material. Items of different orders are combined for the further processing, as long as they fulfill the same criteria regarding bundling, such as length and diameter. The software enables the intelligent combination of different rebar types. While the output of this step is generated automatically based on gathered data, the production times are configurable, depending on the shift schedule of the factory (e.g., 3x6 hours). Having completed step three, the PCM proceeds with the steel bar optimization (R1). The optimization selects the best mix of different bar lengths from the current inventory in order to minimize waste. The broader the portfolio of bar variations the higher chances are that cutting waste is reduced to below 0,5% of processed steel (R4) – In comparison, conventional BPs produce around 2,5% of scrap material (R3). This step involves extensive analytical efforts that could not be calculated by humans for each position during the daily operations in the past and promises higher margins (R4). To measure performance the PCM provides a scoring-system that highlights key performance indicators, such as cutting waste, cycles and variations after each completed production procedure (see Appendix 16). This data is stored in a cloud-system and applied to constantly optimize the overall six-step-based process.

The penultimate step is described as bundling. The smart module determines the composition of the individual positions to bundles with definable weight, cross-section and dimensions. Hereby, it takes into account the logistical possibilities and forms bundles based on steel diameter, machine, commission – also across different machines. The handling of positions to be bent can be defined specifically, for instance determining to generally forward individually but combine partial and graduated positions. The enhanced bundling later supports reducing the number of crane lifts when loading the trucks, saving additional time and labor (R4). As of today, shop-floor employees manually bundle the bars for each order or even single position within the same order. Creating best possible bundles of different positions for the same construction site does not take place, as the workers do not execute their tasks according to a unit logic, but think in single positions. Finally, the decentral machine activation initiates. Via wireless networks the PCM transmits the schedule and information to each machine and requests real-time feedback as progress is made to update the status of the production and each connected physical resource. Automatic, continuous control of the manufacturing process allows the manufacturer to react to incoming orders or changes (R1).

5 Results

This chapter synthesizes the results from the interview-based use cases and links them to the RQ and its underlying hypotheses. Blending the literature-based theory above with real-world applications reveals insights about the current maturity and potentials of I4.0 within the steel trading industry.

5.1 Outcome: Use Case 1

By integrating extensive logistics around the shearline and straightening machine a high-capacity autonomous rebar processing line can be implemented. Apart from an increase in shop-floor productivity by up to 200%, the quality of the end product will improve, due to a frictionless process flow and the avoidance of frequent human error along the whole process chain (R3). Designing a machine park similar to the concept presented above will bring any BP closer towards lean manufacturing – a modern methodology that strives to enhance product quality, lower costs of production and get rid of waste (Pinto et al. 2018, 5-7). Shopfloor labor costs related to rebar steel processing decrease by around 50%, as the smart infrastructure of the factory significantly substitutes the need for iterative and exhausting human work (R1). Steel distributors might choose between an employee lay off, a task change to advanced supervisory duties or an employee shift into different verticals of the company portfolio to support further growth. This use case provides evidence for the first underlying hypotheses of the major RQ referring to a seamless production-flow and higher productivity (chapter 2.6).

The capital expenditure for a machine park without any surroundings, such as building, land, etc., ranges from 2.7 to 3.5 million Euros. The range is based on two independent offers for a similar BP as the one sketched previously (chapter 4.1.1) and varies depending on machine quality and service claims. The substantial investment reflects the major hurdle to implement smart manufacturing for SMEs since the current revenue volumes do not outbalance the financial impact (R2;R4;R5). As of today, there is less than a handful of ST&Ps in Germany, that are equipped with some of the technology described. These organizations include the Suelzle Group, LZR-Stahlform, SCR GmbH and Heyemeyer Steel (R2). All of them justify their I4.0 efforts with a substantial sales growth strategy to compensate the costs of the investments and generate their required return.

5.2 Outcome: Use Case 2

The PCM allows to automatize complete processes within BP factories. Its intelligent software promotes ideal machine utilization and a highly autonomous production. The decentralized control is an innovation that has been discovered earlier in other industries but new to German ST&Ps adding value to the efficiency of their manufacturing processes (R4). By applying the PCM waste will be reduced, as immediate reuse of the remaining lengths is constantly calculated on a broad scale by combining the different orders. Since the module is adjustable to the exact requirements of a customer through many adjustable parameters, ST&Ps can react flexibly to changing customer needs and demands. The PCM is the interface between back-office and factory and adds intelligence and consistency to the daily procedures, eliminating human errors in PPC, while constantly analyzing gathered production data (R1). Nonetheless the PCM still comes with some weaknesses. Since modern comprehensive building software technologies including Building Information Modelling are only slowly gaining overall acceptance, spontaneous and unexpected orders from construction sites still represent a frequent issue (R5). The PCM however cannot interrupt the manufacturing as soon as machines are activated. Instead, the steel distributor must wait until the processed positions are completed before intervening. Valuable time that might damage customer loyalty in this highly competitive industry (R1). In sum, the PCM provides substantial evidence for the second underlying hypotheses, enabling a smart and connected production planning and control system providing transparency and real-time data to managers to continuously optimize manufacturing processes (chapter 2.6).

6 Discussion

6.1 Limitations and Directions for Future Research

The greatest limitation of this research is the lack of publications, as most organizations are SMEs, owned and managed by private shareholders with the least amount of external communication. According to German publication law, requirements for publication do barely exceed annual high-level financial statements, varying upon size of the company (Handelsgesetzbuch, 2020). Second, as this research deals with a niche sector focusing on the German market, international databases contain low amounts of relevant information. Overall I4.0 is a wide-ranging concept with a diversified application portfolio. However, many of these applications are not used by state-of-the-art ST&Ps, such as predictive maintenance (PdM) or virtualization tools including virtual and augmented reality. Insights gathered during the expert interviews have a substantial share in this work. Nevertheless, the number of respondents is constrained and does not necessarily reflect the common sense among the numerous German steel distributors and processors.

In a future research, the actual value of I4.0 should be addressed, measured by the ultimate returns of the investments. Up to now the expert statements regarding profitability and productivity enhancement are not yet finally validated. Further, as technologies continue to develop, there is a high chance of other applications matching the needs of ST&Ps. A technical analysis on how to apply these bears great transformative potential for steel distributors.

6.2 Future Outlook

Overall, the industry is approaching a turning point, at which progressive traders will continue to exist, while conservative players reluctant to change will face huge challenges with regards to costs, customer loyalty and efficiency. Besides the available opportunities that have been analyzed in the use cases above, there is further potential for steel distributors. Major smart manufacturing technologies including artificial intelligence for PdM, intelligent robotics and energy efficiency monitoring systems are still to a large extent untouched (Frank et al. 2019, 15). On a timescale, innovators, such as the Suelzle Group, have already begun transforming their manufacturing processes in 2019. However, the industry-wide innovation journey will still require much time highly correlated to upper management characteristics. As digital natives succeed, a vast amount of manual conducted processes will be streamlined and automatized.

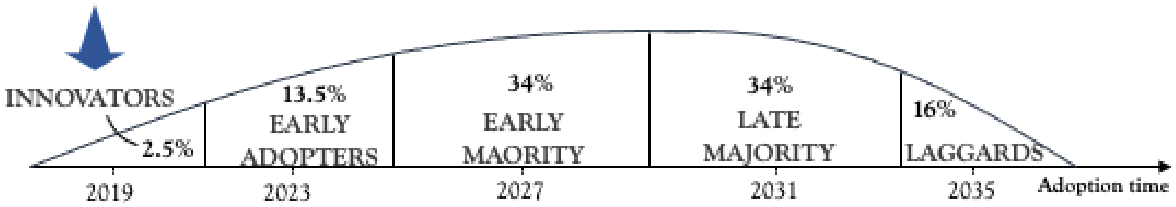

Figure 11. The Diffusion of Innovation Curve for: Time Scope for the Implementation of I4.0 by Steel Distributors (Own Representation based on Rogers 1962, 247)

Financially, I4.0 comes with some risk leading to a potential consolidation of the market. The degree of risk for a company putting large investments into I4.0 is highly correlated to its forecasted revenue development. If the market is in the maturity stage and satisfied, revenue stagnates and the amount of risk for an investing organization increases significantly. On the other hand, if an organization manages to significantly grow revenues, productivity and customer satisfaction increases and the amount of risk will diminish as shown in a sensitivity analysis of three different scenarios (for more information see Appendix 17). Each organization will need to analyze the financial upside versus the downside including the high upfront investment in combination with the increase in interest and down payments/depreciation.

In sum, this research concludes that incorporating I4.0 at small-and medium sized steel distributors will enhance the overall business model towards higher productivity, better customer relations, product quality and employee satisfaction. Whilst in other sectors the ship has sailed already the area of steel trading and processing remains full of opportunities and potentials (Kempermann 2019, 26).

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8 Appendices

Appendix 1 – Lennerts & Partner GmbH

	Respondent 1
Name:	Mr. Florian Kirchner
Organization name:	Lennerts & Partner GmbH
Respondent Function:	Head of Sales
Industry:	Consultancy
Annual Revenue:	NA
Customer Segment:	Reinforcement Steel Traders and Processors
Industry 4.0 background:	High Experience

Date of Interview: 15/10/20 Type of Interview: Personal Meeting

Appendix 2 – EURO STAHL–Handel GmbH & Co. KG.

	Respondent 2
Name:	Mr. Juergen Leukandt
Organization name:	EURO STAHL–Handel GmbH & Co. KG.
Respondent Function:	Location Manager
Industry:	Steel Trade & Processing
Annual Revenue:	> 500 million EUR
Customer Segment:	Contractors, Locksmiths, Project Developers
Industry 4.0 background:	Medium Experience

Date of Interview: 07/11/20 Type of Interview: Phone Call

Appendix 3 – C.A. Weber Eisenhandels GmbH

Respondent 3

Name:	Mr. Dr. Steffen Lehmann
Organization name:	C.A. Weber Eisenhandels GmbH
Respondent Function:	Managing Director
Industry:	Steel Trade & Processing
Annual Revenue:	20 million EUR
Customer Segment:	Contractors, Locksmiths, Project Developers
Industry 4.0 background:	Zero Experience

Date of Interview: 28/10/20 Type of Interview: Personal Meeting

Appendix 4 – LZR Stahlform GmbH

Respondent 4

Name:	Mr. Marek Reich
Organization name:	LZR Stahlform
Respondent Function:	Managing Director
Industry:	Steel Trade & Processing
Annual Revenue:	50 million EUR
Customer Segment:	Contractors, Locksmiths, Project Developers
Industry 4.0 background:	High Experience

Date of Interview: 09/11/20 Type of Interview: Personal Meeting

Appendix 5 – Suelzle Holding GmbH & Co. KG

	Respondent 5
Name:	Mr. Marting Vestring
Organization name:	Suelzle Stahlpartner
Respondent Function:	Location Manager
Industry:	Steel Trade & Processing
Annual Revenue:	> 500 million EUR
Customer Segment:	Contractors, Locksmiths, Project Developers
Industry 4.0 background:	High Experience

Date of Interview: 11/11/20 Type of Interview: Phone Call

Appendix 6 – Memory Minutes – Respondent 1 – Lennerts & Partner GmbH

Interviewer:	Kai Lehmann
Interviewee:	Florian Kirchner
Location:	An der Staustufe 8, 97318 Kitzingen, Germany
Date:	15/10/2020
Duration:	60 min
Type of Interview:	Personal Meeting, German (Author's translation)

Which role does Lennerts & Partner play for steel traders? Which are the core areas of acitivity?	- Core focus on consulting regarding bending plant transformation - Digitalized products for product control and planning, customized to clients' needs - Enabling autonomous decentralized production control and management
Which products do you offer to your customers?	- PCM – Product Control Module - POM – Production Optimization Module - Consulting
How do the two modules differ?	- PCM – Fully automatized bending plants - POM – For semi-automatized bending plants with partially manual control of machines that interrupt the automatized material processing
Please describe, how the PCM is used and how it works.	- Overall process involves six steps - Machine Allocation -> checks capacities and calculates production times for each product line - Prioritization -> based on delivery dates and urgency. Taking into account dependencies for multi-step production processes

	(e.g. Step 1: Cut at shearline or straightening machine, Step 2: bend at bending machine) - Building Production Units -> cross order optimization to avoid frequent changes in production line. Based on determined manufacturing hours - Bar Optimization for waste reduction and optimized usage - Bundling -> Composition of finished products according to weight, length and cross-section parameters. Considers logistical capabilities. - Machine activation -> control and receive production feedback to monitor real time production status
What are the advantages of these modules for steel traders?	- Fully automatized and autonomous processes and production - Ideal machine utilization - Lower material waste amount, close to zero - Customizable by applying different parameters to set up the processes - Integrated bundling across several machines
Which suppliers offer devices that are compatible with the PCM module?	- Schilt Engineering: Already successfully set up of various bending plants together with the Dutch-based machine supplier -> Customized machines with highest quality and reliable service - To some degree the German machine manufacturer EVG and PEDAX
Why do you think does the majority of steel traders resist to approach Industrie 4.0?	- Related upfront investment into new machine parks and software. Most small enterprises would need to change their overall growth strategy as the machines currently available do not pay off for a small revenue volume - Lack of understanding and acceptance -> not knowing what to expect from the transformation. - Afraid to change proven concepts

Appendix 7 – Memory Minutes – Respondent 2 – EURO STAHL–Handel GmbH & Co. KG

Interviewer:	Kai Lehmann
Interviewee:	Juergen Leukandt
Location:	An der Lazarettkirche 5, 55543 Bad Kreuznach, Germany
Date:	07/11/2020
Duration:	25 min
Type of Interview:	Phone Call, German (Author's translation)

Which role does ESH play for steel traders in Europe? Which are the core areas of acitivity?	- Aggregates information of more than 140 SMEs - Coach and accompany member network towards digitalization - Provide a platform for the exchange of insights among different steel traders
What is the status quo regarding industry 4.0 in the area of rebar steel processing within	- A handful of progressive players are located in Germany: Suelzle Group, LZR – Stahlform SCR GmbH Heyemeyer Steel GmbH

the construction industry?	➔ The existing industry 4.0 applications still lack regarding predictive maintenance, robotics and virtualization, such as integrated Virtual – or Augmented Reality - Broad reluctance to change among German steel traders, primarily due to capital constraints and a lack of understanding - The industry is approaching a turning point as first movers have recently begun to gain competitive advantage in terms of lowering their costs and significantly increasing productivity. Customers realize and appreciate the advantages in terms of lower selling prices and higher reliability
Which service does ESH deliver to its members?	- Market research - Purchasing bundling - Market support and consulting - Close strategic cooperation - Derive market trends and forecasts
What are innovative suppliers and service centers to implement the transformation?	- Suppliers with top nod machines include EVG, Schilt Engineering and PEDAX - Leading consultancy for implementation is Lennerts and Partner -> a globally operating organization that has been involved in the set-up of bending plants 4.0 from Germany to Australia
Why do you think does the majority of steel traders resist to approach Industrie 4.0?	- Required capital expenditures are a threat to risk-averse German entrepreneurs. Afraid to lose more than they will benefit -> This is based on the broad lack of understanding. Benefits are not feasible for most steel traders and processors

Appendix 8 – Memory Minutes – Respondent 3 – C.A. Weber Eisenhandels GmbH

Interviewer: Kai Lehmann
Interviewee: Dr. Steffen Lehmann
Location: Nikolas-Otto-Str. 10, 55543 Bad Kreuznach, Germany
Date: 28/10/2020
Duration: 30 min
Type of Interview: Personal Talk in German (Author's translation)

What is the status Quo of C.A. Weber regarding digitalization and industry 4.0?	- Dr. Steffen Lehmann took over the role as Managing Director with the beginning of this year - During past 10 years only very limited efforts towards digitalization - Thus organization has very low level of industry 4.0 experience
Which issues do you want to address first with the help of digitalization projects?	- Prepare the back-office software system to a roll-out of industry 4.0 applications in the factory – e.g., implement new ERP system that is compatible with the needs and preferences of steel traders and less generic than the current one in use - Build up interfaces to customers to speed up the overall order process and eliminate repetitive manual tasks – currently 2 full time employees spend their whole day copying bending lists from structural engineers to the inhouse production planning and execution software

	- Conduct process mining, to uncover potentials and current process inefficiencies - Set-up roadmap to become a industry 4.0 organization within the next 5 years - Solve the problem of manually entering the 50 to 300 positions within a bending list into the bending software by setting up electronic data interchanges and standardizing the format to abs. instead of pdf.
What do you expect from future digitalization projects?	- Decrease dependency on steel price volatility (price varies among coils and bars: coils are 20 EUR higher per ton. Purchasing prices range from 380-450 EUR – Being a commodity, the gross margin is unstable and hard to predict. Range from 15% - 21%. To operate profitable, the second major cost block 'Labor Cost' needs to be under control at a level below 12% of total sales - Significantly reduce the amount of waste – 2019: 2,64% and 2020: 1,88% of total processed steel - Eliminate inefficiencies within the organization and become paper-free - Continuously improve the production process through gathering and analyzing process data

Appendix 9 – Memory Minutes – Respondent 4 – LZR Stahlform GmbH

Interviewer:	Kai Lehmann
Interviewee:	Marek Reich
Location:	Nikolas-Otto-Str. 10, 55543 Bad Kreuznach, Germany
Date:	09/11/2020
Duration:	45 min
Type of Interview:	Personal Talk in German (Author's translation)

How far are you with implementing your industry 4.0 based bending plant?	- Factory already in use -> the whole rebuilding happens during the daily operations – No production stop - Automatic Bar Loader, a conveyor system and Consolidator are already operating - Bending/Stirrup machines are currently not connected to the process flow and are still manually operated
Why did you choose to make this investment?	- Pressure of the larger organizations, such as the Suelzle Group - From a different industry with much more integrated digitalization -> felt like going back to stone age, when he took over the role of the Managing Director of LZR-Stahlform - Create value through real-time information flow, full process transparency and decentralized production control - Efficiency lacks in every process step - Increase overall productivity of the bending plant and eliminate repetitive, exhausting tasks for employees -> Train employees to take on more IT-related supervising responsibilities - Build stronger customer relationships through rapid and reliable delivery as well as increased product quality - Increase work safety by applying sensors to machines

With whom did you plan and execute the project?	- Key players: Lennerts & Partner and Schilt Engineering - Both highly qualified service partners with perseverance and great service - Most important properties of service provider/supplier: (1) Reliable Service and post-sale availability due to complexity of the product, (2) Flexibility and customization: Each organization has its own soft-and hardware infrastructure -> the supplier needs to be able to adapt, (3) High product quality with long lifetime (>15 years)
How can production improve by implementing industry 4.0 application?	- Recent analysis of process data has revealed that the output generated within the same time is tripled – huge productivity increase. Moreover, the duration of operations per day were extended, as the machine park is operating autonomously to a large extent, requiring a low amount of people - Seamless processes without interruptions as machines never need a break - Waste is reduced to 0,5% of total processed steel - Cover substantial downside with the autonomation of our bending plant. As steel prices change continuously, generating higher volume capacities through automatization enables steel traders to outbalance low selling prices over short-time periods
What is important about applying modern software to your operations?	- Gather data - Create process transparency to early identify potential defects and avoid production breakdown - Increase productivity through smart software that perfectly utilizes the machines - Reduce human-made errors by enabling smart software to control the production
Can you name examples of how the new machines lever the factory productivity?	- Automated bundling and labeling machine from Schilt Engineering eliminates hours of hard manual daily work and reduces errors leading to higher customer satisfaction - Consolidators are intelligent interim storage systems. Due to this extra step a continuous production can be assured. The consolidator is controlled by the software provided by Lennerts & Partners that controls and optimizes the processing of material - EVG straightening machines cutting heavy-duty reinforcing steel (feed system with motorized roller straightening unit and a water-cooled electric servo drive → increase output with best dimensional precision of the products) - Autonomous robots for bending machines would have great additional leverage -> Do not exist yet, because of complexity. Physical motion of the robotic arm would need to repetitively identify centers of gravity depending on lengths and angles of the processed material
Why do you think does the majority of steel traders resist to approach Industrie 4.0?	- Most steel traders have an extensive number of existing machines, acquired over the past decades -> these machines do usually not have the capabilities to be connected to wireless networks. As a result, steel traders are required to purchase a whole new machine park, which reflects a relevant cost hurdle

	- People within an organization are trying to avoid any transformation as they fear to become substituted by machines. This internal resistance makes it even harder for upper management to adjust their strategy

Appendix 10 – Memory Minutes – Respondent 5 – Suelzle Holding GmbH & Co. KG

Interviewer: Kai Lehmann
Interviewee: Martin Vestring
Location: An der Lazarettkirche 5, 55543 Bad Kreuznach, Germany
Date: 09/11/2020
Duration: 45 min
Type of Interview: Phone Call in German (Author's translation)

What are the major benefits of industry 4.0 for steel traders and processors in the construction industry?	- Data-based production planning and control reduces human bias and misjudgments - The interconnectivity of the whole organizations increases accuracy and productivity - One overall business intelligence aggregates information and data from all software systems, such as the manufacturing execution system, Enterprise Resource Planning, etc. -> enables better monitoring and decision-making - Higher quality and reliability of output leads to better customer relationships/loyalty and higher revenues
Which are the major challenges of implementing industry 4.0 applications within your organization?	- People are not just the most important enabler, but also represent the biggest challenge -> workers do not promote changes as they fear to lose their jobs or are lacking in qualifications for more sophisticated tasks. "You cannot change the habits of a lifetime." Another aspect is the lack of understanding of the often more senior management - The upfront investment represents a big hurdle. Suelzle, as one of the bigger German players has the financial resources, but smaller companies often do not - The lack of adjustability of existing machines. Typically, bending plant machines are costly assets, as such organizations hesitate to upgrade their factory, as they fear that existing machines become useless
What does the current order processing look like? How did it improve through the upgrade towards the bending plant 4.0, that you implemented in 2019?	- After structural engineers of a contractor have completed the bending list, they are automatically imported to the product control module of Suelzle -> via a multi-compatible interface. CAD data can be digitally transferred based on virtual 3D planning, for instance Building Information Modelling - Interface to the ERP-system - Then production is planned on a daily basis – ideal machine utilization, and processing time - The production planning department verifies the technical data and bending lists. Next, the order is further processed to the machines - Via a sophisticated conveyor system, the material is transported to the different process steps and sensors analyze the production

	progress in real-time -> also provide feedback to the back-office about machine performance and productivity levels - As soon as material is finished, manually controlled high cranes transport it to the loading zone - The truck driver receives a digital delivery bill to assure accurate order picking before leaving the factory to deliver the finished goods - The process became seamless and the duration from order to delivery could be reduced by more than 30%
How did your role change within the company?	- Most of repetitive tasks got eliminated – gained additional time for more value creating tasks. Responsibility increased due to the increase in production volume. - Became manager of a complex digitalized environment – constantly optimizing the machine efficiency and learning from gathered data how to minimize waste and thus save costs - Energy management and optimization is a new task
Why do you think does the majority of steel traders resist to approach Industrie 4.0?	- The overall industry is having an obsolete perspective on issues like Industrie 4.0 or digitalization -> Steel traders are caught in daily operations and miss out on going beyond that - Suelzle is one of the largest rebar steel traders in Germany with sufficient retained earnings and securities to afford such an investment. Further its portfolio is diversified enough to outbalance negative financial short-term effects.

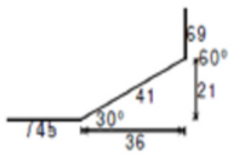
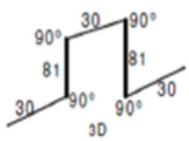
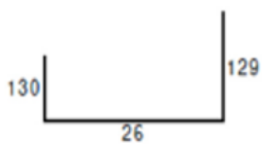
Appendix 11 – Pictures of bundled reinforcement steel bars and coils

Appendix 12 – Rebar price development according in USD (London Metal Exchange 2020)

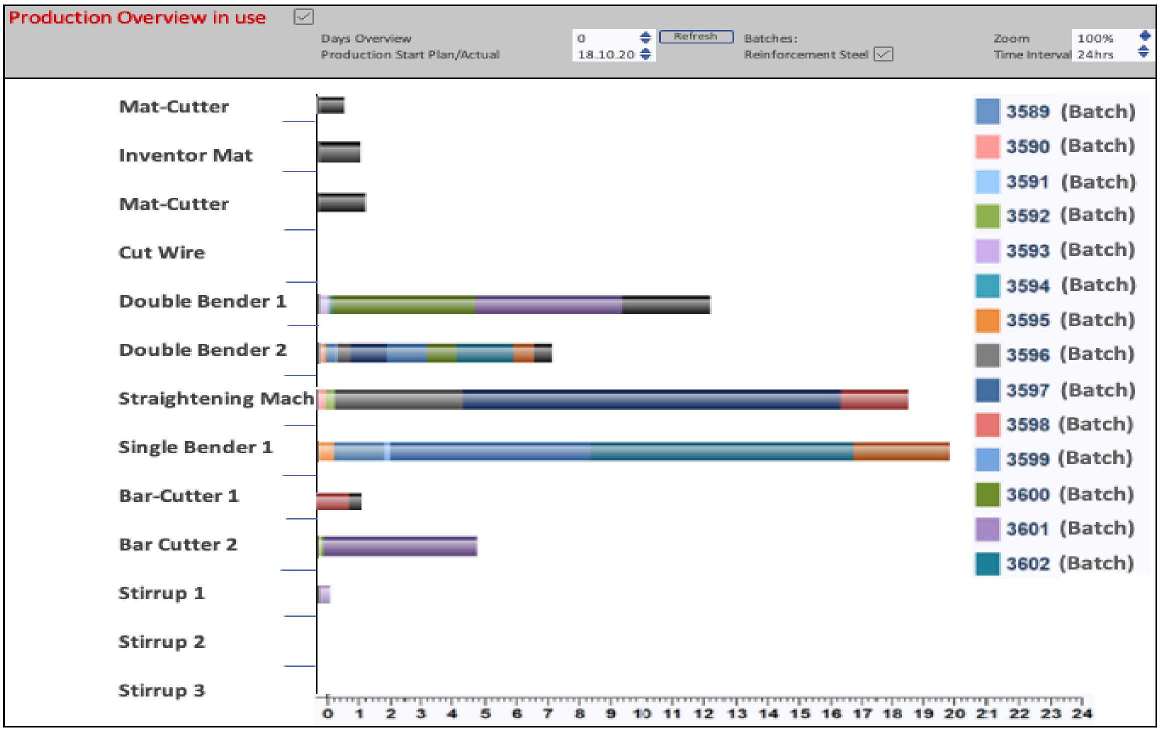
LME Steel Rebar

	Bid quantity	Bid price	Ask price	Ask quantity
Jun-19	2	469	474	2
Jul-19	1	468	472	1
Aug-19	2	468.5	472	5
Sep-19	1	470	471	2
Oct-19	1	470.5	471.5	2
Nov-19	1	468	469	1
Dec-19	1	464	465	1
Jan-20	2	459	461.5	1
Feb-20	4	455	457	2
Mar-20	2	454	456.5	2
Apr-20	2	454	455.5	1
May-20	3	450.5	454	1
Jun-20	1	451	454.5	2
Jul-20	2	445.5	454.5	2

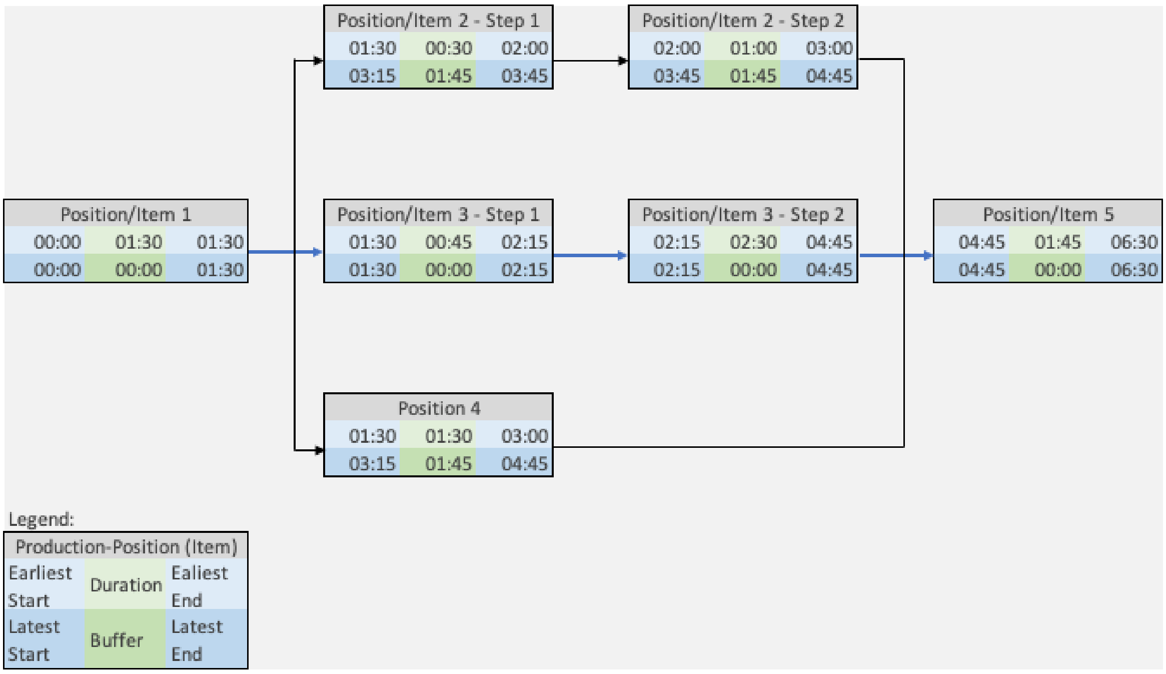
Appendix 13 – Typical bending list with different positions for bended steel bars (Own Representation based on interview with R1)

Factor: 1	Subplan: Sample Bending List			Date of Delivery: 20.10.20		Labelling Color: Blue		Commission:
Position	Quantity	Steel Type	Diameter (mm)	Lenght (m)	Total Length (m)	Weight (kg)	Bending form	Sketch
1	90	RSt500S	20	8,55	769,50	1900,67	229	
27	1325	RS500S	20	2,52	3339	8247,33	432	
29	556	RSt500S	10	2,85	1584,6	977,7	208	

Appendix 14 – Machine utilization and capacity schedule (Own Representation based on interview with R1)



Appendix 15 – Forward Calculation to define earliest start and end for the item processing (Own Representation based on interview with R1)



Appendix 16 – Process performance evaluation based on a set of customizable variables (Own Representation based on interview with R1)

ParameterSet	Combination1	Combination2	Combination3
1	Cuts: 1,69% - 189 pts.	Cuts: 1,53% - 153 pts.	Cuts: 7,08% - 708 pts.
	Cycles: 27 - 135 pts.	Cycles: 28 - 140 pts.	Cycles: 21 - 105 pts.
	Variations: 5 - 50 pts.	Variations: 6 - 60 pts.	Variations: 2 - 20 pts.
	Total: 354 pts.	Total: 3543 pts.	Total: 833 pts.
2	Cuts: 2,37% - 237 pts.	Cuts: 3,72% - 372 pts.	Cuts: 8,19% - 819 pts.
	Cycles: 24 - 120 pts.	Cycles: 22 - 110 pts.	Cycles: 19 - 95 pts.
	Variations: 4 - 40 pts.	Variations: 2 - 20 pts.	Variations: 2 - 20 pts.
	Total: 397 pts.	Total: 502 pts.	Total: 934 pts.
3	Cuts: 1,74% - 174 pts.	Cuts: 2,44% - 244 pts.	Cuts: 6,94% - 694 pts.
	Cycles: 26 - 130 pts.	Cycles: 24 - 120 pts.	Cycles: 22 - 110 pts.
	Variations: 6 - 60 pts.	Variations: 3 - 30 pts.	Variations: 4 - 40 pts.
	Total: 364 pts.	Total: 394 pts.	Total: 844 pts.

Appendix 17 – Three Scenarios: Risk development analysis for organizations considering an invest into industry 4.0. Considered dimensions include the common scale for gross margin volatility as well as labor costs. The red colored area indicates the ranges where the steel distributor generates negative income, thus implicit risk (Own representation)

Scenario (1) – Status Quo, no Investment in I4.0. Revenue remains at 10 million EUR – medium risk, reflecting the current situation with the constant risk of volatile commodity markets.

Gross Margin - Scenario 'Status Quo'

Labor Costs - Scenario 'Status Quo'

23.041	15,25%	15,50%	15,75%	16,00%	16,25%	16,50%	16,75%	17,00%	17,25%	17,50%	17,75%	18,00%	18,25%	18,50%	18,75%	19,00%	19,25%	19,50%	19,75%	20,00%	20,25%	20,50%	20,75%	21,00%	21,25%	21,50%
10,00%	162.290	187.329	212.367	237.406	262.445	287.484	312.522	337.561	362.600	387.639	412.677	437.716	462.755	487.794	512.832	537.871	562.910	587.949	612.987	638.026	663.065	688.104	713.142	738.181	763.220	788.258
10,25%	137.251	162.290	187.329	212.367	237.406	262.445	287.484	312.522	337.561	362.600	387.639	412.677	437.716	462.755	487.794	512.832	537.871	562.910	587.949	612.987	638.026	663.065	688.104	713.142	738.181	763.220
10,50%	112.212	137.251	162.290	187.329	212.367	237.406	262.445	287.484	312.522	337.561	362.600	387.639	412.677	437.716	462.755	487.794	512.832	537.871	562.910	587.949	612.987	638.026	663.065	688.104	713.142	738.181
10,75%	87.174	112.212	137.251	162.290	187.329	212.367	237.406	262.445	287.484	312.522	337.561	362.600	387.639	412.677	437.716	462.755	487.794	512.832	537.871	562.910	587.949	612.987	638.026	663.065	688.104	713.142
11,00%	62.135	87.174	112.212	137.251	162.290	187.329	212.367	237.406	262.445	287.484	312.522	337.561	362.600	387.639	412.677	437.716	462.755	487.794	512.832	537.871	562.910	587.949	612.987	638.026	663.065	688.104
11,25%	37.096	62.135	87.174	112.212	137.251	162.290	187.329	212.367	237.406	262.445	287.484	312.522	337.561	362.600	387.639	412.677	437.716	462.755	487.794	512.832	537.871	562.910	587.949	612.987	638.026	663.065
11,50%	12.057	37.096	62.135	87.174	112.212	137.251	162.290	187.329	212.367	237.406	262.445	287.484	312.522	337.561	362.600	387.639	412.677	437.716	462.755	487.794	512.832	537.871	562.910	587.949	612.987	638.026
11,75%	-12.981	12.057	37.096	62.135	87.174	112.212	137.251	162.290	187.329	212.367	237.406	262.445	287.484	312.522	337.561	362.600	387.639	412.677	437.716	462.755	487.794	512.832	537.871	562.910	587.949	612.987
12,00%	-38.020	-12.981	12.057	37.096	62.135	87.174	112.212	137.251	162.290	187.329	212.367	237.406	262.445	287.484	312.522	337.561	362.600	387.639	412.677	437.716	462.755	487.794	512.832	537.871	562.910	587.949
12,25%	-63.059	-38.020	-12.981	12.057	37.096	62.135	87.174	112.212	137.251	162.290	187.329	212.367	237.406	262.445	287.484	312.522	337.561	362.600	387.639	412.677	437.716	462.755	487.794	512.832	537.871	562.910
12,50%	-88.098	-63.059	-38.020	-12.981	12.057	37.096	62.135	87.174	112.212	137.251	162.290	187.329	212.367	237.406	262.445	287.484	312.522	337.561	362.600	387.639	412.677	437.716	462.755	487.794	512.832	537.871
12,75%	-113.136	-88.098	-63.059	-38.020	-12.981	12.057	37.096	62.135	87.174	112.212	137.251	162.290	187.329	212.367	237.406	262.445	287.484	312.522	337.561	362.600	387.639	412.677	437.716	462.755	487.794	512.832
13,00%	-138.175	-113.136	-88.098	-63.059	-38.020	-12.981	12.057	37.096	62.135	87.174	112.212	137.251	162.290	187.329	212.367	237.406	262.445	287.484	312.522	337.561	362.600	387.639	412.677	437.716	462.755	487.794
13,25%	-163.214	-138.175	-113.136	-88.098	-63.059	-38.020	-12.981	12.057	37.096	62.135	87.174	112.212	137.251	162.290	187.329	212.367	237.406	262.445	287.484	312.522	337.561	362.600	387.639	412.677	437.716	462.755
13,50%	-188.253	-163.214	-138.175	-113.136	-88.098	-63.059	-38.020	-12.981	12.057	37.096	62.135	87.174	112.212	137.251	162.290	187.329	212.367	237.406	262.445	287.484	312.522	337.561	362.600	387.639	412.677	437.716
13,75%	-213.291	-188.253	-163.214	-138.175	-113.136	-88.098	-63.059	-38.020	-12.981	12.057	37.096	62.135	87.174	112.212	137.251	162.290	187.329	212.367	237.406	262.445	287.484	312.522	337.561	362.600	387.639	412.677
14,00%	-238.330	-213.291	-188.253	-163.214	-138.175	-113.136	-88.098	-63.059	-38.020	-12.981	12.057	37.096	62.135	87.174	112.212	137.251	162.290	187.329	212.367	237.406	262.445	287.484	312.522	337.561	362.600	387.639
14,25%	-263.369	-238.330	-213.291	-188.253	-163.214	-138.175	-113.136	-88.098	-63.059	-38.020	-12.981	12.057	37.096	62.135	87.174	112.212	137.251	162.290	187.329	212.367	237.406	262.445	287.484	312.522	337.561	362.600
14,50%	-288.407	-263.369	-238.330	-213.291	-188.253	-163.214	-138.175	-113.136	-88.098	-63.059	-38.020	-12.981	12.057	37.096	62.135	87.174	112.212	137.251	162.290	187.329	212.367	237.406	262.445	287.484	312.522	337.561
14,75%	-313.446	-288.407	-263.369	-238.330	-213.291	-188.253	-163.214	-138.175	-113.136	-88.098	-63.059	-38.020	-12.981	12.057	37.096	62.135	87.174	112.212	137.251	162.290	187.329	212.367	237.406	262.445	287.484	312.522
15,00%	-338.485	-313.446	-288.407	-263.369	-238.330	-213.291	-188.253	-163.214	-138.175	-113.136	-88.098	-63.059	-38.020	-12.981	12.057	37.096	62.135	87.174	112.212	137.251	162.290	187.329	212.367	237.406	262.445	287.484
15,25%	-363.524	-338.485	-313.446	-288.407	-263.369	-238.330	-213.291	-188.253	-163.214	-138.175	-113.136	-88.098	-63.059	-38.020	-12.981	12.057	37.096	62.135	87.174	112.212	137.251	162.290	187.329	212.367	237.406	262.445
15,50%	-388.562	-363.524	-338.485	-313.446	-288.407	-263.369	-238.330	-213.291	-188.253	-163.214	-138.175	-113.136	-88.098	-63.059	-38.020	-12.981	12.057	37.096	62.135	87.174	112.212	137.251	162.290	187.329	212.367	237.406
15,75%	-413.601	-388.562	-363.524	-338.485	-313.446	-288.407	-263.369	-238.330	-213.291	-188.253	-163.214	-138.175	-113.136	-88.098	-63.059	-38.020	-12.981	12.057	37.096	62.135	87.174	112.212	137.251	162.290	187.329	212.367
16,00%	-438.640	-413.601	-388.562	-363.524	-338.485	-313.446	-288.407	-263.369	-238.330	-213.291	-188.253	-163.214	-138.175	-113.136	-88.098	-63.059	-38.020	-12.981	12.057	37.096	62.135	87.174	112.212	137.251	162.290	187.329
16,25%	-463.679	-438.640	-413.601	-388.562	-363.524	-338.485	-313.446	-288.407	-263.369	-238.330	-213.291	-188.253	-163.214	-138.175	-113.136	-88.098	-63.059	-38.020	-12.981	12.057	37.096	62.135	87.174	112.212	137.251	162.290
16,50%	-488.717	-463.679	-438.640	-413.601	-388.562	-363.524	-338.485	-313.446	-288.407	-263.369	-238.330	-213.291	-188.253	-163.214	-138.175	-113.136	-88.098	-63.059	-38.020	-12.981	12.057	37.096	62.135	87.174	112.212	137.251
16,75%	-513.756	-488.717	-463.679	-438.640	-413.601	-388.562	-363.524	-338.485	-313.446	-288.407	-263.369	-238.330	-213.291	-188.253	-163.214	-138.175	-113.136	-88.098	-63.059	-38.020	-12.981	12.057	37.096	62.135	87.174	112.212
17,00%	-538.795	-513.756	-488.717	-463.679	-438.640	-413.601	-388.562	-363.524	-338.485	-313.446	-288.407	-263.369	-238.330	-213.291	-188.253	-163.214	-138.175	-113.136	-88.098	-63.059	-38.020	-12.981	12.057	37.096	62.135	87.174

Scenario (2) – Multi-million investment in I4.0 and no revenue growth – stagnate at 10 million EUR – high risk, due to the strong growth of interest and depreciation expenses.

Gross Margin - Scenario 'Expansion I'

Labor Costs - Scenario 'Expansion I'

-79.202	15,25%	15,50%	15,75%	16,00%	16,25%	16,50%	16,75%	17,00%	17,25%	17,50%	17,75%	18,00%	18,25%	18,50%	18,75%	19,00%	19,25%	19,50%	19,75%	20,00%	20,25%	20,50%	20,75%	21,00%	21,25%	21,50%
10,25%	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318	-129.279	-104.241	-79.202	-54.163	-29.124	-4.086	20.953	45.992	71.030	96.069	121.108	146.147	171.185	196.224	221.263	246.302	271.340	296.379	321.418	346.457
10,50%	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318	-129.279	-104.241	-79.202	-54.163	-29.124	-4.086	20.953	45.992	71.030	96.069	121.108	146.147	171.185	196.224	221.263	246.302	271.340	296.379	321.418
10,75%	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318	-129.279	-104.241	-79.202	-54.163	-29.124	-4.086	20.953	45.992	71.030	96.069	121.108	146.147	171.185	196.224	221.263	246.302	271.340	296.379
11,00%	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318	-129.279	-104.241	-79.202	-54.163	-29.124	-4.086	20.953	45.992	71.030	96.069	121.108	146.147	171.185	196.224	221.263	246.302	271.340
11,25%	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318	-129.279	-104.241	-79.202	-54.163	-29.124	-4.086	20.953	45.992	71.030	96.069	121.108	146.147	171.185	196.224	221.263	246.302
11,50%	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318	-129.279	-104.241	-79.202	-54.163	-29.124	-4.086	20.953	45.992	71.030	96.069	121.108	146.147	171.185	196.224	221.263
11,75%	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318	-129.279	-104.241	-79.202	-54.163	-29.124	-4.086	20.953	45.992	71.030	96.069	121.108	146.147	171.185	196.224
12,00%	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318	-129.279	-104.241	-79.202	-54.163	-29.124	-4.086	20.953	45.992	71.030	96.069	121.108	146.147	171.185
12,25%	-479.822	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318	-129.279	-104.241	-79.202	-54.163	-29.124	-4.086	20.953	45.992	71.030	96.069	121.108	146.147
12,50%	-504.861	-479.822	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318	-129.279	-104.241	-79.202	-54.163	-29.124	-4.086	20.953	45.992	71.030	96.069	121.108
12,75%	-529.899	-504.861	-479.822	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318	-129.279	-104.241	-79.202	-54.163	-29.124	-4.086	20.953	45.992	71.030	96.069
13,00%	-554.938	-529.899	-504.861	-479.822	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318	-129.279	-104.241	-79.202	-54.163	-29.124	-4.086	20.953	45.992	71.030
13,25%	-579.977	-554.938	-529.899	-504.861	-479.822	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318	-129.279	-104.241	-79.202	-54.163	-29.124	-4.086	20.953	45.992
13,50%	-605.016	-579.977	-554.938	-529.899	-504.861	-479.822	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318	-129.279	-104.241	-79.202	-54.163	-29.124	-4.086	20.953
13,75%	-630.054	-605.016	-579.977	-554.938	-529.899	-504.861	-479.822	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318	-129.279	-104.241	-79.202	-54.163	-29.124	-4.086
14,00%	-655.093	-630.054	-605.016	-579.977	-554.938	-529.899	-504.861	-479.822	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318	-129.279	-104.241	-79.202	-54.163	-29.124
14,25%	-680.132	-655.093	-630.054	-605.016	-579.977	-554.938	-529.899	-504.861	-479.822	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318	-129.279	-104.241	-79.202	-54.163
14,50%	-705.171	-680.132	-655.093	-630.054	-605.016	-579.977	-554.938	-529.899	-504.861	-479.822	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318	-129.279	-104.241	-79.202
14,75%	-730.209	-705.171	-680.132	-655.093	-630.054	-605.016	-579.977	-554.938	-529.899	-504.861	-479.822	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318	-129.279	-104.241
15,00%	-755.248	-730.209	-705.171	-680.132	-655.093	-630.054	-605.016	-579.977	-554.938	-529.899	-504.861	-479.822	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318	-129.279
15,25%	-780.287	-755.248	-730.209	-705.171	-680.132	-655.093	-630.054	-605.016	-579.977	-554.938	-529.899	-504.861	-479.822	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357	-154.318
15,50%	-805.326	-780.287	-755.248	-730.209	-705.171	-680.132	-655.093	-630.054	-605.016	-579.977	-554.938	-529.899	-504.861	-479.822	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396	-179.357
15,75%	-830.364	-805.326	-780.287	-755.248	-730.209	-705.171	-680.132	-655.093	-630.054	-605.016	-579.977	-554.938	-529.899	-504.861	-479.822	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434	-204.396
16,00%	-855.403	-830.364	-805.326	-780.287	-755.248	-730.209	-705.171	-680.132	-655.093	-630.054	-605.016	-579.977	-554.938	-529.899	-504.861	-479.822	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473	-229.434
16,25%	-880.442	-855.403	-830.364	-805.326	-780.287	-755.248	-730.209	-705.171	-680.132	-655.093	-630.054	-605.016	-579.977	-554.938	-529.899	-504.861	-479.822	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512	-254.473
16,50%	-905.481	-880.442	-855.403	-830.364	-805.326	-780.287	-755.248	-730.209	-705.171	-680.132	-655.093	-630.054	-605.016	-579.977	-554.938	-529.899	-504.861	-479.822	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551	-279.512
16,75%	-930.519	-905.481	-880.442	-855.403	-830.364	-805.326	-780.287	-755.248	-730.209	-705.171	-680.132	-655.093	-630.054	-605.016	-579.977	-554.938	-529.899	-504.861	-479.822	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589	-304.551
17,00%	-955.558	-930.519	-905.481	-880.442	-855.403	-830.364	-805.326	-780.287	-755.248	-730.209	-705.171	-680.132	-655.093	-630.054	-605.016	-579.977	-554.938	-529.899	-504.861	-479.822	-454.783	-429.744	-404.706	-379.667	-354.628	-329.589

Scenario (3) – Multi million investment in I4.0, and triple revenue from 10 to 30 million EUR – low risk, due to the outbalance of depreciation and interest by the additional revenues.

Gross Margin - Scenario 'Expansion II'

Labor Costs - Scenario 'Expansion II'

1.277.494	15,25%	15,50%	15,75%	16,00%	16,25%	16,50%	16,75%	17,00%	17,25%	17,50%	17,75%	18,00%	18,25%	18,50%	18,75%	19,00%	19,25%	19,50%	19,75%	20,00%	20,25%	20,50%	20,75%	21,00%	21,25%	21,50%
10,25%	776.719	839.316	901.912	964.509	1.027.106	1.089.703	1.152.300	1.214.897	1.277.494	1.340.090	1.402.687	1.465.284	1.527.881	1.590.478	1.653.075	1.715.672	1.778.268	1.840.865	1.903.462	1.966.059	2.028.656	2.091.253	2.153.850	2.216.446	2.279.043	2.341.640
10,50%	714.122	776.719	839.316	901.912	964.509	1.027.106	1.089.703	1.152.300	1.214.897	1.277.494	1.340.090	1.402.687	1.465.284	1.527.881	1.590.478	1.653.075	1.715.672	1.778.268	1.840.865	1.903.462	1.966.059	2.028.656	2.091.253	2.153.850	2.216.446	2.279.043
10,75%	651.525	714.122	776.719	839.316	901.912	964.509	1.027.106	1.089.703	1.152.300	1.214.897	1.277.494	1.340.090	1.402.687	1.465.284	1.527.881	1.590.478	1.653.075	1.715.672	1.778.268	1.840.865	1.903.462	1.966.059	2.028.656	2.091.253	2.153.850	2.216.446
11,00%	588.928	651.525	714.122	776.719	839.316	901.912	964.509	1.027.106	1.089.703	1.152.300	1.214.897	1.277.494	1.340.090	1.402.687	1.465.284	1.527.881	1.590.478	1.653.075	1.715.672	1.778.268	1.840.865	1.903.462	1.966.059	2.028.656	2.091.253	2.153.850
11,25%	526.331	588.928	651.525	714.122	776.719	839.316	901.912	964.509	1.027.106	1.089.703	1.152.300	1.214.897	1.277.494	1.340.090	1.402.687	1.465.284	1.527.881	1.590.478	1.653.075	1.715.672	1.778.268	1.840.865	1.903.462	1.966.059	2.028.656	2.091.253
11,50%	463.734	526.331	588.928	651.525	714.122	776.719	839.316	901.912	964.509	1.027.106	1.089.703	1.152.300	1.214.897	1.277.494	1.340.090	1.402.687	1.465.284	1.527.881	1.590.478	1.653.075	1.715.672	1.778.268	1.840.865	1.903.462	1.966.059	2.028.656
11,75%	401.138	463.734	526.331	588.928	651.525	714.122	776.719	839.316	901.912	964.509	1.027.106	1.089.703	1.152.300	1.214.897	1.277.494	1.340.090	1.402.687	1.465.284	1.527.881	1.590.478	1.653.075	1.715.672	1.778.268	1.840.865	1.903.462	1.966.059
12,00%	338.541	401.138	463.734	526.331	588.928	651.525	714.122	776.719	839.316	901.912	964.509	1.027.106	1.089.703	1.152.300	1.214.897	1.277.494	1.340.090	1.402.687	1.465.284	1.527.881	1.590.478	1.653.075	1.715.672	1.778.268	1.840.865	1.903.462
12,25%	275.944	338.541	401.138	463.734	526.331	588.928	651.525	714.122	776.719	839.316	901.912	964.509	1.027.106	1.089.703	1.152.300	1.214.897	1.277.494	1.340.090	1.402.687	1.465.284	1.527.881	1.590.478	1.653.075	1.715.672	1.778.268	1.840.865
12,50%	213.347	275.944	338.541	401.138	463.734	526.331	588.928	651.525	714.122	776.719	839.316	901.912	964.509	1.027.106	1.089.703	1.152.300	1.214.897	1.277.494	1.340.090	1.402.687	1.465.284	1.527.881	1.590.478	1.653.075	1.715.672	1.778.268
12,75%	150.750	213.347	275.944	338.541	401.138	463.734	526.331	588.928	651.525	714.122	776.719	839.316	901.912	964.509	1.027.106	1.089.703	1.152.300	1.214.897	1.277.494	1.340.090	1.402.687	1.465.284	1.527.881	1.590.478	1.653.075	1.715.672
13,00%	88.153	150.750	213.347	275.944	338.541	401.138	463.734	526.331	588.928	651.525	714.122	776.719	839.316	901.912	964.509	1.027.106	1.089.703	1.152.300	1.214.897	1.277.494	1.340.090	1.402.687	1.465.284	1.527.881	1.590.478	1.653.075
13,25%	25.556	88.153	150.750	213.347	275.944	338.541	401.138	463.734	526.331	588.928	651.525	714.122	776.719	839.316	901.912	964.509	1.027.106	1.089.703	1.152.300	1.214.897	1.277.494	1.340.090	1.402.687	1.465.284	1.527.881	1.590.478
13,50%	-37.040	25.556	88.153	150.750	213.347	275.944	338.541	401.138	463.734	526.331	588.928	651.525	714.122	776.719	839.316	901.912	964.509	1.027.106	1.089.703	1.152.300	1.214.897	1.277.494	1.340.090	1.402.687	1.465.284	1.527.881
13,75%	-99.637	-37.040	25.556	88.153	150.750	213.347	275.944	338.541	401.138	463.734	526.331	588.928	651.525	714.122	776.719	839.316	901.912	964.509	1.027.106	1.089.703	1.152.300	1.214.897	1.277.494	1.340.090	1.402.687	1.465.284
14,00%	-162.234	-99.637	-37.040	25.556	88.153	150.750	213.347	275.944	338.541	401.138	463.734	526.331	588.928	651.525	714.122	776.719	839.316	901.912	964.509	1.027.106	1.089.703	1.152.300	1.214.897	1.277.494	1.340.090	1.402.687
14,25%	-224.831	-162.234	-99.637	-37.040	25.556	88.153	150.750	213.347	275.944	338.541	401.138	463.734	526.331	588.928	651.525	714.122	776.719	839.316	901.912	964.509	1.027.106	1.089.703	1.152.300	1.214.897	1.277.494	1.340.090
14,50%	-287.428	-224.831	-162.234	-99.637	-37.040	25.556	88.153	150.750	213.347	275.944	338.541	401.138	463.734	526.331	588.928	651.525	714.122	776.719	839.316	901.912	964.509	1.027.106	1.089.703	1.152.300	1.214.897	1.277.494
14,75%	-350.025	-287.428	-224.831	-162.234	-99.637	-37.040	25.556	88.153	150.750	213.347	275.944	338.541	401.138	463.734	526.331	588.928	651.525	714.122	776.719	839.316	901.912	964.509	1.027.106	1.089.703	1.152.300	1.214.897
15,00%	-412.622	-350.025	-287.428	-224.831	-162.234	-99.637	-37.040	25.556	88.153	150.750	213.347	275.944	338.541	401.138	463.734	526.331	588.928	651.525	714.122	776.719	839.316	901.912	964.509	1.027.106	1.089.703	1.152.300
15,25%	-475.219	-412.622	-350.025	-287.428	-224.831	-162.234	-99.637	-37.040	25.556	88.153	150.750	213.347	275.944	338.541	401.138	463.734	526.331	588.928	651.525	714.122	776.719	839.316	901.912	964.509	1.027.106	1.089.703
15,50%	-537.815	-475.219	-412.622	-350.025	-287.428	-224.831	-162.234	-99.637	-37.040	25.556	88.153	150.750	213.347	275.944	338.541	401.138	463.734	526.331	588.928	651.525	714.122	776.719	839.316	901.912	964.509	1.027.106
15,75%	-600.412	-537.815	-475.219	-412.622	-350.025	-287.428	-224.831	-162.234	-99.637	-37.040	25.556	88.153	150.750	213.347	275.944	338.541	401.138	463.734	526.331	588.928	651.525	714.122	776.719	839.316	901.912	964.509
16,00%	-663.009	-600.412	-537.815	-475.219	-412.622	-350.025	-287.428	-224.831	-162.234	-99.637	-37.040	25.556	88.153	150.750	213.347	275.944	338.541	401.138	463.734	526.331	588.928	651.525	714.122	776.719	839.316	901.912
16,25%	-725.606	-663.009	-600.412	-537.815	-475.219	-412.622	-350.025	-287.428	-224.831	-162.234	-99.637	-37.040	25.556	88.153	150.750	213.347	275.944	338.541	401.138	463.734	526.331	588.928	651.525	714.122	776.719	839.316
16,50%	-788.203	-725.606	-663.009	-600.412	-537.815	-475.219	-412.622	-350.025	-287.428	-224.831	-162.234	-99.637	-37.040	25.556	88.153	150.750	213.347	275.944	338.541	401.138	463.734	526.331	588.928	651.525	714.122	776.719
16,75%	-850.800	-788.203	-725.606	-663.009	-600.412	-537.815	-475.219	-412.622	-350.025	-287.428	-224.831	-162.234	-99.637	-37.040	25.556	88.153	150.750	213.347	275.944	338.541	401.138	463.734	526.331	588.928	651.525	714.122
17,00%	-913.397	-850.800	-788.203	-725.606	-663.009	-600.412	-537.815	-475.219	-412.622	-350.025	-287.428	-224.831	-162.234	-99.637	-37.040	25.556	88.153	150.750	213.347	275.944	338.541	401.138	463.734	526.331	588.928	651.525

9 Declaration of Authorship

I herewith formally declare that I, Kai Lehmann, have written the submitted thesis independently. I did not use any outside support except for the quoted literature and other sources mentioned in the paper. I clearly marked and separately listed all of the literature and all of the other sources which I employed when producing this academic work, either literally or in content. This thesis has not been handed in or published before in the same or similar form.

Datum / Date: Unterschrift/Signature:

__31.12.2020________ k.lehmann