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Design and Evaluation of a Blue Ocean Strategy for an Open-Core IIoT Platform Provider in the Manufacturing Sector

Master Thesis

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

AGPL	affero general public license
API	application programming interface
B2B	business to business
B2C	business to customer
CNC	computer numerical control
DCC	Digital Capability Center
DHCP	dynamic host configuration protocol
ERP	enterprise resource planning
GDP	gross domestic product
GDPR	general data protection regulation (DSGVO: Datenschutzgrundverordnung)
H1…4	hypothesis 1 to 4
HMI	human machine interface
I	interviewer
IIoT	industrial internet of things
IP	intellectual property
IP	internet protocol
IT	information technology
KPI	key performance indicator
MaaS	manufacturing as a service
MES	manufacturing execution system
MQTT	message queuing telemetry transport

MSP	multi-sided platform
MVP	minimum viable product
OEE	overall equipment effectiveness
OPC UA	open platform communications unified architecture
OT	operational technology
PLC	programmable logic controller
PQ	primary research question
Q1…10	question (on the preparatory questionnaire) 1 to 10
R1…8	respondent 1 to 8
R&D	research and development
REST	representational state transfer
RWTH	Rheinisch-Westfälische Technische Hochschule (Aachen)
SaaS	software as a service
SDK	software development kit
SEO	search engine optimization
SME	small and medium-sized enterprise
SQ1…3	sub-research question 1 to 3
TIM	(Institute for) Technology and Innovation Management
UMH	United Manufacturing Hub
USP	unique selling point
VDMA	Verband Deutscher Maschinen- und Anlagenbauer (German Engineering Federation)

1 Introduction and Motivation

The ongoing trend of digitization does not exclude the manufacturing sector which poses challenges for both involved parties: machine manufacturers and producing companies. While larger corporations and certain industries, such as the automotive industry, may be already well advanced in digitization, small and medium-sized enterprises (SMEs) often still face difficulties. For many producing companies, the added value of digitization is unclear and they also have strong security concerns about making their data available for analyses. On the other hand, machine manufacturers face problems in their transformation from hardware manufacturers to service providers (Bitkom Research & Ernst & Young 2018, p. 21; VDMA & McKinsey 2020, p. 22; Vargo & Lusch 2008, p. 254ff). Due to these difficulties and the currently high implementation costs, IIoT (industrial internet of things) platforms have so far been deployed rather sporadically. However, they can offer great potential for optimization, for example of service processes or the overall equipment effectiveness (OEE) and will play an important role in maintaining competitiveness in the future (VDMA & McKinsey 2020, p. 27ff).

For this reason, more and more startups and third-party providers are currently establishing businesses that are trying to solve the challenges and problems of both sides with a wide variety of approaches. Currently, the market is quite opaque, which makes it difficult to compare providers on the market and thus to compete. This thesis is written in cooperation with the Aachen-based startup developing the IIoT platform “United Manufacturing Hub” (UMH; UMH Systems GmbH). Its objective is to set UMH apart from the existing red-ocean market with the development of a blue ocean strategy. By redistributing the development focus to attributes that are most relevant to customers in the market and reducing efforts in less relevant areas, the goal is to create a new, non-competitive market (Kim & Mauborgne 2015, p. 24ff). UMH has set itself the task of making the digital transformation as easy as possible for machine manufacturers and producing companies as their end customers. To do this, it is important to know the needs and problems of the customers and to obtain their assessment of the solution approaches. As a starting point for market analysis, this thesis focuses on machine manufacturers as customers of the platform.

The research question is divided into sub-questions, which together contribute to answering the primary question (Karmasin & Ribing 2017, p. 24f). While the topic is elaborated on the example of UMH, the underlying questions can be generalized and are not sufficiently addressed in the existing literature. The concepts further described in chapter 2 provide useful insights into IIoT, open-source platforms, as well as blue ocean strategies, but there is limited literature on the linkages between those topics (e.g., Frank et al. 2019; p. 341ff; Shafiq et al. 2018, p. 1076ff) and none describing a blue ocean strategy in an IIoT platform context. Therefore, the primary research question (PQ) is:

PQ: *Which blue ocean strategy has the best potential to set industry standards and establish an IIoT platform in the manufacturing sector?*

Currently, most machine manufacturers rely on in-house developed IIoT platforms (Bender et al. 2020, p. 10f), although using an external platform would reduce duplication costs and provide access to existing applications and customers (Evans & Schmalensee 2008, p. 673). This suggests that currently available external IIoT platforms do not sufficiently cover customer needs. To better understand machine manufacturers' needs and their motivation, the first sub-question (SQ) is therefore:

SQ1: *What functionalities do the manufacturers' platforms include and how were they implemented? Why have machine manufacturers decided to develop their own platform?*

The four actions framework in the blue ocean literature suggests that product attributes need to be raised or created to increase the customer value and create new demand while others are reduced or eliminated to achieve cost leadership (Kim & Mauborgne 2015, p. 51). To assess and extend UMH's solution approaches, the second sub-question is:

SQ2: *What functions or features are currently missing from existing platforms on the market? Which attributes must be raised to fulfill the desired customer benefits?*

Finally, making the core of the software stack open source is a relevant part of UMH's disruptive business model. Open source reduces costs and dependence and promotes among other things value creation. Dedrick and West (2004, p. 5f) found that the perceived reliability of Linux-operated servers was lower than that of servers with a proprietary operating system, which could also be the case for an open-source IIoT platform. To examine the effects of the open-source approach the third sub-question is:

SQ3: *How does an open-source approach affect the value curve and how is it perceived by machine manufacturers?*

To answer these research questions, this thesis first reviews the state of research on digitization and IIoT, platforms, and technology adoption of a market. Next, UMH and its open-core concept are presented based on an implemented proof of concept at the Digital Capability Center (DCC) Aachen. UMH's competitors are then clustered into infrastructure providers, proprietary IIoT platforms, and system integrators, for which value curves are generated that show the current focus of the providers on the market. Hypotheses are formulated about the requirements of the IIoT market based on the literature, a conversation with Bender and Lewandowski (2021; authors of the underlying paper Bender et al. 2020), and an existing market research by UMH (2020). The hypotheses facilitate the preparation of the three-part interview guideline, each dedicated to answering one sub-question. Finally, the interviews with eight development managers at machine manufacturing companies are evaluated. Based on the findings, the hypotheses are assessed and the blue ocean strategy for UMH open core and premium is derived, thus answering the primary research question.

2 Current State of Research

In this chapter, an overview of the current state of research is given. Chapter 2.1 introduces the theoretical backgrounds of digitization in the manufacturing sector and chapter 2.2 introduces selected concepts of multi-sided platforms (MSPs) and open-source platforms. Chapter 2.3 elaborates technology adoption in a market.

2.1 Digitization of Machine Manufacturers and Producing Companies

As this thesis investigates the digital platform market between machine manufacturers and producing companies, the process, and difficulties of digitization for both parties are elaborated in the following. Chapter 2.1.1 shows how machines are becoming smart due to digitization, while chapter 2.1.2 gives an overview of the digital transformation of producing companies using those connected machines.

2.1.1 Machine Manufacturers and Smart Machines

Information technology (IT) and digitization dramatically reshaped companies and their offering in the past sixty years. The introduction of computers increased the efficiency of internal workstreams, while the internet eased the coordination of processes inside the company as well as with external suppliers and customers regardless of their location. The current wave of digitization concerns the products directly, extending the hardware by smart components such as sensors, data storage, and connectivity components like network ports and communication protocols (Porter & Heppelmann 2014, p. 4f).

As Figure 1 shows, there is a clear trend towards digitization in machine manufacturing companies (Ernst & Young 2019, p. 15; Bender et al. 2020, p. 2ff). In 2019, more than 80 % of the 205 machine manufacturers surveyed by Ernst & Young (2019, p. 15) stated that digitization plays a medium to large role in their company.

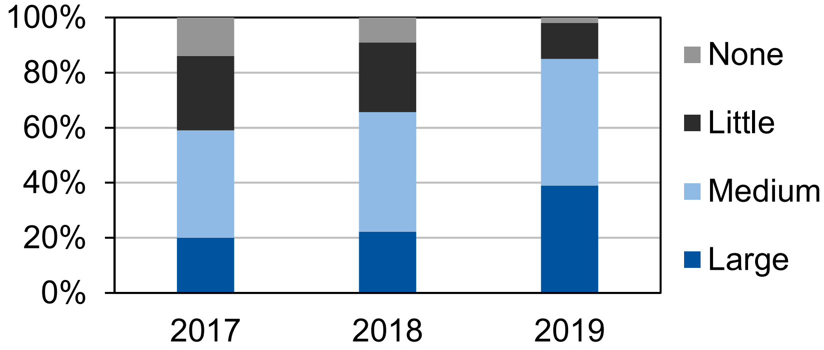

Figure 1: Role of digitization for machine manufacturers in recent years (acc. to Ernst & Young 2019, p. 15)

The additional sensors and connectivity components allow machines to exactly know their status and to communicate with each other and their operators, which is referred to as IIoT. The increased functionality and usability allow flexible, efficient, and adaptable production and logistic systems which may deal with volatile markets, short innovation cycles, mass customization, and intensified competition caused by globalization. The vision is to have self-controlling orders through the entire value chain and automatic rescheduling of production when a defect is forecast. However, control applications at the field level with the associated reliability and limited response time are not provided yet. The fourth industrial revolution (industry 4.0) merges IIoT with cyber-physical production systems, which in turn is a combination of IT and OT (operational technology; Bauer et al. 2014, p. 18ff; Bauernhansl 2014, p. 14ff; Dais 2014, p. 630; Modrák & Šoltysová 2020, p. 215ff; Porter & Heppelmann 2014, p. 7ff; Sisinni et al. 2018, p. 6; Spath et al. 2013, p. 67ff; Wollschlaeger, Sauter & Jasperneite 2017, p. 18).

Since this thesis deals with machines as products of machine manufacturers, in contrast to Porter and Heppelmann (2014, p. 7ff), specifically digitized machines will be mentioned in the following explanations instead of smart products for better comprehensibility. There are four dimensions of digital capabilities of smart machines, which are based on the previous ones: The most elementary one is monitoring, which includes the collection of data about the machine’s condition, environment, and usage via sensors and external sources. In combination with control software, this data can be used to control machine functions in the next step. Thirdly, machine performance can be optimized and predictive maintenance can be enabled through algorithms and machine learning. The most advanced step is autonomy, which allows the machine to operate and improve itself as well as to coordinate operations with other machines and systems. Human operators can work remotely and only keep an eye on the performance of the whole machine park (Porter & Heppelmann 2014, p. 7ff; Sisinni et al. 2018, p. 14). A case study conducted by Pauli and Lin (2019, p. 3ff) finds that only 25 % of the applications and use cases of a European IIoT platform went beyond the monitoring state and none could automate operations in 2019. This shows that the digitization of machines is still in a very early stage.

Digitization makes the comparison in the machine manufacturing market more complex and helps new players to emerge, as it no longer takes place at the machine level but at the system level. It is now more important, how well machines can complement each other and be integrated into a factory completing the whole task, than how well they can fulfill their subtasks. This changes the structure and widens the borders of the machine manufacturing industry, forcing companies to build knowledge in new areas such as IT, or to adapt their business models e.g., by offering new after-sales services to remain competitive (Ehret & Wirtz 2017, p. 1ff; Porter & Heppelmann 2015, p. 7ff; Schuh et al. 2020, p. 5ff).

The trend of adding value to a company's core offerings through services or even transforming a manufacturer's business model from being product sales-based to service-centric is called servitization (Raddats et al. 2019, p. 207, Vandermerwe & Rada 1988, p. 314ff; Vargo & Lusch 2008, p. 254ff). IIoT and servitization are closely linked, as the data acquired do not deliver any added value without innovative services (Bender, Habib & Gronau 2021, p. 72; Klein, Pacheco, Righi 2017, p. 443; VDMA, Deutsche Messe & Roland Berger 2018, p. 6).

An example based on self-directed orders are "manufacturing as a service" (MaaS) business models, which transform machine manufacturers from hardware suppliers into providers of a production platform. This enables products of different brands to be manufactured in decentral, local factories run by the machine manufacturers themselves, which can be easily changed over to specific customer needs. Technological trends such as IIoT or additive manufacturing and economic trends such as the financial burden of the Corona crisis and the resulting need for robust, local supply chains make such innovative business models increasingly attractive (Endres et al. 2019, p. 8ff; Kohtamäki et al. 2019, p. 390f; Piller 2020, p. 3f; VDMA et al. 2018, p. 9f).

Figure 2 shows challenges in implementing digital platforms and applications for Western European machine manufacturers (VDMA & McKinsey 2020, p. 22) and German and Swiss SMEs (< 500 employees) in the producing sector (Bitkom Research & Ernst & Young 2018, p. 21). Similar results emerged in qualitative interviews conducted by the author and colleagues at UMH before the preparation of this thesis (UMH 2020).

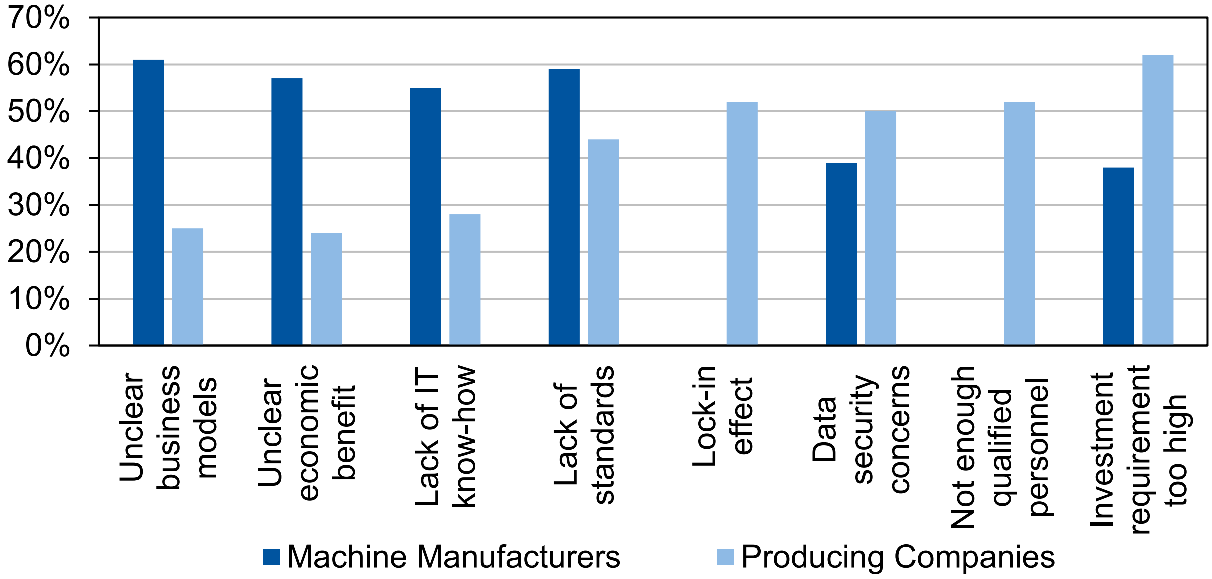

Figure 2: Obstacles to the implementation of digital applications in producing companies and at machine manufacturers (acc. to Bitkom Research & Ernst & Young 2018, p. 21; VDMA & McKinsey 2020, p. 22)

Remarkably, the challenges perceived as most difficult by machine manufacturers tend to be less critical for producing companies and vice versa. The challenges for producing companies are further discussed in chapter 2.1.2. For machine manufacturers, the main concerns are the lack of adapted business models and low prioritization of the topic's strategic relevance. Further points often mentioned are the lack of IT expertise and missing standardization in the market. Less important to machine manufacturers are concerns of losing proprietary process knowledge to competitors or customers and the lack of financial resources (VDMA & McKinsey 2020, p. 22f; Bender et al. 2021, p. 74; UMH 2020).

2.1.2 Transformation of Producing Companies towards Industry 4.0

The digital transformation of producing companies as customers of machine manufacturers is an important part of this thesis. Studies expect the gross value added in the producing sector to be lifted between 0.25 % (Auer 2018, p. 8) and 1 % (Roland Berger 2015, p. 7) due to digitalization in Germany until 2025. This is equivalent to up to 13 % of the German gross domestic product (GDP) in 2020 (Federal Statistical Office 2021) which shows the importance and chances connected to this topic. The increased demand for automation and digitization due to the Corona crisis could even boost these figures (Piller 2020, p. 2; VDMA & McKinsey 2020, p. 10).

The desired main benefits of digital applications are increased machine and cost efficiency, but also remote monitoring, support, and installation including augmented reality applications. Producing companies are willing to invest in digitization if the application brings clear, immediate, and quantifiable improvements. Manufacturer independence and user-friendliness of the applications are also important, as the risk is high that the costs of training or errors exceed the added value (VDMA & McKinsey 2020, p. 31ff).

Schuh et al. (2017 p. 5ff) introduced and revised (Schuh et al. 2020 p. 5ff) the industry 4.0 maturity index, which provides producing companies with a guideline for digitization. Therefore, it gives a good overview of the requirements and components of an industry 4.0 ready production and is introduced in the following. Apart from the technological changes, the most important factor is increasing the agility of a company, e.g., enable it to quickly respond to new market requirements. The index is based on six (technology and agility) stages that build on the previous ones. While the first two stages are requirements, the next four are advanced industry 4.0 capabilities as shown in Figure 3. The extent to which it is feasible to implement these stages varies for each company and should be evaluated at the beginning of the transformation process.

The most basic requirement for industry 4.0 is computerization. Here, different computer systems (like a computer numerical control [CNC] milling machine) are used in isolation, which is currently the case for most companies. Companies are divided into separate working departments held together by the management which is also responsible for changes and innovation. In the connectivity stage, the IT- and OT- of the core business processes are connected, but there is no full integration of all systems. Companies in the second stage are willing to adopt changes, but the used traditional project management methods are too inert for agile adjustments.

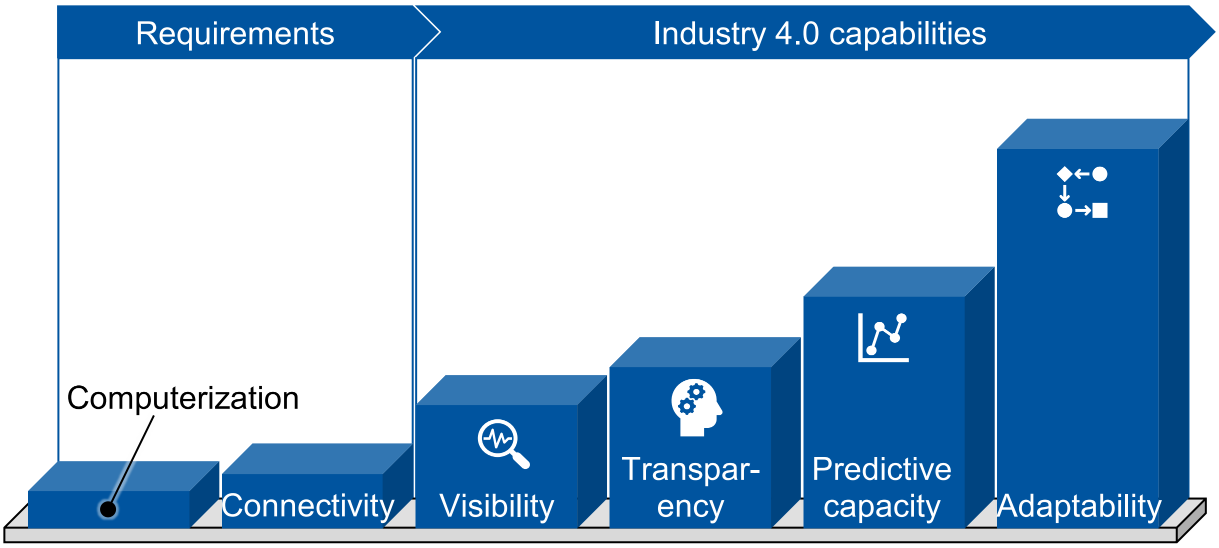

Figure 3: Stages in the industry 4.0 transformation process (acc. to Schuh et al. 2020 p. 18)

As soon as those requirements are fulfilled, companies can proceed to build up industry 4.0 capabilities, starting at the visibility stage. A digital shadow is implemented, a model containing real-time information about the current proceedings in the company which serves as a basis for quick and data-driven strategic decisions. It is realized using smart and connected components through the entire value chain, such as the smart machines described in chapter 2.1.1, as well as integrated MES (manufacturing execution system) or ERP (enterprise resource planning) systems. At the transparency stage, root cause analyses are performed based on the obtained raw data. By using big data analyses and process models, dependencies in the measured data can be found and interpreted as complex (machine) states. To gather the benefits of these analyses, employees from different departments and hierarchy levels must work closely together in agile projects.

While the previous stages have been analyzing the status quo, the fifth stage uses the gathered knowledge to predict future scenarios and adapt to the most likely ones. This helps companies to plan further in advance and avoid costly mistakes in projects. To avoid negative effects of the anticipated events, employees need increased power to enable quick decisions. Once a company can predict possible future scenarios, decisions can be automated carefully to further reduce the adaption time. This should be done for repeating decisions that follow a clear logic, for example reacting to delivery delays. Companies in this last stage are highly flexible and continuous change and learning are part of their everyday business (Schuh et al. 2020, p. 17ff).

Even though this and other theoretical paths to digitization have been demonstrated, many SMEs still face major challenges in its implementation (Orzes et al. 2018 p. 1348ff), as Figure 2 (p. 15) shows. The most important challenge for producing companies is the allocation of financial and human resources to digitize the production. Furthermore, there are concerns about virus attacks or that confidential process data could be leaked to competitors with machines connected to the internet, and data stored in a central cloud. The lack of standards makes it difficult to completely retrofit heterogeneous machine parks with machines from different manufacturers and with different interfaces and is a major challenge to overcome for an IIoT platform (Gilrichst 2016, p. 20f; Toivanen, Mazhelis & Luoma 2015, p.32ff). Another problem is the fear of long-term dependence (lock-in) when acquiring vendor-specific solutions. As some companies face difficulties in predicting the economic benefit of digitalization, they do not invest in building IT knowledge or adapting their business model to the new chances (Bitkom Research & Ernst & Young 2018, p. 21; VDMA & McKinsey 2020, p.31f; UMH 2020).

Compared to large companies, SMEs may face minor challenges in implementing industry 4.0 measures, as they can restructure their IT and manufacturing processes more easily. On the other hand, large companies can invest more time, money, and expertise into the transformation process (Deloitte 2014, p. 10; Modrák & Šoltysová

2020, p. 225). The UMH platform presented in chapter 3.1 addresses those challenges of machine manufacturers and producing companies.

2.2 Multi-Sided Platforms

In modern markets and industries, platforms play an increasingly significant role, as they have the potential to generate a larger impact than they require input (Thomas, Autio & Gann 2014, p. 211). They can be physical like shopping malls or credit cards, but also digital like social networks, SAP’s ecosystem, Uber, or Airbnb (Eisenmann, Parker & Alstyne 2006, p. 93; McIntyre & Srinivasan 2017, p. 141f). Since this thesis examines strategies to establish a multi-sided platform, the following chapter will give an overview of the most relevant aspects of platforms’ theoretical background. While chapter 2.2.1 reviews the concepts and terminology found in the literature, chapter 2.2.1 explains different challenges for multi-sided platforms, and chapters 2.2.3 and 2.2.4 elaborate digital and open-source platforms in the producing industry, respectively.

2.2.1 Challenges in Multi-Sided Markets

Due to the described network effects, platform markets exhibit increasing returns to scale, which contrasts with traditional markets, where demand decreases with the number of customers. This leads to strong competition and high instability, especially in early stages. Insignificant events may give one platform an initial advantage over another, which will then lead to its stronger adoption and higher returns. These are reinvested to further improve the platform or to lower the prices until finally a critical mass of users is reached and a lock-in takes place. At this point, which is certain to occur, the positive network effect is stronger than the benefits of the other platforms for most customers. As a result of this “winner-takes-all competition”, just one to only a few platforms survive in most mature platform markets with strong positive network effects, if costs to participate in multiple platforms are high for at least one user group or the need for product differentiation is low (Arthur 1989, p. 116f; Eisenmann et al. 2006, p. 93f; Tiwana 2014, p. 37).

Pricing is considered one of the key challenges in multi-sided platforms. Usually, one user side is subsidized below the price that would be charged in an independent market, while the other ones are charged a premium to gain access to the potentially large subsidized group. This subsidizing side pays more than it would in an independent market. Widespread examples of two similar two-sided platforms with opposite pricing strategies are video game consoles and computer operating systems. In the video game industry, users are subsidized by receiving the consoles at or below their price, while game developers pay a certain percentage of the games' sales price to the platform providers. On the other side, computer operating systems are sold above their sole value to customers, while developers may use the respective software development kits for free (Economides & Katsamakas 2006, p. 1057ff; Eisenmann et al. 2006, p. 94ff; 2007, p. 10f; Rochet & Tirole 2003, p. 990ff).

According to Eisenmann et al. (2006, p. 96f; 2007, p. 10f), several relevant factors are influencing the pricing model for multi-sided platforms. The first thing to consider is the ability to capture indirect network effects. As soon as a competing platform offers interaction of its subsidizing side with the own one, the network loses attractiveness for its own subsidizers as the user base gets smaller. Further, the more price and / or quality-sensitive user group should be subsidized. A platform will have a much smaller user base if it charges (high) fees from a price-sensitive user group or offers low quality to quality-sensitive users. The latter can be avoided by charging high fees to the subsidizing side so that it must prospect high sales figures to recover its fixed costs. Next, the costs per user on the subsidized side should be low (i.e., for software), especially if there is not a high willingness to pay on the subsidizing side. This explains, why the younger, more price and quality sensitive user group of game consoles is subsidized while computer users see the product as a necessity and are willing to pay for the large number of applications made available the subsidized developers (Eisenmann et al. 2006, p. 97; Rochet & Tirole 2003, p. 1016f).

Finally, it is to evaluate if negative direct network effects can occur. Sellers for example do not like to compete with direct rivals while buyers value few other buyers if the goods are scarce. Therefore, it can be useful for sponsors to exclude users or to conclude exclusive contracts with key partners with high brand value, who will not participate in other networks (Eisenmann et al. 2006, p. 97f; 2007, p. 11).

2.2.2 Basic Concepts and Terminology

Thomas et al. (2014, p. 200ff) found that there are four main types of platforms in the literature. First, there is the (internal) organizational platform, where the organization is the platform, managing its own resources and dynamic capabilities. In product family platforms, products share common components while others are customizable, enabling economies of scale and scope simultaneously. Market intermediary platforms serve the exchange between several markets so that at least one side can leverage. In a platform ecosystem, several parties co-create value through a common set of technologies and standards for the given digital ecosystem.

Literature is available for two non-exclusive views of platforms: the technology- and the market-oriented view (Schreieck et al. 2016, p. 5f). Technology-oriented literature describes platforms as a set of core components and boundary resources like interfaces, which remain stable over time. Their purpose is the co-creation of value through complements which use the core component's boundary resources, but can easily vary to adapt to market demands (Baldwin & Woodard 2008, p. 2f; Schreieck et al. 2016, p. 6; Tiwana 2014, p. 5ff).

In the market-oriented perspective, external platforms provide needed infrastructure, compatibility, and interaction to bring together one or more user groups and to reduce their transaction- and duplication costs. Their benefits to the participants can be divided into two effects: Direct network effects are driven by interaction with other users on the same side. A social network will be more attractive to its users the more other users are available for interaction. They may be negative as well, meaning that additional users decrease the network value to the existing users. An example are more drivers that further congest highways. The other effect are indirect network effects, which are dependent on the offerings from one user group to another. They are typically positive and the more relevant ones in multi-sided platforms. An example is the increased attractiveness of a video streaming platform to its users once it offers more content and on the other side to the movie makers if it has a larger customer base (Eisenmann et al. 2006, p. 93ff; 2007, p. 2f; 2011, p. 1270f; McIntyre & Srinivasan 2017, p. 141ff; Tiwana 2014, p. 33ff).

A platform is multi-sided if it serves two or more distinct user groups that are attracted to each other (Evans & Schmalensee 2008, p. 667ff; Parker & Van Alstyne 2005, p. 4; Rochet & Tirole 2003, p. 990; 2006 p. 645f) and play a seller or buyer role in transactions consistently (Eisenman et al. 2008, p. 4). The platform itself is the product, service, or technology enabling the value-adding interaction (McIntyre & Srinivasan 2017, p. 142).

Concluding, the companies and individuals involved in a platform market play different roles. Eisenmann et al. (2007, p. 2f; 2008, p. 1f) according to Katz and Shapiro (1986, p. 822f) distinguish between platform providers, who are users' primary point of contact and mediate their interaction and platform sponsors, who develop the platform technology, have proprietary rights to the core components, and decide who may participate in the network. These roles can be taken over by one company or shared by several ones. Independent third parties can complement and thereby extend the offering of the platform, leveraging indirect network effects. They are called complementors (McIntyre & Srinivasan 2017, p. 143f) or component suppliers (Eisenmann et al. 2007, p. 2f; 2008, p. 1f). Finally, the customers of the platform are called users (Eisenmann et al. 2007, p. 2f; 2008, p. 1f). The platform ecosystem, consisting of the platform and its complementors, uses boundary resources like common interfaces and standards to co-create value. It may also set industry standards once the user base gets big enough (McIntyre & Srinivasan 2017, p. 143f; Thomas et al. 2014, p. 212f).

2.2.3 Digital Platform Ecosystems in the Manufacturing Industry

In recent years, platforms relying on new digital technologies like cloud computing or big data analyses have taken over several markets such as the media (e.g., Netflix) or cab industry (e.g., Uber; Hein et al. 2020, p. 88f). This also applies to the production sector, where the IIoT platform market is expected to grow annually by 11 % in western

Europe, from roughly three billion euros in 2019 to five billion in 2024 (VDMA & McKinsey 2020, p. 18).

IIoT platforms monitor, facilitate, and automate processes by connecting sensors, actuators, smart machines (see chapter 2.1.1), and control systems. This enables the optimization of industrial operation by creating digital shadows or twins of the factories including condition monitoring or predictive maintenance. Additionally, new smart services or business models based in the gathered data can be offered (Bender et al. 2021, p. 71; Endres et al. 2019, p. 1ff; Schermuly et al. 2019, p. 1; Schreieck et al. 2017, p. 1f; Sisinni et al. 2018, p. 2ff; Stecken et al. 2019, p. 204f; VDMA et al. 2018, p. 6f; Yoo, Henfridsson & Lyytinen 2010, p. 724ff). While IIoT platforms are rather seen as enablers by producing companies, the offered applications and services are evaluated based on return on investment criteria like the reduction of resource consumption (e.g., material, energy, time) of the manufacturing process or the increase in quality (VDMA et al. 2018, p. 6f; VDMA & McKinsey 2020, p. 32ff).

One of the key differences in business-to-business (B2B) markets compared to business-to-customer (B2C) markets is their fragmentation. Customers in different industries have specific needs and use cases. Platforms can take a horizontal approach and offer a common set of core features in a layered, modular architecture appealing to a variety of industries. Alternatively following a vertical strategy means to specialize in one industry and offer a tailored integration from the data acquisition to the end-user application. The high market fragmentation also leads to lower network effects in IIoT markets compared to other multi-sided platforms (see chapter 2.2.1, Schermuly et al. 2019, p. 1f; Schreieck et al. 2017, p. 10)

In software-dominated markets like the IIoT market, a shift from vertically to horizontally organized ecosystems can be observed. This is due to the lock-in effect of established platforms (see chapter 2.2.1) and the high innovation capability of horizontal platforms' complementors, which makes it hard to keep up for closed vertical platforms. Horizontal competition between platforms is not only on the platform features anymore, but also on the availability and support of complements. Vertical competition between the platform's complementors fosters quality and reasonable, value-based pricing (Cusumano 2010, p. 34; Schermuly et al. 2019, p. 3f; Tiwana 2014, p. 232ff).

Schreieck et al. (2017, p. 5) propose seven layers of IIoT platforms, which can be divided into three groups according to the structure of an IIoT stack implemented by the German Engineering Federation (VDMA) and McKinsey (VDMA & McKinsey 2020, p.9), as shown in Figure 4.

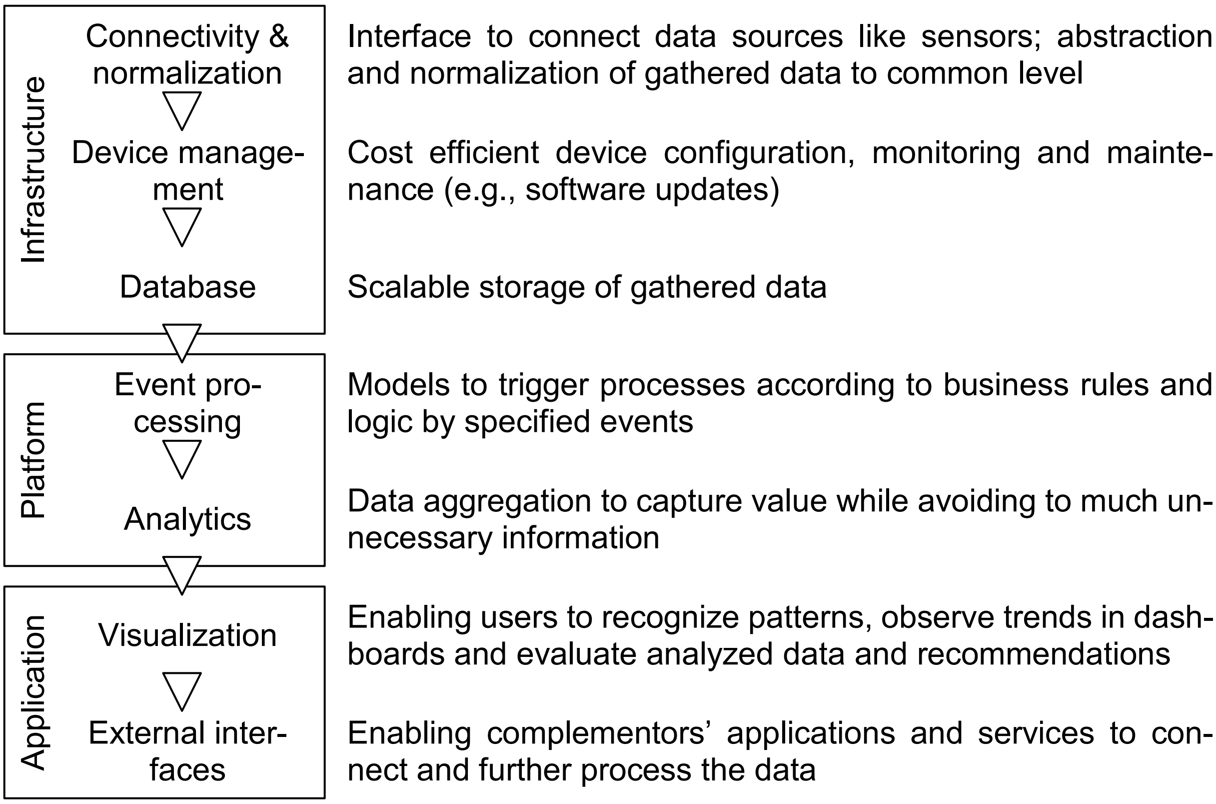

Figure 4: Structure of an IIoT platform acc. to Schreieck et al. (2017 p. 5) and VDMA & McKinsey (2020, p. 9)

At the infrastructure layer, to connect different data sources, interfaces and a standardized data model must be available. Additionally, the platform must allow the connected devices to be configured and maintained as well as the data to be stored safely. At the platform layer, all available data is accumulated and processed to capture value. Models of physical correlations or business processes must be defined to automate processes and aggregate the data, reducing the amount of irrelevant or duplicate information shown to users or operators. Finally, at the application level, data is visualized so users can identify patterns to optimize operations and monitor trends to make predictions. The knowledge can also be transferred to complementary applications via interfaces like APIs (application programming interfaces; Schreieck et al. 2017, p. 5; VDMA & McKinsey 2020, p.9).

Data-driven business models are often applied in conjunction with platforms because they benefit from connecting market players and sharing best practices. Their core business is data collection, processing, and its descriptive or predictive analysis, which in combination with consulting services enables improvement of the clients' operating results (Bender et al. 2021, p. 71ff; Endres et al. 2019, p. 8ff). These business models are mainly used by startups and usually include subscription, freemium or pay-as-you-grow pricing, making them attractive to all sizes of enterprises from startups to large-scale corporations (Menascé & Ngo 2009, p. 4).

The new focus on platform-based data utilization also involves new possible business models for all stakeholders. Sensor suppliers might want to extend their product sales-based business model by their own applications to analyze the sensor data, while software developers can use IIoT platforms as a new sales channel. Companies implementing a platform can reach new target groups, as former competitors often become customers of the platform. Producing companies may enhance the efficiency along the whole value chain using IIoT platforms while machine manufacturers can use the increased transparency to offer performance- or service-based business models (see chapter 2.1.1 for servitization; Bender et al. 2021, p. 71ff; Endres et al. 2019, p. 8ff; Pauli, Marx & Matzner 2020, p. 3).

Bender et al. (2021, p. 71ff) compare incentives for machine manufacturers to build their own service platform with joining an existing platform. They state that machine manufacturers have limited autonomy on existing platforms. Thus, they might want to develop their own platform to have complete freedom of design when implementing their desired business model. On the other hand, joining an existing platform requires much fewer resources and knowledge. Additionally, an existing platform might offer additional applications and the possibility to connect machines of other manufacturers, which is much appreciated by producing companies (see chapter 2.1.2). They find that 84 % of the 97 considered machine manufacturers have developed their own platform. Since SMEs tend to have less IT expertise, they use an external or jointly developed platform in 21 % of the cases. In industries with a high demand for application specialization, such as the mining industry, all platforms are developed in-house. However, only 54 % of multi-industry companies rely on their own platforms (Bender et al. 2020, p. 9ff; 2021, p. 72f).

2.2.4 Open Innovation and Open-Source Platforms

Innovation describes the process of inventing (e.g., research and development; R&D), and commercialization (e.g., production, launch, and distribution) of a new product, service, or process (Schumpeter 1983, p. 88f). In contrast to vertically integrated innovation, where this is carried out internally by a company, open innovation approaches integrate internal and external sources like customers, rivals, academics, and companies in unrelated industries. This leads to a novel way how companies use and manage their intellectual property (IP). In addition to the classic generation of internal knowledge for internal commercialization, this can also be used for external commercialization or bring in indirect revenues through spillover and the sale of related products. Similarly, external knowledge can be identified by R&D and used internally. (Chesbrough 2003a, p. 43 ff; 2003b, p. 12f; von Hippel 1988, p. 3ff; West & Gallagher 2006, p. 86ff).

There are many cases for open innovation in the early stages of disruptive technologies like the Bessemer steel process, Linux as an open-source operating system, or Tesla’s patent open-source strategy for mobility electrification. It is helpful establishing a new technology to jointly develop the necessary standards, infrastructure, and complementary products while avoiding lengthy patent licensing processes. As the technology becomes more attractive to innovators and users the more features, applications, and open patents are added by the community. Thus, the technology can also be viewed as a platform exhibiting network effects. Once the technology is established, the main competitor shifts from other technologies to other companies using the same technology. At this point, the scope of knowledge to be shared must be reevaluated

(Bessen 2014, p.1ff; Rimmer 2018, p. 521ff; Schreieck et al. 2017, p. 10f; Wang & Peng 2020, p. 387ff).

A key challenge for sponsors of open-source platforms is to find a compromise between openness to attract enough adopters of the platform's standards, monetization to recoup development costs, and protection of IP to maintain competitive advantages (Dedrick & West 2003, p. 236f; 2004, p. 1f; West 2003, p. 1259ff; Wang & Peng 2020, p. 387). Platform providers can open the core layers while retaining full control over layers that offer better opportunities for differentiation, which is a suitable strategy to speed up the adoption of platform-related standards. This is referred to as "open-core" according to Lampitt (2008). Another strategy is to make the technology available under restrictive licenses so that it adds value for users but cannot be used directly by competitors. This way standards are adopted by the industry and implemented by key users more easily, which increases the chance of lock-in and the number of available complements (Lerner & Tirole 2005, p. 20ff; West 2003, p. 1279f).

Economides and Katsamakas (2006, p. 1060ff) developed a framework to study the differences between open-source and proprietary platforms. They conclude that complementary applications based on an open-source platform can be more profitable alone than a proprietary platform. However, a proprietary platform is likely to dominate an open-source platform with proprietary applications in terms of market share and profitability, which may explain parts of Microsoft's success. Open-source platforms offer a larger variety of applications, especially if the application side is subsidized. If the users face high switching costs, they should be subsidized, even if they do not all buy proprietary applications (Economides & Katsamakas 2006, p. 1058ff).

Regarding data security and the protection of open-source software, the question arises whether it is good or bad if many people can find flaws in the source code and thus if a system is more secure if bugs are found and fixed, or if they are never discovered. To answer this, Payne (2000, p. 278ff) conducts an empirical study, which compares the Unix-Based operating systems Sun Microsystems Solaris as a closed source system, with Debian GNU / Linux and OpenBSD as open-source operating systems. He concludes that OpenBSD as an open-source system is the most secure. However, this is not due to open source, but because it was developed with a constant focus on security. This shows that it is possible to develop secure systems with open source, but as it is with proprietary software, this must be done deliberately (Payne 2000, p. 278ff; 2002, p. 63ff; Lawton 2002, p. 18ff).

According to West (2003, p. 1281f), open source primarily offers advantages to the few technically proficient users with high customization needs, e.g., complementors using the platform’s infrastructure to develop applications. The added value for the main user group depends on the extent to which attributes important to them, such as lower costs or availability of applications, are enabled. Thus, in Moore’s technology adoption life cycle (see chapter 2.3.2) a platform sponsor needs to attract innovators who develop applications in the early stages. These are then beta-tested by early adopters who are tolerant of some missing features or bugs. In the next step, a fully functional product can be offered to the early majority.

Dedrick and West (2003, p. 245ff; 2004, p. 5ff) investigated the influences of Rogers’ factors (e.g., relative advantage, compatibility, trialability; see chapter 2.3; Rogers 1962, p. 15f) on companies’ decision to adopt Linux as the operating system for their servers. They find a relative advantage of the open-source platform over its proprietary competitors, since the software is free of charge, and economies of scale may emerge for supported hardware. The software can also be easily tried out because it can be run on existing hardware. Nominal costs have limited direct impact on the trialability for companies. However, there is an indirect effect, as in some cases programmers casually try out Linux at home, generating knowledge which in turn reduces the risks and leads to companies’ incremental adoption.

Compatibility with organizations’ existing applications, skills (e.g., of IT), and tasks is very important and may outweigh the indirect network effects of open-source platforms with a wide variety of incompatible applications (see chapter 2.2.1). In the case of Linux servers, the relative advantage of being able to customize the source code to meet the needs of the organization is not valued by the majority, which may not be true for other use cases. Finally, the potentially lower reliability compared to proprietary software developed by a company is a relative disadvantage of the open-source servers (Dedrick & West 2003, p.245ff; 2004, p. 5ff).

Concluding, Dahlander and Wallin (2020, p. 2ff) argue that value co-creation becomes even more important in economically challenging times with volatile customer needs such as the current Corona crisis. Concerns about IP and short-term profit are outweighed in the long run by well-established partnerships, built reputation, gained knowledge through the network, and resulting reduced innovation times. They further state that with the higher demand and thus larger market for co-creation, the search costs for suitable partners are lower during crises. Open innovation nevertheless entails costs to validate partners and compliance, and to adapt own structures to the process.

2.3 Technology Adoption in a Market

In the following, the technology adoption process is examined from the market perspective, with chapter 2.3.1 describing general influences and chapters 2.3.2 and 2.3.3 discussing Moore's technology adoption lifecycle and the concept of blue ocean markets, respectively.

2.3.1 Influencing Factors on Technology Adoption

There are several influences on an industry's adoption of new technologies and therefore the required marketing strategies, which will be discussed in the following. While technology-push innovations offer improvements enabled by technological advances and enter the market without a known user need (Mowery & Rosenberg 1979, p. 103ff, Freeman & Soete 1997, p. 316ff), the development of market-pull innovations is triggered by a market need (Langrish et al. 1972, p. 50ff; Meyers & Marquis 1969, p. 31ff; Utterback & Abernathy 1975, p. 642f). Both views represent extremes on a continuous scale that can be found in various German manufacturing industries concerning digital platforms. In some industries, companies are well advanced, while other industries still do not recognize benefits through digitization (Bitkom Research 2020, p. 8ff; UMH 2020). Pure technology-push commercialization requires long, risky, and expensive marketing with few early adopters (Bower & Christensen 1995, p. 44f; Walsh et al. 2002 p. 345).

Disruptive technologies enable new products, services, or even business models of machine manufacturers. The resulting innovations require a change of behavior, new manufacturing practices, and technological capabilities of producing companies and are therefore called discontinuous innovations (Bower & Christensen 1995, p. 46ff; Moore 1991, p. 7). As this applies to digitization technology (see chapter 2.1), it can be regarded as disruptive in the manufacturing sector. While evolutionary technologies are usually adopted quicker by the market as they are compatible with existing infrastructure and the implementation effort is comparably low, disruptive technologies require considerable marketing efforts to successfully be sold to customers (Walsh et al. 2002, p. 343ff).

Another influence is the innovating enterprise's customer base. Established companies have a loyal customer base with potentially high switching costs and face therefore fewer problems selling innovative products than new ventures. But they may not be interested in implementing a technology-push innovation because, in their opinion, it might not primarily address the next-generation needs of their customers. However, if a startup manages to bring the innovation to some visionary companies in the market, it can develop it further with comparably little effort. By increasing the performance in features that mainstream customers value, it may outperform the incumbents. The process of finding those early adopters is difficult, as the new companies lack reputation in the market and face resistant potential users. On the other hand, new ventures are free to look for applications of their technologies in different markets and may thereby enhance or replace existing products of an established company in a completely different industry (Bower & Christensen 1995, p. 45; Walsh et al. 2002, p. 5).

Further literature sees management attitude as a key variable in the introduction and automation of manufacturing processes. Additional influences are the number of employees, as larger companies tend to have more in-house expertise, and larger batch sizes typically produced (Munro & Noori 1988, p. 69; Zmud 1984, p. 730f). Rogers (1962, p. 15f) sees the innovation’s perceived relative advantage, compatibility with existing applications, tasks, and skills, as well as complexity, trialability, and observability of the effects as the main influences on technology adoption rates. Chapter 2.2.4 discusses these factors in the example of the open-source operating system Linux.

2.3.2 Moore’s Technology Adoption Life Cycle

Moore (1991 p. 8ff), based on Rogers (1961 p. 4ff), focuses on the adoption process of discontinuous innovations. He divides the market into five groups based on the time of adoption, each relying on recommendations from previous groups (see Figure 5). These groups have characteristic responses to the innovation and therefore require individual marketing approaches. The first very small group are the innovators, technologists who sometimes buy the product even before a marketing campaign begins because they are interested in and informed about the new technology in a specific segment and want to explore its advancements. Their confirmation that the product works is important to win the second group, the early adopters. This segment consists of visionaries, who understand the benefits of new technologies and can assess if they could solve their problems. Relying on their intuition and vision rather than sound credentials, they can contribute to a critical mass of recommendations that may then convince the early majority. The most critical period for the innovator and is referred to by Moore as the "chasm”. Here, the rest of the market is observing to see if the technology catches on, and a value proposition is discovered that promises to be deliverable to a targeted group of customers at a reasonable price.

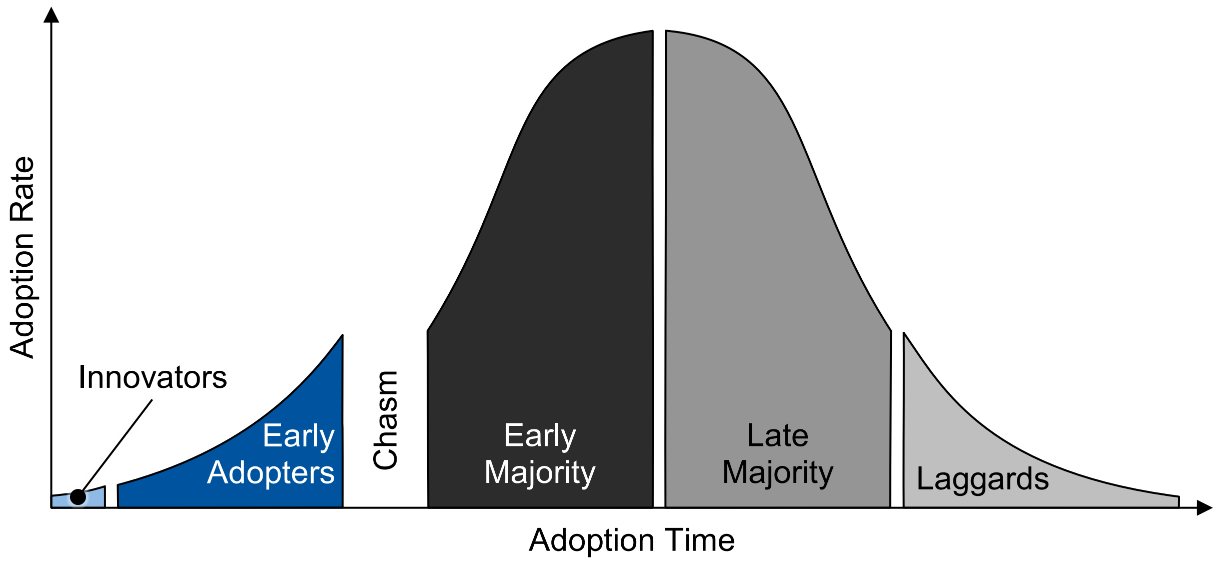

Figure 5: Technology adoption life cycle (Moore 1991, p. 13)

The early majority consists of pragmatists, who care about product quality, availability, and reliability of service and complementing products and most importantly references by other established market players. Like the late majority, they account for about a third of the market, which is why both groups are highly profitable. The late majority values the same things as the early majority, but additionally, they are not comfortable handling the new technology. Therefore, they need a lot of support and prefer large and well-established companies. Finally, laggards are fundamentally averse to new technologies and only accept them if they are embedded in a product and they have no direct contact with them. This group typically remains unconvinced even by marketing measures (Moore 1991, p. 8ff).

The recommended strategy to cross the chasm is to first target innovators and early adopters in a niche market, the beachhead, where the objective is to win domination. From there, a venture moves to adjacent extended markets, where the gained word-of-mouth reputation is required to convince the pragmatist majority (Moore 1991, p. 47ff). Bresnahan and Greenstein (1999, p. 20ff) find this pattern in successful platform adoptions in the early stages of the US computer industry. Selling companies must attend industry-specific conferences and trade shows, have references, partnerships, and alliances with other companies and suppliers in the industry, and have earned a reputation for quality and service (Moore 1991, p. 33).

Innovations in manufacturing are typically demanded by end-users (e.g., management or machine operators) who have a problem to solve. Therefore, applications offer a better opportunity to cross the chasm than pure infrastructure platforms, as end-users can interact with them directly and see their potential to solve the problem. A platform only providing the necessary infrastructure to host applications (see chapter 2.2) crosses the chasm less easily because it targets IT, which tends to be reluctant to make extensive changes to the existing systems and can derive little benefit from them. Thus, it is important to offer applications on the platform from the beginning to successfully sell it (Moore 1991, p. 62f; Gallagher & Park 2002 p. 77ff). In addition, platforms use or define standards (see chapter 2.2.1) that are associated with high switching costs or a limited supply of complimentary applications if they fail to catch on. This increases the risk and uncertainty in the adoption decision (Dedrick & West 2003, p. 236f; 2004, p. 1f).

2.3.3 Blue Ocean Strategy

Classically, companies compete for existing demand in a defined market, so-called red ocean markets, resulting in shrinking profit margins. However, companies that successfully pursue a blue ocean strategy create a new market by simultaneously exhibiting differentiation and cost leadership and thereby render the competition irrelevant. Kim and Mauborgne (2015, p. 30) found that only 14 % of 108 analyzed business launches created blue oceans but accounted for 61 % of the profits.

They examined the underlying processes and derived risk-minimizing frameworks. First, the strategy canvas assesses the attributes of existing products or services in the known market space. By assigning the level of fulfillment from low to high on the vertical axis and connecting the points, the resulting value curve depicts the investments and value propositions of the existing market. Strategies of different competitors may be evaluated in different curves (Kim & Mauborgne 2015, p. 45ff). To create a fundamentally new value curve, a company must focus on current non-customers in different markets and create alternatives by reconstructing the value proposition. This can be achieved using the four actions framework which aims at shifting focus from beating the competition to meeting customer needs. First, attributes that are no longer valued or even interfere with other attributes are eliminated. Second, attributes that are overdesigned to outcompete rivals are reduced. Then, the potential compromises an industry forces its customers to make, are eliminated by raising attributes above the standard. Finally, new sources of value are discovered by creating attributes new to the industry. The first two steps aim at reducing costs, while the second two steps aim at differentiation, increasing buyer value, and creating new demand (Kim & Mauborgne 2015, p. 50ff).

Finally, Kim and Mauborgne (2015, p. 59ff) give three criteria for good blue ocean strategies. First, a value curve must focus on a few key attributes to keep costs down and avoid complex business models. Second, it needs to clearly diverge from competitors to create a real alternative instead of just scaling existing value curve patterns up or down. Finally, it needs to have a compelling tagline to easily communicate the value proposition to the market.

3 Presentation of the Practical Problem

The subject of this thesis is the strategic positioning of an IIoT platform addressing the digitization of machine manufacturers and producing companies. For a better understanding, this chapter briefly introduces the considered digitization platform UMH, which is created by the UMH Systems GmbH, a spin-off of the Digital Capability Center Aachen. The DCC Aachen in turn is a collaboration between the Institute of Textile Technology at RWTH Aachen University (Rheinisch-Westfälische Technische Hochschule), and the top management consultancy McKinsey & Company (McKinsey & Company 2018). UMH's goal is to support machine manufacturers in digitizing their machines and thus promote the digitization of the German manufacturing sector with a focus on SMEs. In the following, UMH is positioned in the frameworks previously presented (chapter 3.1.1) and it is described how it helps to overcome the challenges in digitization (chapter 3.1.2). Chapter 3.1.3 explains the open-core components of the platform, while chapter 3.1.4 explains the fee-based premium features and services. To give an example of an implementation, chapter 3.2 provides insights into a use case at the DCC Aachen.

3.1 Positioning and Structure of the Platform

3.1.1 Positioning in the Described Frameworks

In the IIoT ecosystem introduced by VDMA et al. (2018, p. 12) according to Roland Berger (2017, p. 5), UMH Systems is positioned as an IIoT platform provider (see Figure 6). In addition, UMH Systems develops software that can be operated on the platform alongside third-party apps and software, which is important for the successful market launch of a platform (see chapter 2.3.2; Moore 1991, p. 62f; Gallagher & Park 2002 p. 77ff). In the role framework of Eisenmann et al. (2007, p. 2f; 2008, p. 1f), UMH Systems is the platform provider and sponsor.

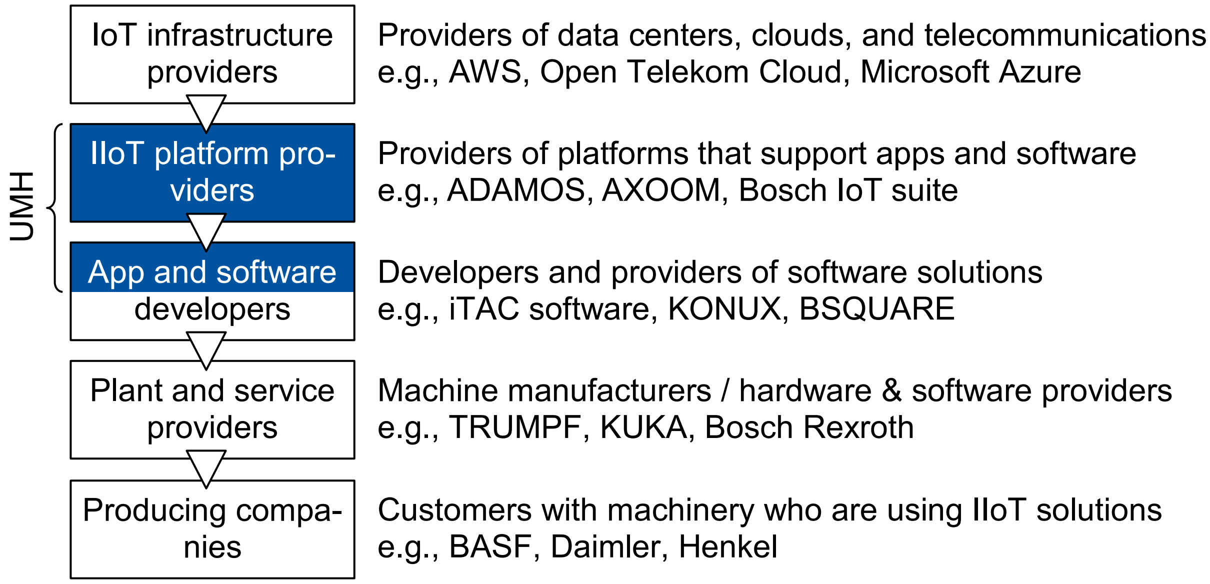

Figure 6: Layers of an IIoT ecosystem (VDMA et al. 2018, p. 12 acc. to Roland Berger 2017, p. 5)

The platform allows the connection and setup of various data sources such as plug-and-play sensors, barcode readers, and machine PLCs (programmable logic controlllers). This way, machines equipped by machine manufacturers can be combined with retrofitted machines and assembly lines in heterogenous plants using a single system, which helps to overcome a major entry barrier into an IIoT application for producing companies (Gilrichst 2016, p. 20f; Toivanen et al. 2015, p.32ff; see chapter 2.1.2). The gathered data is processed and aggregated using logical models and pattern recognition to enable sophisticated analyses and recommendations like prescriptive maintenance or OEE analyses. Finally, it is stored in a cloud and displayed in an inhouse dashboard, or it is transferred via interfaces and further processed by MES and ERP systems or industry-specific third-party applications and dashboards (see Figure 4, p. 24 for a more detailed structure of an IIoT platform).

According to the classification introduced by Porter and Heppelmann (2014, p. 7f) currently supported applications are in the monitoring stage, as the warranty is not provided for control applications (see chapter 2.1.1). According to Pauli et al. (2020, p. 8), the ability to control machines is appreciated by complementors and should thus be addressed in the future. In the industry 4.0 maturity index by Schuh et al. (2020, p. 17ff), current applications reach up to the transparency level. As soon as industry-specific knowledge is built up or complementors implement the required models and applications, the final stages predictive capacity and adaptability can also be accessed (see chapter 2.1.2).

As the platform promotes value co-creation by offering core technologies and standards, it is classified as a platform ecosystem according to Thomas et al. (2014, p. 201; see chapter 2.2.1). It follows a horizontal approach, offering standardized core components like the data model and interfaces that remain stable over time. Based on that, applications may be developed by UMH or complementors, which serve a vertical, potentially volatile, industry-specific need (Baldwin and Woodard 2008, p. 3f; see chapter 2.2.1 for the technology-based platform view). This approach is consistent with a trend in software-dominated platforms identified by Schermuly et al. (2019, p. 3f).

3.1.2 Target Markets

Industries ideal for deploying the platform are characterized by high cost-pressure, mass production with low product customization, and multi-shift operation. In the steel industry, for example, low production depth, low margins, and high price fluctuations of the raw material are common. Therefore, high process efficiency and planning capability is important to reduce production costs and inventories. This also applies to the beverage industry, where the competition takes place between many similar suppliers. Further examples are the pharmaceutical packaging industry, where EU regulations require the traceability of drugs to individual machines, or CNC machines, which have high procurement costs and typically low utilization (UMH 2021). Currently, there are pilot projects taking place with innovators in those industries. This is an important first step to establishment and helps to further develop features in line with customer needs (Moore 1991, p. 47ff; Walsh et al 2002, p. 345; see chapter 2.3 for technology adoption).

According to a study by VDMA and McKinsey (2020 p. 19), 85 % of European machine manufacturers are pursuing a fast-follower strategy digitizing their machines to reduce risks and learn from the mistakes of the first-movers. However, this is considered critical because, on the one hand, there is not a sufficient mass of first movers and, on the other hand, startups and tech players are entering the market that could outpace established machine manufacturers. To avoid this, UMH helps to overcome the challenges described in chapter 2.1 and offers a ready-to-use solution (see Figure 2, p. 15).

Implementing the technology, machine manufacturers can evaluate real-time breakdowns and planned maintenance activities for all their machines in the field, and thus not only improve the product quality where needed but also proactively offer and coordinate service orders (see chapter 2.1.1 for servitization). This increases satisfaction and loyalty of producing companies for only the cost of the edge device added to the control cabinet (Bender et al. 2021, p. 72; Frank et al. 2019, p. 344). Therefore, a clear path to new service-centered business models and potential economic benefit is shown, which are major concerns for machine manufacturers considering digitization (VDMA & McKinsey 2020, p. 22).

The current lack of standards is a main concern by both parties, which can only be overcome if the platform is adopted by a large enough user group (Dedrick & West 2004, p. 1f; see chapter 2.3.2). As the operating system for the computing unit comes with a built-in state-of-the-art firewall and uses secured connections to the cloud, there is no reason for concerns about unauthorized access to machines or unprotected data. The open-source approach further explained in chapter 3.1.3 stands out from the current rather homogeneous market and reduces the previously high investment requirement for an appropriate digitization solution. It also copes with producing companies' fears of a long-term dependence from a manufacturer-specific platform or a startup that may no longer exist in a few years (Bitkom Research & Ernst & Young 2018, p. 21; VDMA & McKinsey 2020, p. 22).

3.1.3 Open-Core Platform Structure

The platform pursues an open-core approach, contributing core components to the community under the AGPL v3 license (affero general public license) while offering certain add-ons under a commercial license. Therefore, the core components are open source and copyleft, meaning they can be used and adapted to individual needs if the same rights are preserved in the created derivates (Free Software Foundation 2007; 2018; Lampitt 2008; Open Source Initiative 2007).

The software stack is based on the microservices approach, i.e., it consists of loosely coupled, self-contained services communicating via clear interfaces (Jamshidi et al. 2018, p. 25ff). Those services can either be run on the edge device itself or in the cloud. UMH's software includes only scalable open-source components by established companies which are adapted and extended by in-house components to enable a wide range of functionalities while ensuring maintainability. The services are based on Docker, which enables short development cycles and improved resource utilization (Docker 2020).

To implement the platform into the equipment, machine manufacturers need to procure only the computing unit once. They can either buy certified edge devices, which allow the software stack to be installed with one click, or manually set up other devices. The software stack includes the firewall and router software OPNsense. Producing companies, in turn, can retrofit their existing machine park with the UMH Factorycube, which combines the edge device with WiFi and cellular connectivity and various data ports in an IP 65 protected housing for usage in industrial environments (see chapter 3.2).

In the next step, machine PLCs using Siemens S7, Modbus or OPC UA (open platform communications unified architecture) can be connected so the data can be read out and normalized according to the data model using easy to adapt Node-RED flows. Retrofitted IO-Link sensors of all kinds, barcode readers, or cameras compatible with Cognex or GenICam can be connected plug-and-play and readout via hardware interfaces. Market gaps are filled using hardware developed in-house, like a ruggedized button panel for manual input. Those data sources rely on preconfigured plug-and-play data processing algorithms. The processed data is then stored on the edge device for a limited time and simultaneously sent to the cloud or server (if run on-premise) via the MQTT protocol (message queuing telemetry transport).

On the cloud or server level, the received data is then stored in the database TimescaleDB. Based on the data, KPIs (key performance indicators) are calculated and anomaly detections are performed. Those calculations are used by apps, e.g., to calculate and analyze the OEE, to break down optimization potentials, to facilitate reporting, to monitor diverse processes via alarms, or to enable condition-based preventive maintenance and are displayed in Grafana dashboards in real-time. Applications like ERP, MES, or PowerBI can receive live data via MQTT or request historical data from the database using a REST API (Representational state transfer). Apps can also push data into the system using a REST interface and historical data can be edited in the Grafana dashboard. Figure 7 gives an overview of the open-core and priced components of the platform.

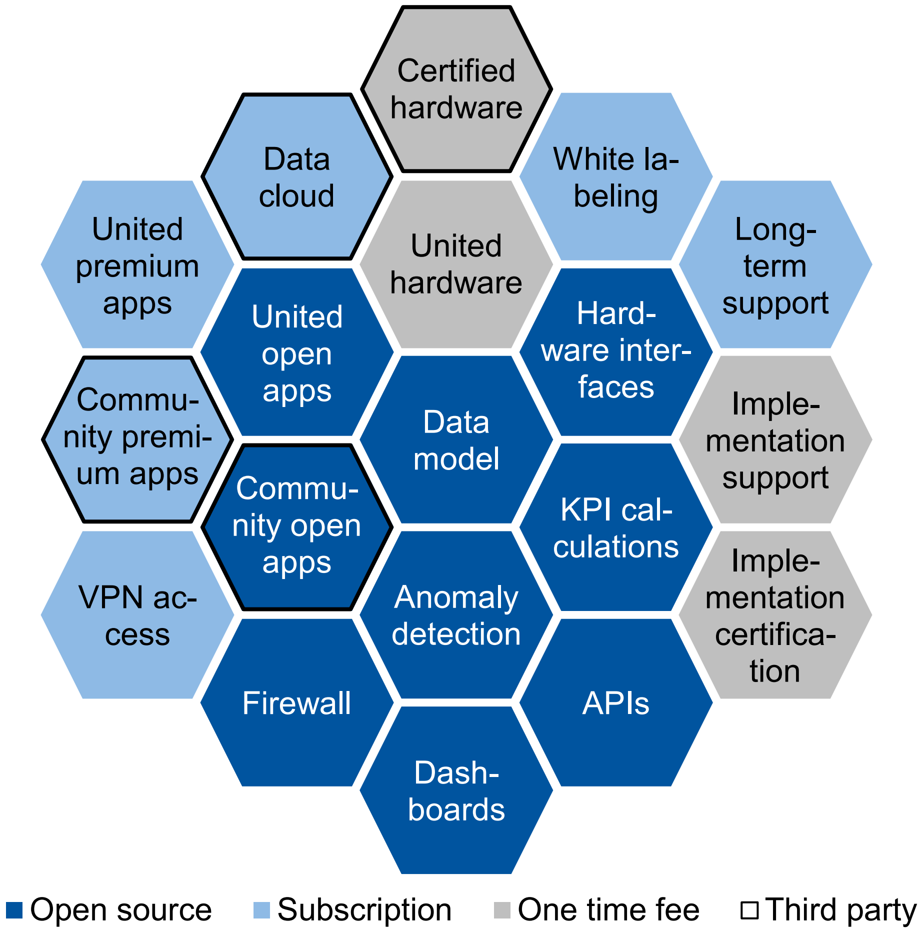

Figure 7: Open-core and pricing structure of UMH

3.1.4 Monetization through Premium Apps and Services

The open-core model offers not only benefits to the platform users by offering freely accessible core products and paid complements, but also to the platform sponsors, who can generate income through premium features and complementary services built around the core (Lampitt 2008). If the needs of machine manufacturers exceed the basic features of the open core, they can either develop their own applications or rely on off-the-shelf premium applications by UMH and the community, which requires much less knowledge and safes many resources. A software-as-a-service (SaaS) subscription model including cloud hosting, continuous updates, customer service, uptime guarantee, and maintenance is offered specifically for SMEs with little expertise. Additionally, UMH offers one-time paid implementation support for machine manufacturers or producing companies and a certification service for implementations by system integrators and consultants to ensure seamless functionality.

Machine manufacturers with large IT departments and system integrators may choose the modular premium components according to their needs. They may white-label the solution and integrate it into their systems for a subscription fee. To encourage additional free or premium app creation, a Python software development kit (SDK) is offered free of charge to the community. UMH's premium apps include a video telephony plugin for the dashboard that allows machine manufacturers to remotely support their customers with maintenance and installation of their production equipment or a recommendation engine that assists shift supervisors in deriving specific measures from the data. The possibility to access certified gateways worldwide via VPN (virtual private network) for setup and maintenance is a premium feature as well.

3.2 Use case at the DCC Aachen

To provide a better understanding of the components, the implementation at DCC Aachen is presented below as an example. The DCC Aachen offers workshops to teach executives how to launch, scale and sustain their digital manufacturing transformation. It demonstrates various use cases on a model factory depicting the production process of an RFID wristband: yarn take-off, fabric production, heat treatment, printing, and assembly (McKinsey & Company 2018).

The five textile machines of the Swiss machine manufacturer Jakob Müller have mostly digital PLCs but no connectivity components. They were retrofitted and show various problems of digitization as well as the solution possibilities provided by UMH. In the first production step, the warping machine MW 700 (Jakob Müller 2011, p. 2ff), produces warp beams from 96 yarn bobbins. During the project, it was retrofitted with the edge device, 24 yarn tension sensors, and a UMH button panel. Figure 8 gives an overview of the network structure and the protocols used.

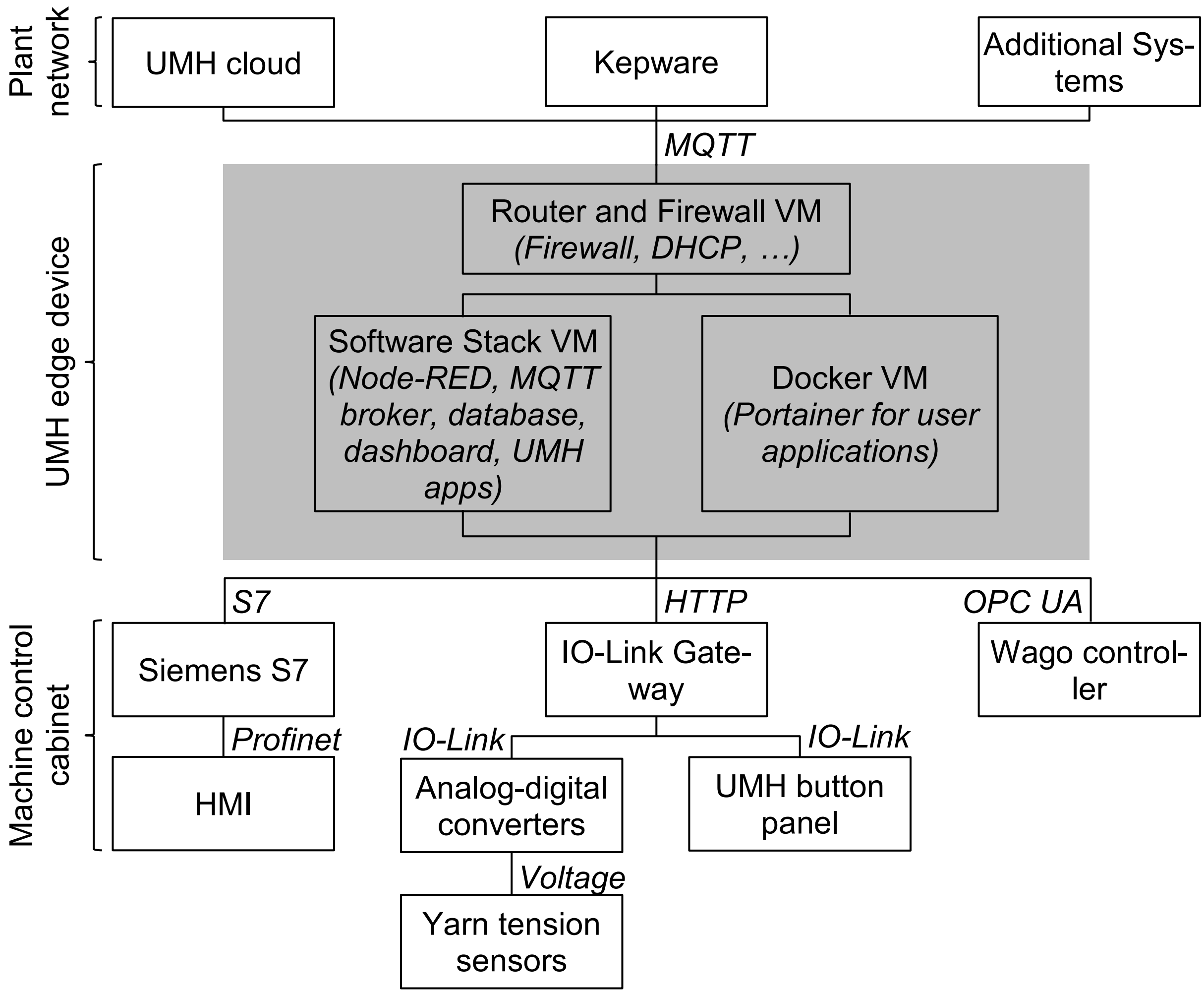

Figure 8: Network structure at the warping machine

The edge device is installed in the control cabinet and has three individual network ports, of which the first one is connected to the plant network to publish production data and analysis to the UMH cloud and additional applications used by the DCC. The edge device runs three separate virtual machines (VMs). The plant network port is connected to the Router and Firewall VM, which restricts access to the machine and takes over several network functionalities, such as IP address (internet protocol) assignment via DHCP (dynamic host configuration protocol). Downstream are two further VMs, which are connected to the devices in the control cabinet via the second network port. The UMH Stack VM is protected from access and runs the several functionalities described in chapter 3.1.3, while the Docker VM allows for changes through authorized users, who may install their own software and addons.

On the side of the control cabinet shown in Figure 9, the machine data is acquired from the Siemens PLC via the S7 protocol and an already installed Wago controller measuring the machine's energy consumption is connected via OPC UA. In addition, an IO-Link gateway connects the UMH button panel for manual inputs as well as the yarn tension sensors, whose output voltage is converted into a digital IO-Link signal.

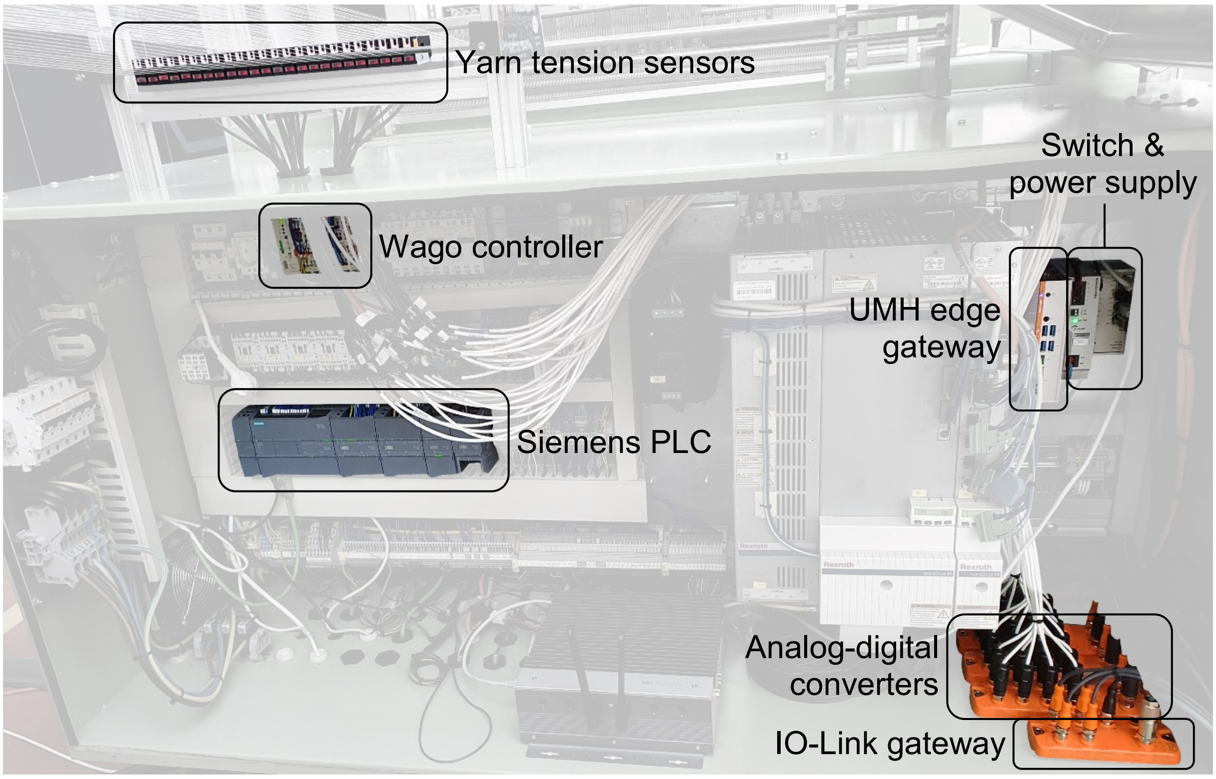

Figure 9: Warping machine control cabinet with implemented components

In the next production step, the warp threads are woven into a narrow elastic band using the weaving machine NH2 53 (Jakob Müller 2010, p. 2ff). It has simple control electronics instead of a PLC and no control cabinet and is therefore retrofitted with the UMH Factorycube shown in Figure 10. The Factorycube is connected to the electrical running and warning lamp signals on the circuit board, as well as control mechanisms that close a circuit in case of a weft or warp breakage, and a button panel.

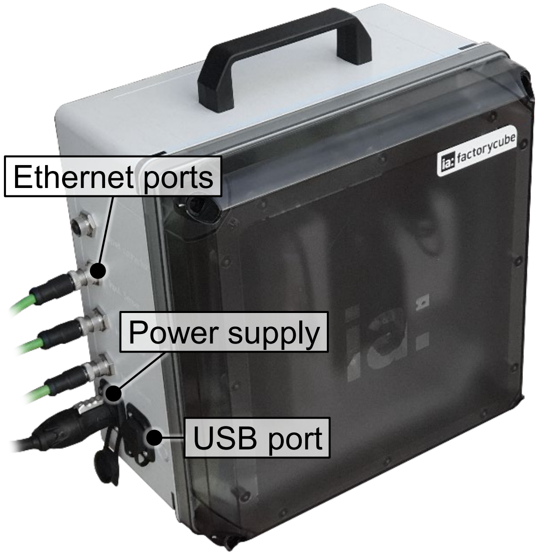

Figure 10: UMH Factorycube

The band is then coated and heat set in the finishing machine MFR 2A 2C ST (Jakob Müller 2004, p. 2ff), which is retrofitted with a gateway as well as a button panel and the Wago energy measurement is connected. The same applies for the following printing machine MDP2 E (Jakob Müller 2017, p. 2ff). In the last machining step, the band is cut, and the parts are distributed to four boxes by the making-up machine UV 40. As the machine manufacturer does not grant access to the PLC, it is retrofitted with a Factorycube as well. Connected are a button panel and two laser distance sensors that detect a cutting operation and the box to which the tape is fed. The following manual assembly process is not yet equipped with UMH hardware to measure KPIs.

4 Methodology and Data Collection

The purpose of this thesis is to answer the research questions defined in chapter 1 using the methods of qualitative research. The methodological procedure and the data evaluation are presented in the following chapter.

In chapter 4.1, the value curve framework is first used to depict attributes that selected competitors currently focus on. Then, based on the perception of the market's current barriers of adoption (c.f. chapter 2.1) and the vision of UMH's open-core strategy, hypotheses for the positioning of the UMH in the market are formulated. Semi-structured interviews are used to test the underlying hypotheses, identify the needs of machine manufacturers, and evaluate the focal points set to solve those needs. Furthermore, it is evaluated whether there are biases towards open source, to identify potential threats to proper standard adoption. To do so, based on the hypotheses and the theoretical backgrounds of the qualitative approach described in chapter 4.2, the interview guideline is prepared and explained in chapter 4.3. Next, chapter 4.4 explains the sampling of respondents and chapter 4.5 addresses the interview transcription and evaluation methods.

4.1 Mapping the Market Using the Strategy Canvas

To get an overview of the current value propositions of competing companies, the strategy canvas introduced by Kim and Mauborgne (2015, p.47ff; see chapter 2.3.3) is used. However, they do not provide further guidance on how to map the competitors' attributes in this framework, so the method used is presented in chapter 4.1.1. The classification and positioning of the competition are presented in chapter 4.1.2, while chapter 4.1.3 formulates hypotheses of barriers to adopt and implement IIoT platforms.

4.1.1 Value Mapping of the Competition

In the first step, relevant competitors are identified and clustered into groups based on internet research and UMH internal analyses (UMH 2021). The companies considered must offer an end-to-end solution from connecting data points to performing analyses and visualizing the data. Then, based on an initial analysis of the websites, relevant attributes are identified in which competition is currently taking place. These attributes are further divided into sub-attributes to ease the competitor comparison.

Next, based on a detailed analysis of the websites, the perceived relative degree of fulfillment of the companies for each sub-attribute is evaluated on a scale from zero to ten. If there is not enough information available to evaluate an attribute for a company, the field is left blank and is not further considered. Subsequently, the fulfillment rates of the sub-attributes are averaged over the companies considered in each competition cluster. To obtain the final score for the value curves, the sub-attributes are then weighted according to their contribution to the fulfillment of the overall attribute and added together for each cluster. The resulting value curves for the three clusters can be found in Figure 11.

4.1.2 Competition Classification

The first cluster identified are system integrators. Since there are many suppliers on the market, three companies are presented as examples. The considered companies focus mainly on implementation services and offer their customers a solution fully tailored to their needs. They describe themselves as software developers, creating interfaces, analysis algorithms, and dashboards. While *Neogramm* (Neogramm 2021) and *MAS Management und Software* (MAS-Software 2021) focus on producing companies, *Konzeptpark* (Konzeptpark 2021) offers services for machine manufacturers. Uniquely, system integrators offer consultation services to help their customers transform their business models. There is no pricing information available, but since the services are customized and not scalable, they are considered the most expensive. Apart from defining the requirements and monitoring progress, the customer does not incur any additional effort and is supplied with a complete turnkey solution. As the system integrator creates interfaces to machines and data sources, the system is considered open but not in terms of co-creation. In further projects, additional functionalities, interfaces, and machines can be implemented by the system integrator, so there is flexibility to some extent. As no technical know-how is required or built up in the company, there is a low demand for personnel capacities, but also customers are unable to customize the solution themselves. Customers usually do not need additional vendors but are dependent if they want to expand the system or roll it out to additional machine types. As the interfaces and algorithms are customized, system integrators offer the highest potential for differentiation at the infrastructure and application level.

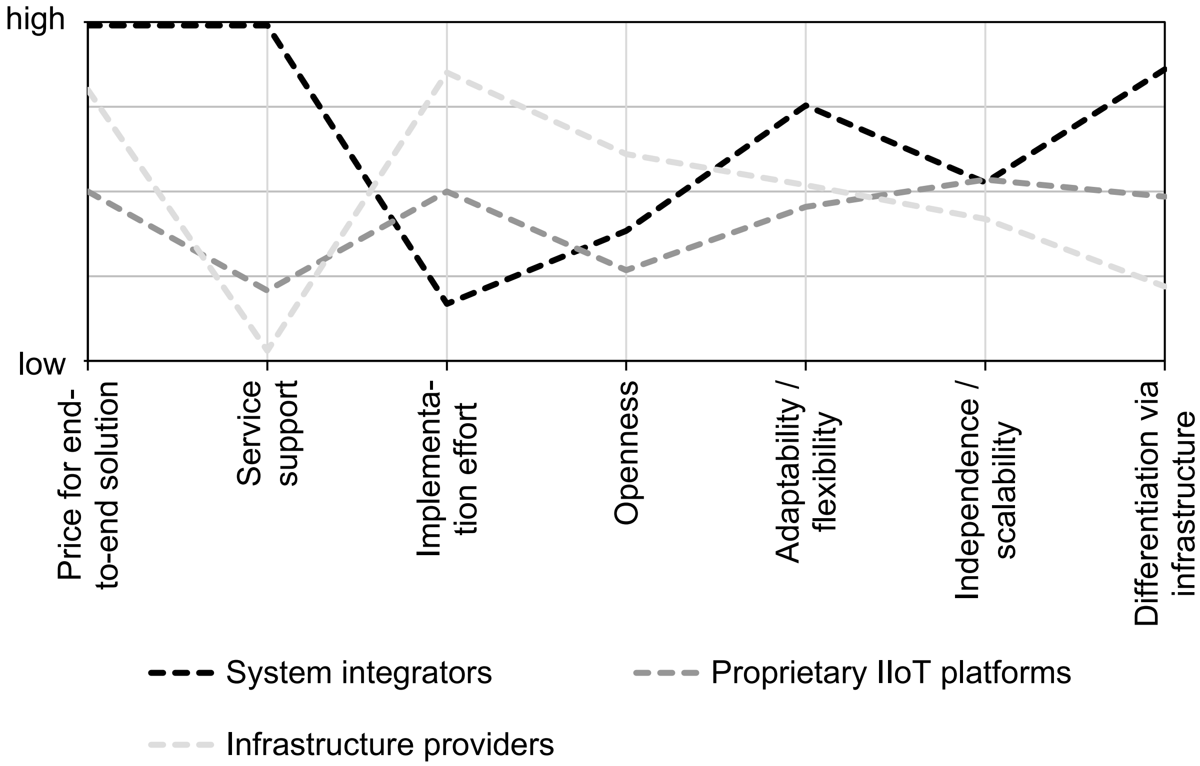

Figure 11: Strategy canvas for existing IIoT platforms

The next cluster are IIoT platform providers that focus on hardware rather than services and software. Except for *3dSignals* (3D Signals 2021), whose offer is combined with implementation services, all of them only offer ready-to-use ecosystems that are implemented by the customers themselves, resulting in medium effort and low service availability in this cluster. Machine PLCs and supported sensors can be connected to an offered edge device. The data can then be viewed and analyzed in in-house dashboards. Apart from the supported data sources and offered applications, there is no possibility to extend the system by own use cases using offered interfaces or extract the raw data for analyses in further applications leading to low openness. Since the solution space is limited, the implementation and creation of dashboards follow a standardized process, making it comparably easy. The biggest ecosystem is offered by *Tulip* (Tulip 2021), which supports PLC connection, a variety of data sources, and highly customizable dashboards. It is the only considered platform provider offering on-premise operation on customers' servers as a paid premium feature. *Auk.Industries* (Auk.Industries 2021) only offers PLC connection, while *Blackbird* (Blackbird ApS 2021) supports only the connection of sensors and offers additional edge devices to connect cameras and operator buttons, resulting in low flexibility. 40 % of *Tulip*'s funding is acquired by *DMG* Mori (Crunchbase 2021) and *3dSignals* has ties to *DMG Mori* on its advisory board (3dSignals 2021). *DMG Mori* is an international manufacturer of CNC and other machines (DMG Mori 2021) and thus a direct competitor to some machine manufacturers, posing a potential IP threat as soon as data is shared with the respective platforms, which leads to shortcomings in independence. The price classification for IIoT platform providers is based on a previous thesis by Jurkiewicz (2020, p. 59, confidential).

Infrastructure providers form the last cluster. On the one hand, some providers primarily offer hardware such as *Cloudrail* (CloudRail 2021), *Autosen* (Autosen 2021)*, or Wago* (WAGO 2021), whose gateways can be connected to various plug-and-play sensors or machine PLCs and send data to a cloud, but there is little to no functionality offered to process and evaluate the data from there. On the other hand, there are server providers like *Microsoft Azure* (Microsoft 2021) or *Amazon AWS* (Amazon 2021), who offer a cloud including computing power to create applications and evaluations. Instead of a ready-to-use solution, infrastructure providers offer toolkits to build a highly customized solution but no services. This leads to a high knowledge requirement and implementation effort, so in addition to the platforms' comparably high costs, for a fully functional solution running on many devices, there are also high internal personnel costs for knowledge generation and implementation. Those platforms are comparably open, as there are interfaces to connect various data sources. Especially the hardware vendor platforms offer little adaptability, while software platforms are volatile enough to adapt to specific use cases, which positions the cluster in the midfield of this attribute. Finally, systems of infrastructure providers mostly require additional providers, as they can supply only a part of the complete solution. Adapting the functions requires specific knowledge, which most of the producing companies and machine manufacturers lack. In addition, customers risk losing their data and digitization progress if they decide to switch providers, which makes them very dependent on the vendor. As the internal interfaces and applications are all pre-built, there is the smallest chance of differentiation to potential competitors on the infrastructure level.

4.1.3 Hypotheses About the IIoT Market

To facilitate the creation and structuring of the interview guideline in chapter 4.3, hypotheses are formulated which attributes are important to machine manufacturers and how UMH can be optimally positioned in the market. Additionally, UMH's solution approaches (UMH 2021) for the hypothetical problems are presented. The approaches are evaluated in the interviews regarding their suitability to reduce the entry barriers for machine manufacturers (see Figure 2, p. 15; Bender & Lewandowski 2021). Nevertheless, the interviews will remain open and unbiased to allow for the discovery of new concepts and the formulation of additional hypotheses (cf. Gioia, Corley & Hamilton 2013, p. 17). The results of the interviews are then used to create two new value curves for UMH's open core and premium versions in chapter 5.3.

The first hypothesis to test is that machine manufacturers in certain industries are developing platforms themselves because no platform is offering enough flexibility and a solution space large enough to meet their needs. This can include certain algorithms, applications, or even (servitization) business models that cannot be realized due to a lack of features and interfaces or too high fees of the platforms in the market. As Figure 11 shows, current IIoT platforms in the market are heavily based on proprietary business models that maximize monetization opportunities but incur high internal development costs and thus offer limited flexibility. A digitization platform should be flexible in terms of adaption to the customers' specific needs on the one hand, and in terms of the ability to grow with the customer on the other hand (H1).

UMH addresses this by removing barriers to co-creation through a free Python SDK for convenient development of apps and data processing algorithms. Secondly, an app store leverages the platform’s network effects through a marketplace that gives developers in the community access to a large user base and financial compensation for their efforts. This allows UMH’s solution space to include industry-specific applications, eliminating the need for complete in-house developments by customers for specialized use cases.

As the offered interfaces and plug-and-play data sources offer a wide range of applications and can be extended easily, UMH offers high customization potential. It further reduces the customers’ knowledge requirements and effort as there are services offered to tailor the platform to customers’ needs, extend it with interfaces and specific apps, or install it on-site if required. Those services are available to UMH premium customers to lower the entry barrier into digitization for machine manufacturers and producing companies. However, since such services are not scalable, they cannot be offered by an open-source provider and are therefore not considered in its value curve. Nevertheless, using the platform as a marketplace, bounty-driven development can be offered and demanded by the open-source community, giving also the open-source variant a small increase in the service support attribute.

The second hypothesis is that some machine manufacturers initially underestimate the effort and cost of creating their own platform that is tailored perfectly to their needs. In many cases, external developers ultimately must be hired to complete the projects, and the costs exceed the planned budget. An IIoT platform should offer implementation services for non-technical customers or have partners who do (H2).

UMH offers a toolbox that can be used to any extent, from guidance on creating a completely customized solution to full implementation with little to zero in-house effort. The investment required to implement an end-to-end solution using the open-core stack is comparatively low, especially for larger companies with large IT departments and in-house expertise that can easily customize the stack. However, due to the high degree of standardization of interfaces and the app store, even a premium solution including implementation services from UMH is not as expensive as a comparable project based on an infrastructure provider's offering or a fully customized solution. Depending on the scope of the customizations, the premium implementation can be priced close to proprietary IIoT platforms but includes the described additional benefits. Customers who are starting to deal with IIoT and have already implemented their own first steps with the open-source stack are also able to consult services for completion as soon as the project exceeds their capabilities or time resources.

Further attributes reducing the adoption barriers are UMH's high standardization and thus readiness for operation and retrofitting capability, which is achieved through the prebuilt external interfaces as well as the internal ones between different components. The application capabilities are extended by plug-and-play hardware to retrofit existing machines quickly and turnkey software modules that can be added with little implementation effort. However, open-core users implement the stack themselves and are only consulted by the community, which takes more time and effort than an implementation by a system integrator and results in its reduced readiness for operation.

The next hypothesis is that some machine manufacturers do not know how to start digitizing their plants, as there is a diverse and opaque offering on the market, and it is difficult to define their requirements without IIoT knowledge. A platform should cover a broad spectrum of the user-friendliness vs. flexibility trade-off for the individual customer needs and communicate this clearly (H3).

As there are examples of best practices and tutorials publicly available on the UMH website, the open-source code is well documented, and the community can support in technical questions, the knowledge generation and implementation effort of UMH's open-core stack is lower than of a solution developed on an infrastructure provider's hard- or software. This reduces the need for IT knowledge and qualified personnel (see Figure 2, p. 15). However, since the UMH open core offers more flexibility, it is more complex to implement than the closed and thus limited solution of an IIoT platform provider in most cases. UMH premium competes with system integrators, who cannot rely on a rich interface library and have fewer standardized procedures for implementing data sources like a customer's MES system, resulting UMH's reduction of implementation effort and complexity and thus project duration.

The final hypothesis is that machine manufacturers and producing companies are very reluctant to transfer their data to platforms, especially if these are operated by direct competitors or if they are also customers there. A platform should be independent of other players in an industry and make data protection one of its top priorities (H4). Unlike some other IIoT platform providers (see chapter 4.1.2), UMH is independent of machine manufacturers and producing companies, which ensures data security and precludes a lock-in effect.

4.2 Qualitative Research Approach

Since this thesis deals with a largely unexplored field of research, an open approach to the topic is necessary to holistically capture opinions, associations, and attitudes. Qualitative research meets this requirement and is characterized by its exploratory nature, focusing on the subjective views of the participants (Hopf 2019, p. 350). The variety of qualitative research methods described in the literature should be understood as guidelines that need to be adapted to the specific conditions and research questions (Mayring 2002, p. 65; Mruck & Mey 2009, p. 24ff). Qualitative interviews should gather enough information to answer the research questions but be limited in time and budget to avoid extensive duplication of recorded data (Seidman 2006, p. 55).

According to Holzmüller and Buber (2009, p. 7ff), three central characteristics of qualitative methods are important to fulfill the underlying market research task. First, they are suitable to explore new research areas and market phenomena and provides structural guidance. Second, they can reveal subconscious attitudes and perceptions and overcome limitations of verbalization. Finally, because of the open and empathic approach, they are suitable to represent complex psychological, physical, or social conditions.

Interview forms can be classified according to their openness, which refers to the restriction of the respondents' answer options, their structure, which is the degree to which the interviewer is free to formulate the questions according to the situation, and the distinction between qualitative and quantitative analyses (Mayring 2002, p. 66f).

Semi-structured interviews with open questions are called problem-centered interviews according to Witzel (1985, p. 227ff).

Problem-centered interviews are designed for theory-driven research and use cases in which concrete and specific questions are to be discussed. Problem-centeredness means that the interview serves to answer a specific question introduced by the researcher, which has been theoretically investigated in advance (see chapter 4.1) and is central to the interview guideline (Mayring 2002, p. 70). Consequently, this interview form is well suited to answer the given research questions, with a comparatively unstructured form chosen to ensure a holistic recording of the machine manufacturer's needs and perception of the market.

4.3 Preparation of the Interview Guideline

As described above, the development of the interview guideline is based on the findings of the literature review as well as the hypotheses developed (see chapter 4.1.3). The guideline simplifies the conduct of the interviews and structures them for better comparability of the results (Hopf 2019, p. 351).

Prior to the interviews, the respondents complete a short preparatory questionnaire designed to get to know their relationship to digitization and that of their company better. After briefly describing their field of activity in the company (Q2), the participants assess their own knowledge in digitization and IIoT (Q3) and indicate whether they use open-source software privately or at work (Q4). Next, based on Porter and Heppelmann (2014, p. 7ff; see chapter 2.1.1), the degree of digitization, connectivity, and data utilization of the machines is assessed on a five-point scale from no digitization to autonomous optimization of the production process (Q5). Furthermore, it is assessed if the company's business model is focused on hardware, software, or services (Q6). Finally, in case the machines are digitized, it is queried whether the customer's machine data is also evaluated by the machine manufacturer and, if so, for what purpose (Q7) and to what extent the implemented solution is based on internal or external hardware and software components (Q8). Attached is also a declaration of consent for the collection and processing of personal interview data. The data collection is carried out with the online tool "SoSci Survey" (Leiner 2021), for which the participants receive a link.

The following interviews are loosely structured with open questions that allow a natural and informative conversation. After a brief introduction of UMH and the topic of the thesis, the interview guideline is divided into three sections that address the sub-research questions (see chapter 1). It is adapted to the answers in the preparatory questionnaire and online research on the companies' websites before each interview. Irrelevant options are removed and the given answers as well as product facts are inserted in the respective positions. Based on the hypotheses generated in chapter 4.1.3, the interview guideline contains expected response options at several points. After the respondent has answered the question openly, these options, which are marked in italics in the guideline, enable targeted follow-up questions on the relevance of further points that have not been mentioned yet. If new aspects are uncovered, they are included in the guideline for further interviews. This allows illuminating new aspects on the one hand and testing the established hypotheses on the other hand.

In the first section, the current state of digitization of the company under consideration is further detailed (SQ1). If it does not offer connectivity for its machines, respondents are asked to indicate which barriers to adoption exist in their company, with the expected responses corresponding to the categories in Figure 2 (p. 15). If the machines are connected, respondents are asked to describe the scope and functionalities of their solution. Next, the development process of the digitization solution is addressed. After the respondents described the process in their company, it is further investigated if the solution is developed together with other machine manufacturers and if it is based on open-source components. If the companies had a fixed target in mind, it is assessed whether project costs and duration, as well as the result, met expectations. In the case of in-house development, it is of further interest whether the system is based on the offering of infrastructure providers or an IIoT platform. If an existing platform was used or a technology partner was commissioned to create the solution, the decision and selection process should be described to find out what features and attributes the manufacturers paid attention to.

The second section aims to understand what features or characteristics machine manufacturers are currently missing in offered platforms. Depending on the starting point in section 1, respondents are asked to describe what would help them overcome the perceived entry barriers to digitization, what was missing from the range of existing IIoT platforms so that they decided to develop their own one despite the high expense, or whether the purchased solution covers the desired range of functions. Here, the expected answers are derived from the hypotheses in chapter 4.1.3 and are also extended by further aspects mentioned by the respondents. In cases where the functional scope of existing platforms is too small, the offers on the market are too opaque, there are concerns about data security, or the project complexity has been underestimated, the respondents are at first motivated to provide their own solution ideas or describe how they solved the problem. Next, UMH’s envisioned solution concepts described in chapter 3.1 are presented and evaluated by the respondents in terms of their suitability for solving the problems encountered in their company. This way, missing aspects of existing platforms are uncovered, and the value curves for UMH are developed and validated (SQ2).

Finally, the opinion and biases of the machine manufacturers on open source are evaluated, thus providing the data basis to answer SQ3. On the one hand, risks regarding data security, reliability, and programming effort of the platform are assessed. On the other hand the added value of an open-source solution in terms of independence from the platform and infrastructure providers, flexibility, scalability, and the possible support by the community in development projects is evaluated in detail.

In addition to incorporating the findings from the questionnaire, the interview guideline is expanded to include company-specific questions arising from research into the machine manufacturer's solution. Sources include the internet and journals that report on previous interviews with respondents or contain articles written by them. However, to maintain anonymity, the customized questionnaires, as well as the sources, are not provided in this thesis.

4.4 Selection of Respondents

As the samples in qualitative research are significantly smaller than in quantitative research, respondents must be selected carefully (Ruyter & Scholl 1998, p. 8). To ensure a suitable selection of respondents, the purposeful sampling method was used, which does not aim to achieve statistical representativeness of the underlying group but to focus on cases that are particularly rich in information (Patton 2002, p. 230 ff).

For the present application, this means identifying relevant contacts in key companies and interviewing them. For an initial assessment, the most relevant platform users are the machine manufacturers, as they are the ones who evaluate the current market of IIoT platforms and decide on their digitization strategy. Of particular interest are machine manufacturers, who decided to create their own IIoT platform, as they can best provide insights, what they were missing and what would have helped them. As a starting point, a selection of such manufacturers in German-speaking countries is provided by Bender and Lewandowski (2021) based on their previous research. Explicitly excluded are manufacturers of mobile machinery such as farming or mining vehicles, which are also moving strongly into digitization but are not part of the UMH's primary target group.

Regarding the company size, SMEs with limited financial resources and IT capabilities are interesting, as they have the biggest need for a quick and easy to implement IIoT solution, but also larger companies that can benefit from the open-source toolkit are helpful. In these companies, the relevant people are responsible for research and development or IT and thus the digitization of the machines produced. Depending on the size of the company, these can be directors, development managers, or project managers. Eight interviews were conducted with an average duration of 50 minutes.

Table 1 shows the respondents in chronological order according to the conduct of the interview, their position as well as the industry and the size and turnover of their company (North Data 2021, Weltmarktführerindex 2020), which are given in ranges to preserve anonymity.

Table 1: Overview of respondents

	Position	Industry	Employees [-]	Turnover [M. €]
R1	Head of development	Food	1,000 – 5,000	500 – 1,000
R2	Head of mechanical and process development	Textile	100 – 500	100 – 500
R3	Vice president engineering / products	Mineral processing	100 – 500	100 – 500
R4	Head of digital business	Machine tools	> 10,000	> 1,000
R5	Head of development	Filling	100 – 500	10 – 50
R6	Commercial manager at a digitization spin-off	Compressed air	< 10	
R7	Manager of strategic development	Plastics	500 – 1,000	100 – 500
R8	Head of IT	Surface treatment	100 – 500	50 – 100

4.5 Interview Transcription and Data Evaluation

The interviews are conducted via video call due to physical distance and Corona protective measures. With the consent of the respondents in the preparatory questionnaire, the interviews are recorded, which facilitates the later analysis and the conduct of the interviews, as they are not disturbed by the taking of notes. Subsequently, the interviews are transcribed using the software MAXQDA (VERBI 2021), which simplifies the process and allows for detailed analyses. To preserve the anonymity of the respondents, only excerpts of the transcripts are included to support the presentation of results.

To evaluate the transcripts, qualitative content analysis in the form of content structuring analysis is used, which can also be conducted with MAXQDA. Kuckarts (2018, p. 97ff) presents a seven-step process which is closely aligned with the research question. The first step is to read and work through the transcripts carefully, marking important passages and writing memos. Next, based on the research question, theoretical foundations, and underlying hypotheses, deductive main codes are formed. The collected material is then assigned to the main codes, which can be expanded and adapted inductively in the process if necessary. In addition, sub-codes are inductively formed, which are then used to fine-code the material. Coded segments may contain multiple paragraphs but should consist of at least one sentence to provide context. These steps represent an iterative process, which can be strongly supported by MAXQDA. In the final step, the coded material is interpreted and examined, for example, for different views of the participants on various topics.

The resulting code systems are shown in Figure 12 for the analysis of the state of digitization in the machine manufacturing industry (see chapter 5.1), in Figure 13 for the problem analysis and evaluation of UMH's solution approaches (see chapter 5.2.1), and in Figure 14 specifically for open-source properties of the platform (see chapter 5.2.2). In some cases, where specific details of a topic were addressed repeatedly, sub-codes were formed, while general statements were assigned to the appropriate main code. To give an impression of which topics were discussed to what extent, the number of coded segments for the individual codes is shown (cf. Mayring 2002, p. 117).

Status in machine manufacturing		
Technical implementation		10
	Open-source components	6
	Third-party components (e.g., cloud, …)	7
Implementation process		3
	Market analysis for existing components / suppliers	5
	Fixed target in view	7
	Development with technology partner	9
	Development with universities / consortia	2
	Development with other machine manufacturers	5
Functional scope		11
	Remote services / maintenance	10
	Condition monitoring / OEE	9
	Predictive maintenance	6
	Pay-per-use / MaaS	3
General attitude in the industry		13

Figure 12: Code system for digitization status analysis

Problems & solution approaches in the IIoT market	**Effort / time reduction**		0
		Easy entry / guideline / tutorials	11
		Building on existing infrastructure	5
		Services (programming / SaaS)	2
	Building on existing modules		0
		Open interfaces	2
		Standardization / uniform system	7
		Appstore / modularity	11
		Loss of differentiation to competitors	7
	Strategic factors		0
		Business model transformation	2
		Customers are afraid of lock-in	2
		Customers do not disclose data	5
		Customers are not technology-savvy	3
		Customers do not see the added value	3

Figure 13: Code system for challenges and solution approaches evaluation

Open-source approach	**Inhouse programming**		0
		Programming need is deterrent	7
		Reliability / "tinkering character"	7
	Flexibility / adaptability		8
		Existing platforms are too limited in their functions	5
	Independence / scalability		0
		Independence from platform provider / infrastructure	3
		High costs / poor scalability	6
	Data security		0
		Data protection / security risks	13
		USA, China / Legal Compliance	3
		Communication	2
	Willingness to collaborate in B2B		5

Figure 14: Code system for open-source assessment

5 Results and Analysis

As described in chapter 4.3, the interviews were structured in three parts. Chapter 5.1 discusses the results of the first part on the status quo of implemented platforms answering sub-research question 1. Next, chapter 5.2 evaluates the respondents' assessment of UMH's approach and the open-core model to lay the foundation to answer sub-questions 2 and 3. Finally, chapter 5.3 sums up the findings and derives UMH’s value curves.

5.1 Digitization Status and Implemented Solutions

To introduce machine manufacturers’ current digital platforms, chapter 5.1.1 addresses the scope of functions, and chapter 5.1.2 the digitization approach.

5.1.1 Functional Scope

Figure 15 shows the currently implemented and planned functionalities of the interviewed machine manufacturers’ digital solutions and platforms. Included is communicated information and publicly available information gathered online.

Only machine manufacturers with existing digital solutions were examined (see chapter 4.3), all of which use the established connectivity for remote services. They are implemented either cloud-based (R1: 14; R6: 2), so that proactive services can also be offered via the continuous evaluation of data, or with pure on-premise solutions, for which access authorizations must be granted in every maintenance case (R2: 8; R5: 10-12). Some manufacturers offer both variants to not scare off customers with data security concerns.

Remote services offer clear economic benefits, as travel costs and working time can be saved, especially for globally operating machine manufacturers, which is why they are already being implemented so comprehensively (R7: 2; R8: 2). They can include support for the customer during maintenance or process optimization. Another use case is the support of in-house technicians during commissioning or in solving special problems, for which an expert is consulted (R7: 2). In one case, an augmented reality solution is being tested that allows service employees to point to relevant locations via smart glasses or the customer's smartphone, which helps to overcome language barriers and quickly identifying the causes of errors (R8: 2). Other companies offer spare part procurement in their platform (R3 company website) or plan to do so (R2: 12).

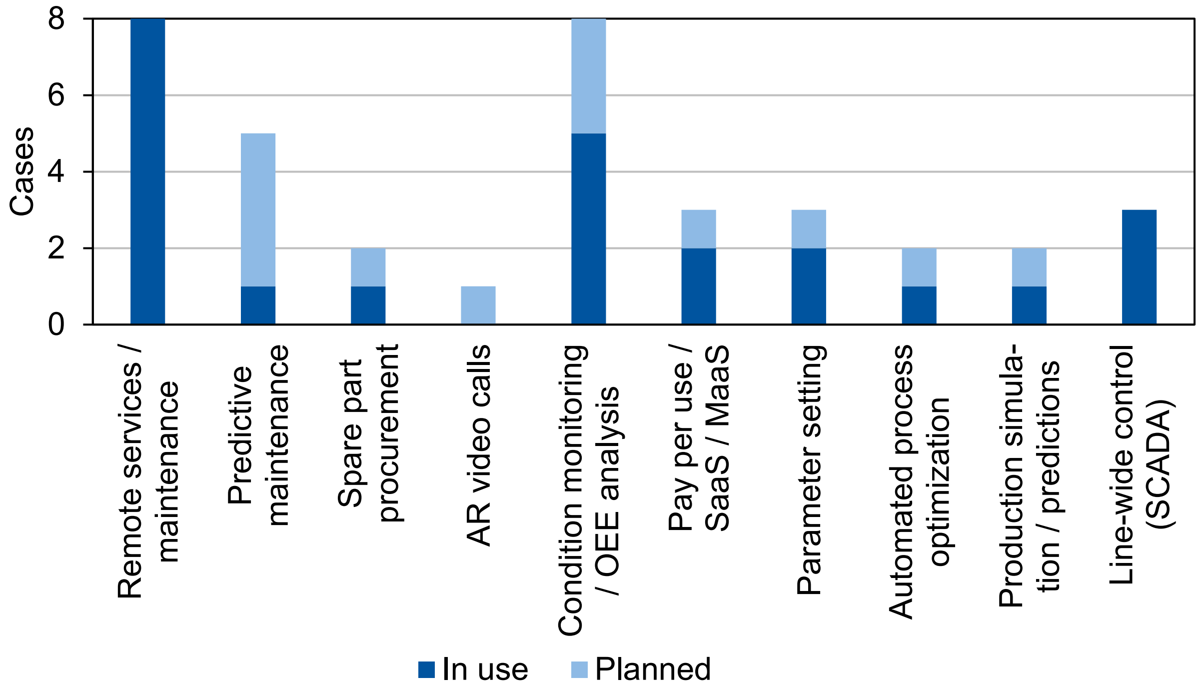

Figure 15: Currently implemented and planned digital functionalities in manufacturers' platforms

A related topic, which is viewed with great respect and uncertainty, is predictive maintenance. Only one machine manufacturer indicates that it is currently able to schedule wear part replacement based on machine learning predictions (R3: 2, company website). Four further manufacturers are planning predictive maintenance functionality but are in the early stages of development or looking for a provider (R1: 6, 14; R2: 30-32; R6: 2; R7: 4). The general perception is that currently very few providers and competitors are truly capable of realizing predictive maintenance.

R6: 2 *“And we are currently doing some really cool predictive maintenance pilot projects. I call them pilot projects because everyone is claiming predictive maintenance, yet very few are actually doing it.”*

R7: 6 *“[…] whether it is a machine manufacturer or an end customer that says they do predictive maintenance. At least that is what it says in their PowerPoint, but if you ask more specifically, there is not much to find there. I think that is the case with a lot of companies. And precisely because this topic is still relatively new, there is not yet enough experience of what really has been proven to work.”*

A major hurdle in implementing predictive maintenance is acquiring data in sufficient quantity and quality to "make statistically robust statements" (R7: 4). This leads to the second major component that is currently used by five and planned by the other three manufacturers: data collection to enable condition monitoring and efficiency improvements. Although on-premise solutions can be found here (R5: 16), there is a clear trend towards cloud implementation, as computing power and prebuilt modules for evaluations are available and cross-plant analyses become possible (R1: 2; R2: 12-14; R4: 2).

In three cases, machine manufacturers have implemented comprehensive data collection and analysis, which allows them to plan maintenance activities efficiently and thus to ensure machine uptime. They can therefore offer pay-per-use models in addition to traditional machine sales but still describe themselves as hardware-oriented (R1: 26-28; R4: 16-18; R6: 2-6; preparatory questionnaires). R4 states that the company currently generates roughly a third of its turnover from services, but that he is committed to further transforming the business model towards services (R4: 16-18; see chapter 2.1.1 for servitization). Another interesting case is the supply of compressed air, which is provided by R6 with a high level of process reliability and can thus be billed according to actual consumption (pay-per-use) like electricity.

R6: 4 *“And we can […] provide the customer with this expensive form of energy, compressed air, in the best possible way. And this works best when this overall process is well thought out, which also includes service and maintenance.”*

On the other hand, machine manufacturers still have to deal with the very conservative industry in Germany. In the case of R1, some end customers even accept higher costs combined with lower guaranteed machine availability to not have to provide the machine manufacturer with the machine data despite using the manufacturing-as-a-service offer.

R1: 26 *“Because we also want to offer our customers a cost-effective solution that includes maintenance and availability of the machine for a certain fee. In this case, it is very interesting for us to access the data, and we say: if you [use our service], you must connect your machines [to our platform]. They still do not always do so. Then the price for the full service simply is higher.”*

Apart from remote services and condition monitoring, each industry and machine manufacturer has additional specific use cases and requirements for IIoT platforms. Especially in the food industry, a sensitive control loop for the filling weight is necessary to comply with regulations without giving away too much of the product (R1: 2). Interviewed machine manufacturers in the food and textile industry use the connection of the machines to offer a possibility of managing their lines and setting recipes from a central location (R1: 2; R2: 26). Some even plan to offer automated process optimization based on the measured data (R1: 6; R4 company website) or based on predictive simulations (R2 company website, R6 company website).

In machine manufacturing, there is currently a slow trend towards the creation and use of open interfaces. While OPC UA has already become widely accepted as a standard at the machine level (R1: 10; R2: 44; R3: 14; R4: 10; R8: 16), standards and interfaces for a cross-manufacturer production system are only slowly emerging. Interfaces are planned for integration in existing MES- or ERP-Systems or the provision of data for factory-wide monitoring in third-party or other manufacturers’ platforms (R1: 42; R2:

24; R4:10). The following statements show that most machine manufacturers recognize the urge and benefits of openness and standardization, but that the market currently lacks satisfactory solutions that provide a solid starting point and minimize the effort.

R3: 14 *“In the end, there is hardly an industrial bus that our system cannot handle, whether it is Profinet, Modbus, or whatever. We already have a lot of communication capabilities that our system brings along right from the beginning. And of course, something that is on the rise now strongly, and which we also appreciate very much, is this whole topic of OPC UA. Because you can link directly with almost all manufacturers who have recently dealt with control technology. A Siemens, an Allen Bradley, a Becker [PLC], they all have their OPC UA interfaces by now, and of course, this makes it easier to access the datasets.”*

R4: 14 *“And of course we also use connectivity as a really big standardization program. For example, we want all our machines to have the same OPC UA implementation. We are also in the core group of [a] consortium, where we see that open, standardized interfaces are the only way in the medium term to be able to offer these smart monitoring concepts and to sell them successfully on the market.”*

R1: 42 *“We are a medium-sized company [...] and the production processes at our customers are much larger and longer than what we offer. We always offer a partial aspect. Maybe a broad one, but at some point, it ends and then there is an interface to other manufacturers. And we look for certain alliances where we can perhaps also offer platforms for overall line monitoring and so on. But everything has its limits, so we have not really come very far yet.”*

R2: 24 *“That is the main topic of this research project that we make this data available for ERP systems. But we do not want to link up strongly with other manufacturers because that would probably overstrain us as a subdivision.”*

R7: 30 *“If we have our own platform, then the other machine manufacturer from whom the customer also has a machine will probably have a different solution. If*

> *these different solutions can be merged via a standardized interface or however that is implemented that makes sense in any case. I think everyone would like to have something like that, but I am not aware that something like that exists. I do not know exactly how something like that could be solved."*

However, in some cases, the manufacturers' machines can be integrated and controlled via an overarching production system, for example, a Siemens factory control (R8: 8-12) or an ERP-system (R2: 22-24). In these cases, larger producing companies already have their customized, overarching system that provides all the necessary information, while SMEs often see no need for machine connectivity because their processes are less complicated (R2: 26; R8: 8), so that machine manufacturers do not engage in the development of an own overarching condition monitoring solution.

Other manufacturers use the established connectivity to control additional machines in the line, even if they are from different manufacturers. Those manufacturers use self-developed machine PLCs instead of building on existing ones and started early to equip them with connectivity components (R1: 2, 8; R3: 18-20, 26). Since the required knowledge in IT has been built up in the company to develop those solutions, the step to comprehensive integration and control of whole production lines is associated with less effort compared to competitors with little IT knowledge.

5.1.2 Digitization Strategies and Implementation Processes

The motivations of machine manufacturers to start a digitization project vary. Some started recording data to find out what added value and use cases they could generate with it (R1: 6; R2: 29-30). Others had a fixed target in mind, which was either requested by customers (R3: 17-22; R7: 2; R8: 2) or intended to increase internal maintenance efficiency (R6: 9-10). None of the respondents indicates that development is completed yet, so even established platforms are constantly being enhanced with new features resulting from new requirements or new technical possibilities (R1: 6; R3: 22). It follows that even manufacturers with existing platforms are also potential future users of open-source components that add a feature or interface to their solution. Thus, they are potential customers of UMH.

At the beginning of the digitization project, companies seek information on which competencies and components are needed for a platform with the desired functionalities. As machine manufacturers' core business is the production of hardware, they usually do not have large IT departments with the capability of developing such a platform in-house (R2: 34; R3: 6; R6: 12, 22).

R3: 24 *"First of all, we tried to find out what capacities we would need internally to do something like this ourselves. And then, unfortunately, you very quickly come to an amount of needed personnel and, above all, to different skills that you cannot combine in one person so that we very quickly realized that developing something like that all by ourselves in-house would be completely unfeasible for us. That would never have worked because we would have had so much initial investment."*

But even if manufacturers plan to outsource the development, they need to build up a basic understanding and knowledge to be able to clearly define the specification (R2: 60; R6: 20).

R2: 60 *"But you can only get the specification if you familiarize yourself a little, because then you can roughly estimate what the system is capable of and then you can also better define the boundary conditions. [...] if you do not really know in advance or you only have a vague idea of what the systems can do, then, of course, the specifications and requirements are also formulated in a vague way, which leads to a lot of subsequent business. And that is of course always to the disadvantage of the customer […]."*

To build up knowledge and develop a solution, most machine manufacturers rely on external sources. Manufacturers with concrete ideas and a high need for flexibility rely on technology partners for development. Some work with a vendor that has prior knowledge and partial solutions in the IIoT space and develop the solution together. In R3's case a flexible solution was required that could connect and control individual machines from different manufacturers in a production line (R3: 18-22). To implement this, they cooperated with a technology partner who had already implemented basic functionalities such as PLC communication, which accounts for about 20 % of the current solution (R3: 6-10). Since this partner is also a medium-sized company, the joint further development took place on an equal footing, which was an important selection criterion (R3: 24). R4's company followed a similar strategy, but as a large corporation, it bought the corresponding partner, which still also sells the solution to direct competitors (R4: 2-4).

Manufacturers who have little in-house knowledge or conservative customers and thus less specific requirements tend to purchase off-the-shelf solutions or platforms. In the case of R8, the company has tried to introduce digital solutions pushed by the IT department such as machine connectivity and an OEE cockpit to its customers in several places, but interest has been low (R8: 10, 36-40). Therefore, it is currently sufficient if they use standard components of a proprietary IIoT platform for their remote maintenance service (R8: 16-20). R6's company initially opted for a cloud and then looked for a solution to record and upload the data. There is a broad market for this, so at the beginning, an external solution could be purchased that required little in-house knowledge. During the implementation process, they gathered IIoT-knowledge and were able to formulate more specific requirements for their solution. Although the company is quite small (<100 employees), they decided to spin out a digitalization startup. With the knowledge built up in the process and a newly hired technically proficient CTO, it is now able to gradually replace the purchased components with open-source solutions to gain flexibility and expand the solution (R6: 12, 20-22, 30).

R7's company also relies on an existing open-source stack, which meets their requirements for flexibility and independence of a platform provider in terms of cost and data security. As a larger company (> 500 employees), they have the capability to customize and maintain the solution (R7: 2, 8). With an even larger company that also develops its PLCs entirely in-house and therefore has in-depth IT knowledge, it made sense in R1's case to also drive digitization in-house. This was especially due to the non-existent IIoT market and the resulting lack of alternatives when the project was started in 2005 (R1: 2, 8).

In general, open source is interesting for smaller companies as well. Of the six companies surveyed in this regard, the solution of five is based at least partly on open-source components (R3: 15-17; R4: 8; R5: 29-30; R6: 12; R7: 2; R8: 15-16). The perceived advantages and disadvantages are further elaborated in chapter 5.2.2.

Overall, it can be stated that the competitor categories selected in chapter 4.1.1 primarily target producing companies and therefore only fit the context of this thesis to a limited extent. Only system integrators offer the necessary flexibility to meet the requirements of machine manufacturers and become their technology partners. Therefore, they are the main competitors for UMH regarding this customer group. A classic IIoT platform is only used by R8, whereby only the subcomponents for connectivity and VPN are currently relevant (R8: 20). The offer of infrastructure providers requires corresponding expertise and is perceived by the smaller interviewed companies as being directed more at large corporations, particularly due to the high prices and the great dependence into which SMEs are placed (R3: 24; R5: 14-26; R7: 8; R8: 10). This assessment is reinforced by the fact that R4's company, as the largest one surveyed (>10,000 employees), actually partners with Microsoft and develops its platform based on Azure. However, they have also decided against Windows 10 IoT and in favor of Linux as the open-source operating system for their edge devices to maintain independence, comply with international regulations, and maintain customer trust through their openness (R4: 8-12; 20).

A further strategy to build up knowledge in the early stages is the collaboration with universities and consortia during research projects (R2: 2; R5: 19-22). This is done mainly when machine manufacturers want to address the topic to ensure their competitiveness, but customers do not yet demand digital solutions (R2: 27-30). Consequently, research projects are a promising marketing channel for UMH, as companies can quickly learn how to use the platform to drive their digitization in early development stages.

A third strategy is a joint development with other machine manufacturers to share knowledge and costs and to develop overarching standards. This is done by 7 % of the 116 companies analyzed by Bender et al. (2020, p. 10), but by none of the companies considered in this thesis due to the respondent selection described in chapter 4.3. One manufacturer indicates that it is generally interested in collaborating with other vendors along the value chain (R2: 62). However, some manufacturers indicate that collaboration is not necessary because smaller or specialized customers only use machines from one manufacturer, while in most cases their larger customers implemented overarching data management via an ERP system or a custom developed IIoT solution based on an infrastructure provider for which they only provide the data (R2: 21-24, 26; R8: 10-12). Another reason against collaboration is the fear of losing differentiation from the competition:

R1: 4 *"It is a fully in-house developed solution. I would say that it is typical of machine manufacturers that we always try to set ourselves apart and create our own solutions to have a special position. I think machine manufacturers in Germany traditionally have a hard time with open interfaces, with comprehensive solutions, and so on. We are simply very traditional, which is not always good, but that is just the way it is."*

5.2 Assessment of the UMH Approach

After an overview of the status quo and the platforms of the machine manufacturers has been given, the following chapter is dedicated to their assessment of UMH as an IIoT platform. Chapter 5.2.1 addresses the problems on the market perceived by machine manufacturers and their opinion of UMH's solution approaches, thus answering sub-question 2. Chapter 5.2.2 is about the perceived advantages and disadvantages of open source, answering sub-question 3.

5.2.1 Platform Properties and Blue Ocean Strategy

5.2.1.1 Implementation Effort and Time-to-Market Reduction

The first advantage of a platform from a technology-oriented perspective is the possibility to share technologies and build on existing structures (see chapter 2.2.1), which is also appreciated by the respondents (R1: 12, R2: 62, R5: 30). This reduces the need for monetary, time, and human resources to implement a working solution. This is particularly important for SMEs, which are naturally scarcer in these resources than large corporations. Even for the very conservative company of R1, which wants to develop as much as possible in-house, the aspect of saving time has priority over differentiation.

R1: 12 *“From today’s perspective, I would say that it is reasonable to use platforms and to use existing things, simply to move forward more quickly. In fact, time-to-market clearly is more important than any USPs [unique selling points] that you can generate. You really must move forward in a customer-oriented way [...]. So, the whole way of development has definitely and clearly changed in the last 20 years [...]. The world is much, much more fast-paced, and of course, you must take that into account. And it certainly makes sense to make better use of existing platforms to move forward more quickly.”*

Below, UMH's approaches to effort and thus time-to-market reduction are evaluated in the phases of the machine manufacturers' digitization projects identified in chapter 5.1.2. The first step of manufacturers of every size is knowledge building. A concentrated knowledge database with articles and explanatory videos on basic IIoT-relevant topics, which components are needed for which functions, and how these specific platform modules are used and set up, received positive feedback and was consistently rated very helpful (R1: 18; R4: 35-38; R6: 15-20; R7: 24; R8: 33-36). The same applies to forums that help to solve problems faster and with less effort by consulting the community (R2: 52; more on B2B collaboration in chapter 5.2.2.4).

R1: 18 *“The smaller the company, the more you will have to rely on existing building blocks. And it helps, of course, if you say you have good instructions on how I can connect them [...]. That certainly helps for companies that […] do not have the possibility or that cannot afford this personnel deployment [...]. It would also help us here and there. As I said, we are a typical machine manufacturer who is also very conservative and wants to do everything in-house, although we actually sometimes have a hard time doing so in practice.”*

For UMH, this form of content marketing is a very promising mechanism, as it targets also non-technical customers in those early stages who are seeking specific information. A website with a wiki contains a lot of technical vocabulary, which is an important factor for search engine optimization (SEO). Therefore, this technique is used by more and more companies also in the B2B area. It promotes the customer-centricity of business activities and builds trust with customers (Holliman & Rowley 2014, p. 269ff), which is also appreciated by R7:

R7: 24 *“Yes, I think that is good if you mean that you show non-professional programmers how everything is built up in the background, how it fits together, and how you can develop it further. Whether they can do it, in the end, is a different story [...], but there will surely be a better understanding. And I honestly think that is very good, I think that is absolutely great. And it also arouses more trust on the customer side if you understand what is happening in the background. That is the big drawback with any off-the-shelf solutions that you purchase, where you cannot understand what is happening in the background and have no influence on it. It is just opaque at that point, and this would make it transparent. I think that is totally great, to be honest.”*

Once companies have understood which components and which knowledge they need on their way to digitization, they have the choice of either having everything developed externally or providing internal resources. At present, the only way to gradually balance the own effort between required flexibility and needed resources is to co-develop with a technology partner, whose search and selection involve expense.

UMH remedies this by offering modular, pre-configured components that can be quickly implemented into a functional solution and then customized step-by-step to meet the customer's specific needs. In combination with the wiki, this provides a smooth entry to the subject. In addition, at any point, there is the option to access UMH development services that will complete the solution building on the customer's progress. This safety net ensures that even as resource allocations change within the organization, full control of project progress is maintained and costs already incurred are not wasted, minimizing the barrier to entry.

R2: 60 *"For sure [such service is helpful], yes. As I said, there will be such and such clientele. Some are a bit more willing to experiment, they just start experimenting with it and see how far they get. And at best, they get so far with it that they do not need anyone else and just implement it with guidance [from the wiki]. And then there are others, just like our customers, who want everything from a single source and do not want to suffer any pain of their own, but let the provider do everything. I think there is a wide range."*

This range can be covered by such flexible services, which is unique on the market and highly valued by the respondents. The free, nonbinding access to modular components and apps (see chapter 5.2.1.2) is not only interesting for newcomers, but also for machine manufacturers who want to add further functionalities and components to their existing platform through open interfaces. In cases with uncertainty about whether a customer need will be met by a planned application and whether there is a willingness to pay (see chapter 5.2.1.4), resource-saving pilot projects and minimum viable products (MVPs) can be implemented quickly and then gradually enhanced if producing companies are interested in the solution.

5.2.1.2 Open Interfaces and Platform Standards

As described in chapter 5.1.1, standardization and open interfaces are considered necessary by most machine manufacturers to move forward in digitization. However, it must be considered at the platform level to what extent common standards are agreed upon and at what point competitors differ. It is certainly necessary to have common standards at the infrastructure level (see Figure 4, p. 24; connectivity, device management, database structure), to enable manufacturing companies to smoothly integrate their heterogeneous machinery and other data sources (R1: 10; R2: 44; R4: 32-34; R6: 38; R7: 6, 30-32). But how far machine manufacturers can differentiate on the platform (data processing and aggregation) and application-level (visualization, industry-specific use cases, interfaces to further systems; see chapter 5.2.1.3) is difficult to assess at this stage and depends largely on the sector-specific strategies of competitors.

R7: 36 *“The question is whether you want to differentiate from the competition [...] with the software solution itself. To stay with our case, that would mean just because I do predictive maintenance and condition monitoring, the customer buys my machine. Of course, if I have this capability and the competition does not, then I can use it to differentiate. But is that really a criterion for the customer? There is another way of looking at it: As you just said, there will be standards, so [my solution] can be coupled with several other platforms. Maybe that counts more, maybe it is more of a buying point for the customers that they can integrate [the machine into their existing system] and that is why they are choosing my machine, me as a provider [...].”*

Similarly, R6 notes that standards help companies focus on their core business and expertise by covering basic functions with off-the-shelf building blocks while being open to extensions. On the other hand, she has the impression that the topic of standardization is viewed too theoretically and is given too much emphasis in some cases, ultimately leading to a less pragmatic approach (R6: 38).

R6: 38 *“I would find it boring if my pure expertise were in data mining. It is much more exciting if I can use the knowledge I have about the data to build analyses, intelligence, and algorithms in all forms. [...] That is why standards are basically a good thing, as long as they are not so exaggerated.”*

R4 assesses that, in the long term, differentiation in the global operating machine manufacturing industry can only take place via the business model, which matches their comparatively strong service orientation (R4: 15-16; cf. servitization, chapter 2.1.1).

R4: 32 *“I was involved in the time when our [IIoT platform] was a unique selling point, but and in the meantime, the platforms have become a standard. It is more about the business model, if we have a good idea and if it is implemented well. But the platform itself is no longer a unique selling point in my opinion.”*

5.2.1.3 Modularity and Appstore

But also, on the application level, some features barely differ from industry to industry. For example, remote maintenance services via video, or the basis for calculating the OEE and its presentation in a dashboard is consistent. In these cases, it makes sense for an IIoT platform to offer ready-to-use applications that require only minor customization in an app store. This way, machine manufacturers can cover the wide range of applications their customers require with little expenses (R4: 22-24; R6: 39-42; R8: 23-24).

R3: 44 *“It depends on the toolbox that you now have to build up creatively. You must find out what the smallest common multiples of the various sectors are and which patterns and questions recur. And then you must make very special, but extremely variable, proven, and reliable building blocks out of it. I am pretty sure you can make money with this.”*

It is not only the field of IIoT platforms where it makes sense to design the offer in a modular way for different industries. R7's company is considering to offer own apps on its envisioned platform to the customers, as the requirements and opportunities for generating added value with digital solutions differ greatly even within the customer base of the same industry. However, they would still be glad to build on existing apps to reduce in-house development efforts.

R7: 14 *“But we are also considering offering our customers corresponding apps, depending on what they want to do. It must be said that we are a machine manufacturer and not a software producer. The more development is done for us, the better. The more ready-made things we can purchase and offer directly to the customer, the better. But without neglecting adaptability and flexibility.”*

Another advantage of commonly used apps with standardized basic functions and visualizations is that they can be improved quickly through constant feedback from a wide range of customers. By constantly increasing the user-friendliness, even technology-averse companies can quickly benefit from the adaptations. For example, R1 notes that some producing companies have respect for abstract, AI-powered functionality like automatically generated recommendations for action and are not sure how to use it, which probably can be overcome more quickly if a common standard is used and continuously improved.

R1: 30 *“And I think there is still a certain amount of work to be done to overcome this respect and to offer building blocks that can be used and integrated better and more easily. I believe that there is still a need for this because it is simply more difficult to grasp than a clear algorithm.”*

Modularity is also important in terms of the customer's existing infrastructure. There are all cases, from non-existent infrastructure in the production plants to producing companies that control their entire production with an infrastructure provider's system such as Siemens Mindsphere, and those that demand a purely on-premise solution due to data protection concerns. Therefore, it is important to be able to support various infrastructures for data storage and processing (R1: 24; R4: 24-26; R5: 6-8; R7: 6; R8: 30).

R8: 30 *“The connection of the customer's system to the Internet accounts for 99 % of our problems. Some customers do not want the system to talk to the outside world, some of them are big companies. And some of the others have only a limited comprehension. [...] A system is set up, and it is ensured that electricity, water, exhaust, and fresh air are available. But the fact that the internet is needed, the network, is forgotten. [...] You cannot even imagine it nowadays, but the connection of the machines to the internet is still one of the most important issues for us.”*

R1: 24 *“What we actually find is that the biggest problem is convincing our customers to provide data. Some of our technology users have directives that no data is to leave the company and to be sent to the cloud. There is no way to access the data in any form, so they are very restrictive.”*

R4: 26 *“[On premise] is not available off the shelf, because that still involves a lot of implementation effort. It also depends on the customer, how much experience they have, and whether they already have an on-premise solution. It should be* *our goal to be able to offer that relatively smoothly, but there is still a long way to go to offer seamless modularity.”*

R5's company was looking for a modular on-premise solution that could record data from the PLC and store it locally. External access via VPN should only be possible after an explicit request by the customer in case of maintenance. These functionalities are not offered by smaller IIoT platforms and large solutions from infrastructure providers like Siemens or Telekom would be far too expensive, so a solution was developed in-house. This shows that there is a need but currently no modular offering for such basic functionalities (R5: 23-28).

Finally, similar to the platform level, some manufacturers are concerned that their competitive differentiation will be lost if the same apps are used across the industry (R1:14). However, a comparison can be drawn here with the mechanical product. There are basic machine components that must be the same across the entire industry to complete the task. In the future, this may also include basic apps. Based on this, machine manufacturers have their specialties with which they stand out from the market today at the machine level. This is also possible on the software side (R4: 6; R7: 38).

R7: 38 *“You also mentioned the topic of apps earlier. You can develop very specific apps that other providers do not have and then use them to differentiate yourself. Maybe you can combine the best of both worlds [standardization and differentiation].”*

5.2.1.4 Strategic Factors for Machine Manufacturers

In summary, the tradeoff between standardization and differentiation is a strategic one and must be decided for each specific use case at the management level with the involvement of experts from development and marketing.

R1: 20 *“I believe that there has to be openness at the management level and that persuasion is needed [to become less conservative].”*

At present, the machine manufacturing industry is very conservative (R1: 4; R2: 24; R3: 38; R6: 8; R8: 36), but there is a trend towards openness and cooperation (R1: 12, 18-23, 38; R2: 52; R3: 12; see chapter 5.2.2.4). This applies not only to the different attitudes to innovation management between executives and developers within the companies themselves but also on the end customer side. R8, for example, faces the problem that their customers do not yet see the added value of condition monitoring and evaluation of production data. They believe that digital solutions will find their way into production, but they cannot predict when. So far, their developments have met with only mild enthusiasm (R8: 9-12, 36-40).

R8: 36 *“I do believe that there is a clear need for this because machine connectivity and issues like that will definitely be necessary. [...] I just do not know exactly when the right moment will be, it is always a question of timing. […] As I said, the dashboard development was a memorable experience for me. A lot of time was invested and then you present it to customers, and they say: yeah nice… great (ironically). That is frustrating and makes you wonder whether the customer did not understand the added value or whether we did not understand the customer. There are always two views on such things.”*

Some manufacturers are thus uncertain, which technologies and IIoT platforms will prevail and whether their customers will accept the solutions and be willing to pay for them. This is also the case for R7 and R8 regarding predictive maintenance. They are therefore pursuing a fast-follower strategy and are currently waiting for clarity in the market, while they are already building up knowledge internally.

R7: 6 *“And precisely because this topic is still relatively young, there are not yet enough empirical values as to what really proves its worth. We are certainly not a small machine manufacturer, but there are certainly many that are much, much larger. That is why we must make sure that we do not invest huge sums of money to end up with a half-working solution. I believe that this is simply a topic where companies that have enough money to further develop such topics are now jumping on the bandwagon and then the others must simply catch up.”*

R8: 6 *"That is why, as part of a student project, we also looked at predictive maintenance and the evaluation of production data. [...] So far, we see only limited necessity or added value for our customers. [...] The question always is what is the added value afterwards and what can I commercialize from it? What is the benefit for me? What does the customer actually pay if I provide him with more data? Some customers are more interested in this, others do not really care because they have a fixed maintenance cycle. And that is why we are already checking it out [...], but we still lack a bit of faith that this will really make a breakthrough."*

This behavior is described by Moore as typical for early adopters (Moore 1991, p. 9; see chapter 2.3.2). The opportunities to build a lean MVP with the platform and capture the learning experiences during the process are promising for attracting such customers and thus crossing the chasm.

Finally, the servitization trend itself burdens machine manufacturers with the transformation of their business model to service providers in addition to the required knowledge acquisition in the IT area (R1: 26; R2: 12; R4: 16-18; R6: 2-6; cf. servitization, chapter 2.1.1). Targeted wiki pages and forum exchanges can also be helpful here.

R4: 16 *"But in the future, integration with customers will be the key, and that can really only be achieved through open collaboration. And my job is [...] to be able to bring the new business models to the customer cleanly. For example, bringing subscription models, software-as-a-service concepts to the machine HMIs [human machine interfaces]. These are all new issues for us, also in terms of our*
R4: 18 *organization, and we must address and deliver them cleanly. […] So that we can on the one hand strengthen the conventional business, the sale of our machines, but of course that we can also bring our machines closer to the customer with better services."*

5.2.2 Evaluation of the Open-Source Approach

As already stated in chapter 5.1, more than 80 % of the companies surveyed on this subject rely on open-source components. The following chapter presents the perceived advantages and disadvantages of the open-source characteristics.

5.2.2.1 Programming Effort and Reliability

The biggest tradeoff for companies establishing an IIoT system is between necessary programming effort and flexibility. Machine manufacturers have to build up IT knowledge or rely on services to tailor the open-source stack to their needs and integrate the interfaces into their systems, but in return, it offers them the flexibility to implement, constantly adapt, and optimize their specific requirements. A solution is the implementation and programming service offered by UMH described in chapter 5.2.1.1. Particularly in cases where machine manufacturers have little background knowledge of programming and open source (R6: 23-28), there may be concerns that an open-source solution would have a "tinkering character" and could not compete with a proprietary solution.

R6: 28 *"I think this is simply because there is no knowledge. Let us think about Firefox, which is also an open-source solution. Do I know that if I do not think about it? Not necessarily. And I think there is a [knowledge] gap here that you just have to close. So, from that point of view, I think it is not a bad approach to say "we might start by giving somebody the needed tools and a lot of explanations".*

Those concerns are amplified when critical processes are controlled (not just displayed) by the IIoT platform, for which the manufacturer does not have the confidence to achieve sufficient reliability, real-time capability, and fail-safety with a self-developed solution. R3 shares his concerns about this, emphasizing repeatedly in the interview that solutions have to prove themselves to convince him, which also applies to the open-source aspect. However, since they have dealt intensively with the topic of IIoT and developed their own solution, they can as well be assigned to Moore's early majority, i.e., the most critical group in technology adoption (Moore 1991, p. 9; see chapter

2.3.2). The following quotes illustrate a possible mindset of the group members and confirm the importance of showing successfully deployed use cases with innovators and early adopters to demonstrate system reliability.

R3: 37 "*Maybe it is just my industry, but we are extremely conservative in special-purpose machine manufacturing and if someone comes around the corner with open source [...] and I imagine assigning one of my engineers to it, then this would have a tinkering-cellar atmosphere that we simply cannot afford. We are a premium manufacturer and, in this respect [...] I personally have different requirements.*"

R3: 39 *"What is always lacking at the end of the day is the technical implementation, [...] you need someone who can do that and who clearly also has the sovereignty to say "yes, of course, I can do that, and it will also work reliably". You always have to remember that some of these things are vital to people's existence, and they become very, very cautious when it comes to any solutions that have more of a tinkering character."*

R3: 45 *"Open source naturally conveys this hobbyist message somewhere. If you get into it a bit and if you have the right people who can deal with it, and I can only emphasize that twice, then you can create excellent things with it […]. Thus, I would not see it as critical. But especially with the security-related components, firewalls, etc., you have to put a lot of thought into it so that you do not give the impression that it is tinkered together. Otherwise, you have lost."*

For less critical functions like VPN, remote maintenance, or condition monitoring, open-source solutions are already commonly adopted with no concerns regarding the reliability (R5: 33-35; R6: 23-28; R7: 25-28). In his position as IT manager of a machine manufacturer with an IT background, R8 was able to identify interesting differences in approach and perspective between software and mechanical engineers.

R8: 56 *"I am quite open about that because it is a bit frustrating for me: We build some software up and it is running and I am actually totally happy. And then my colleagues come by and say "it is crashed again", and I say "yes hello, 99 %*

availability". Then they say "yes, but not 100 %!". For an IT specialist that is actually nonsense. […] We develop quickly according to Scrum until we have an executable solution, and then we move on. But they do not know this procedure. […] And this understanding of IT is, in my view, rather slowly arriving in mechanical engineering. […] The fact that you have to increase the speed of change to remain competitive in the future and that you then have to accept that some things are not 100 % fully developed is something that mechanical engineering still has to learn from my point of view."

This shows that there is a certain potential for conflict in development now that machine manufacturers and software specialists inevitably have to work together. A reasonable approach for machine manufacturers is therefore to start by implementing non-critical interfaces, processes, and functions into their platform. These are rolled out as soon as they are functional and then continuously updated and improved. As soon as reliability allows, more critical applications can be added. In the case of R7, this process was performed by an external software company.

R7: 22 *"We do not have our own programmers, but the system is based on open source anyway. As I said, the programmers are external, but that did not deter us. We also saw that we would be more independent and flexible. At the end of the day, we have calculated that it is cheaper. But we also have to make sure that the solution is developed further ourselves."*

This shows a need for UMH's offered programming and implementation services, which include consultation for further development and maintenance in the case of issues. Those services can be consulted by companies that are overburdened with the adaptation of open-source components, which may be the case for many SMEs (R3: 33, 39; R4: 36).

Since the platform itself is continuously used and improved by a large user group, problems are found and fixed earlier compared to a proprietary system, ultimately leading to a potential higher reliability of UMH from a certain point. This also applies to the apps (see chapter 5.2.1.3), which just have to be adapted to the industry- and company-specific needs and help to decrease the programming effort.

R7: 14 *“The more ready-made building blocks we can buy and offer directly to the customer, the better. But without neglecting adaptability and flexibility. [...] You have to combine the best of the different worlds. That way, we do not have to go from being a machine manufacturer to a software company just because a solution is adaptable, flexible, and open source."*

In terms of programming effort and reliability, UMH is in direct competition with infrastructure providers such as Siemens Mindsphere, which also require customization effort but may be perceived as more proven by the market.

R4: 36 *“You require quite a lot of know-how before [the customer] dares to start an open-source project. That is where all the Trumpfs and Adamos come in. They have formed a large ecosystem, and they try to exploit the insecurity and ignorance of [the SMEs with little IT knowledge] and say "come on, we have already prepared everything, you can actually just get started.”*

5.2.2.2 Flexibility, Independence, and Scalability

One possible solution is to communicate the clear advantages of open source over such a solution: flexibility, independence, and scalability, which are indispensable for machine manufacturers in the IIoT sector (R1: 23-24; R4: 8-10; R6: 46; R7: 8-14).

R6: 20 *“We have now made a decision that we will change things and partly use open-source solutions to [...] meet the desire to be able to design more things according to our ideas out of this flexibility. [...] And I think we could perhaps have made the decision a year ago if we had had the tools and had recognized earlier that we were lacking this necessary flexibility in some points.”*

R8, as the only respondent with an IT background, attests that a solution that is supposed to enable such flexibility "is properly located in the open-source domain" (R8: 24). R7 also reflects that when looking for a suitable provider, they had the choice between ready-made IIoT platforms or solutions composed by system integrators from various building blocks on the market (R7: 8). They prefer the individually assembled solutions, as these can be "customized according to the preferences or the things [they] value" (R7: 8), while current platforms offer little customizability. This was also important for R4, who wanted to preserve flexibility and independence to serve all their customers with various systems and thus did not choose a solution built on an infrastructure provider like Siemens Mindsphere (R4: 20-22). Another important factor in independency from a particular vendor is the solution’s scalability and costs. Machine manufacturers undertake large initial investments and are often unable to predict whether a solution will still meet their needs in a few years (R5: 26; R7: 2, 8).

R7: 8 *„License fees are also a big issue. The more you grow, the more expensive it gets of course, and one is simply dependent. The data is then stored on their servers, and if we want to switch to another provider tomorrow, I do not know how that will work. Because, of course, we do not want to start from scratch again.”*

A final important aspect of the independence of open source is consistency. The code will remain publicly available regardless of the existence or potentially changing strategies of the platform provider so that companies can continue to pursue their individual objectives without adapting (R1: 23-24). Concluding, open source offers huge benefits in terms of flexibility, independence, and scalability, which are very relevant in the IIoT business.

R7: 12 *"While [IoT platforms] may allow some room for expansion, I think with open-source solutions there is a lot more room for the solution to grow with the requirements. I think that is a huge point, you have full control then. And concerning dependence, it depends on how the turnkey [IoT platform] provider designs its licensing model. Perhaps in five years, it will pursue a completely different strategy that no longer suits us at all. So, I see a lot of risks there and I also think that it is definitely not that flexible. That is why I see modular open-source solutions as advantageous, solutions that are adaptable, scalable, and* *can be further developed in line with the requirements of the company and, of course, its customers."*

5.2.2.3 Data Protection and Legal Compliance

One of the most critical issues with IIoT and cloud connectivity for machine manufacturers and producing companies is data security. On the one hand, machine manufacturers are concerned that the data they provide will be shared (R2: 54; R7: 8). On the other hand, many producing companies have data protection concerns with cloud solutions, which poses challenges for machine manufacturers to offer services that naturally rely on production data (R1: 26; R4: 44-46). These concerns may stem from the typical conservative attitude of not wanting to provide more data to the machine manufacturer, to whom there already is some customer dependency (R6: 46). However, in most cases, manufacturing companies are concerned that a machine manufacturer, that typically supplies an industry and thus also direct competitors, cannot adequately protect the data from access by other platform users or actively shares findings from it (R2: 54; R4: 40; R6: 34-36; R7: 6).

R6 was often able to rebut arguments during customer meetings through prior background research on the customers' cloud collaborations, while R4 states that figurative language is a promising way to reassure customers. Those communication strategies may help UMH as well.

R6: 36 "*I am really glad that cloud is no longer a topic of discussion [in our industry], it was much worse two years ago. [...] How many customer appointments did we have where we got the feedback: on the cloud, no way! And we always googled beforehand if there was any news that customer A had entered a deal with cloud provider B, which was the case 90 % of the time. And then we could say: Strange, your company has already refuted this argument itself."*

R4: 40 *"And that is why it is extremely difficult to offer a cloud solution because you have to be able to convince the customer. We try to say figuratively what we value, and we try to convince them that this is a good approach: "signed with* *my blood, no data will ever go from one customer to another" or "before something happens you will no longer have a bank account and someone can see all your transactions". But you cannot see the security. You are connected to a cloud, what does that mean? I do not think there is a patent remedy."*

However, if a customer cannot be convinced, it is a bonus for UMH to be able to roll out the platform on-premise through its open and modular approach (R3: 47). Some machine manufacturers state that the topic of data protection was recently discussed less with manufacturing companies, as they are slowly accepting the necessity and consequences of cloud solutions (R6: 36; R7: 6).

Especially for globally operating companies, the current challenge is rather the compliance with the various data protection laws, e.g., in the European Union (GDPR, general data protection regulation), USA and China (R4: 10, 44-46; R5: 8; R6: 34; R7: 6; R8: 48). A distinction must be made between one-time data access requested by the customer, for example in maintenance cases, and permanent data evaluation by the platform. For one-time maintenance accesses to the PLCs, where error codes are looked at or updates are applied, there may be fewer difficulties, depending on the country. While this can become a problem in the EU and some parts of Asia and Russia, it is not critical in the USA and Canada (R8: 48-54).

R8: 52 *"Our data protection officer always says that as long as we are in Germany or Europe, we are very strongly regulated. As soon as we are in companies worldwide, the issue is handled differently. As I said, we do not store data from the company, we just focus on troubleshooting reading out PLCs, [...], but we do not optimize the customer in the production process."*

As soon as data is permanently extracted and stored, the issue of data protection is particularly critical (R4: 40-48; R5: 8; R6: 36). In addition to the concerns mentioned above, the handling of personal data must then be legally compliant. This is already the case with abstract key figures such as the calculation of the OEE and thus the possibility of drawing conclusions about the shift or operator efficiencies. This is exaggerated as soon as a company in the EU wants to extract data from the USA or China (R4: 44-46).

R4: 46 *“Because of these data act issues, you may not take out any data at all or only analyzed [and abstracted] data. How do I then still do fleet management? How do I still do a service concept? These are really difficult questions, and they have nothing to do with a cloud solution alone. But if I want to run this worldwide as a machine manufacturer, then I have to give it a lot of thought.”*

The machine manufacturers interviewed are open to the use of open source also for security-critical applications such as firewalls or have no security concerns. However, extreme caution is required in order not to lose the trust of customers (R2: 58; R3: 45; R5: 33-34; R7: 8). Similar to Payne (2000, p. 278ff; 2002, p. 63ff), R4 weighs the benefits of collaboration in open source against those of intensive resource deployment in infrastructures such as Microsoft Azure and concludes that open source, while being secure in his opinion, is likely to have difficulty keeping up with a proprietary platform (R4: 48).

Since a cloud solution is abstract and it is difficult for a customer to verify GDPR compliance, customer trust is very important for a platform provider (R2: 54; R4: 12 R7: 8). R4 emphasizes the importance of a disclosed code, especially to gain confidence and traction in restrictive economies like China.

R4: 12 *“[We are on the safe side with open source] not only in terms of technology but also of compliance, so that we can say: Look, here is the source code that has been disclosed. Legal compliance plays an important role that we can say: Dear customer worldwide, you can [see] all our software code, everything we do here is comprehensible.”*

5.2.2.4 Collaboration in B2B

Finally, given the conservative attitude of the mechanical engineering sector, the question arises whether it is realistic that an active community will emerge in B2B that supports each other on issues and projects, as is the case in the home sector. Collaboration in forums is very similar to the platform idea in general, with the difference that the existing is not shared, but the future is built together (cf. chapter 5.2.1.1). The assessment of the willingness to collaborate therefore correlates strongly with the conservatism of the companies and their executive board (R2: 54).

R2: 54 *“It depends on the companies. I think that companies that are not yet involved in the topics [IoT and open source] tend to be afraid of revealing too much about themselves. On the other hand, if you look at the private domain [...], people already use forums to get information more quickly. So, I think the future path will be that you only get faster if you use the intelligence of many. Otherwise, you will just [...] have to work everything out for yourself, which has the advantage of a huge learning effect, but it takes much longer. [...] The question is, can you nowadays afford to mess around with something forever until you get to a solution, or not?”*

R1 assumes that the German mechanical engineering industry "is not yet ready [...] to really support others" (R1: 36) in forums, but rather prefers to invest more to obtain its own solution (R1: 36-38). On the other hand, R2 speculates that "globalized networking in open-source systems to easily obtain information and get assistance" (R2: 52) will be necessary to remain competitive in the future (R2: 52). R7 is very open to collaboration and draws the comparison to conferences and other events, where companies in the same industry already exchange experiences.

R7: 34 *“There is also already [collaboration at] events where companies exchange information on certain topics. And they can all be in the same industry. I do not see a big problem, as long as they are not direct competitors. In the end, it is* *a win-win situation for everyone. There are already many events where experiences are exchanged. [...] So there is nothing that speaks against an exchange between different companies."*

Certainly, rethinking is still required in many areas, but basically, the willingness of the industry to cooperate and to quickly generate added value for the customer in a uniform system is evident.

5.3 Hypotheses Evaluation and Derivation of UMH's Value Curves

To summarize the material, the following section evaluates the hypotheses formulated in chapter 4.1.3 and discusses new insights from the interviews about the needs of machine manufacturers described in chapters 5.1 and 5.2. Based on the respondents' evaluations of UMH's approaches, the value curves shown in Figure 16 for the open-core and premium versions of UMH's offer are derived using the four actions framework (Kim & Mauborgne 2015, p. 51).

First, the "price for an end-to-end solution" is noticeably reduced, which is especially important to reduce SMEs' entry barriers and has direct implications on the remaining attributes. This is possible for UMH open core, as the free components already form a functional system and are pre-configured so that they only need to be adapted to the customer's needs. This entails moderate internal personnel costs or external ones if a service is booked for this. UMH premium also benefits from the same principle but is priced at a higher level due to the adaptation to customer-specific requirements, the individual use cases implemented and the use of premium features (see Figure 7, p. 40). Nevertheless, the price level is comparable to IIoT platforms and is thus situated at the lower end of the companies compared.

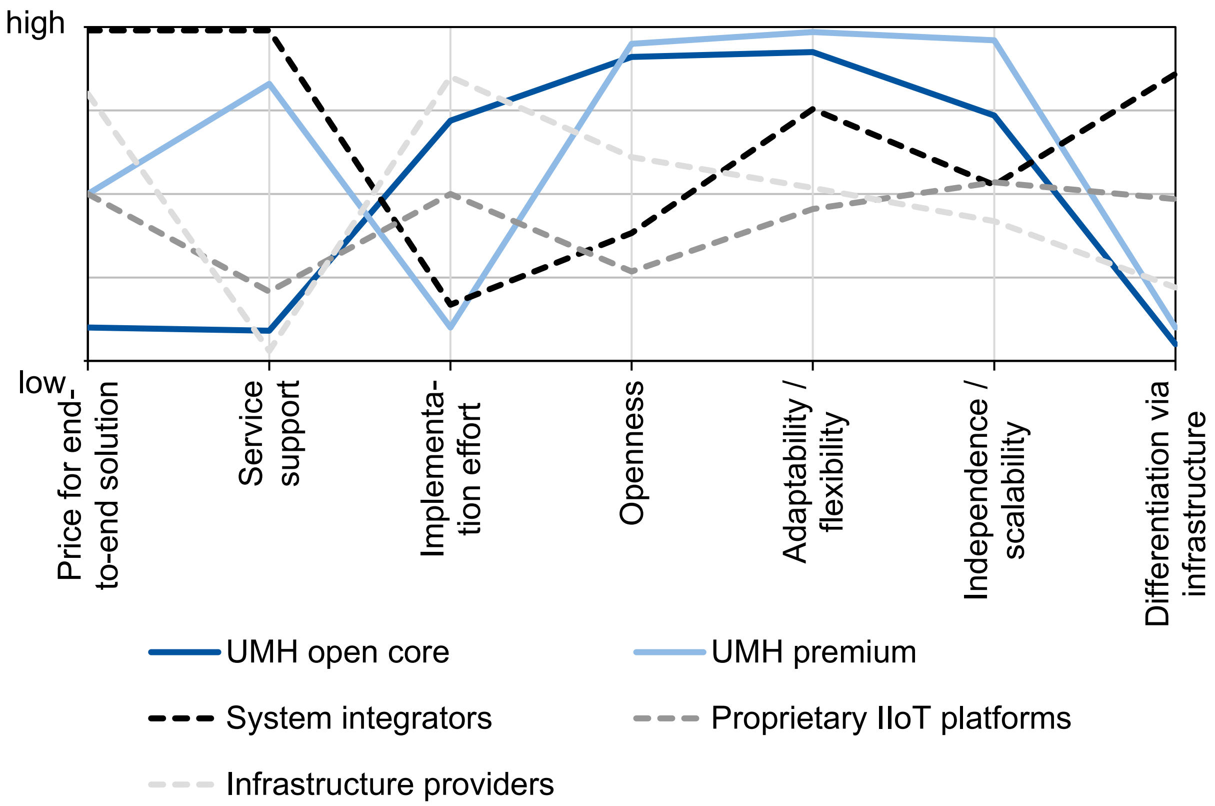

Figure 16: Full strategy canvas covering UMH and competition

As assumed in hypothesis one (H1), the main motivation for machine manufacturers to create their own platforms is in fact the limited flexibility of the existing ones. This addresses the range of functions on the one hand, which is taken up in the attribute "adaptability / flexibility", and on the other hand its ability to grow with the customers without them becoming financially dependent, which is covered by the attribute "independence / scalability". This confirms the first hypothesis, which is why UMH elevates these attributes above its competitors using the approaches discussed below, while the competition is positioned in the middle of the range. Since external programming services may have to be consulted when using UMH open core, independence is rated lower than with premium. However, since implementing new machines into the platform does not necessarily involve programming, it does not conflict with scalability.

A basic principle for achieving high flexibility at low cost is the modularity of the hard- and software components among the different IIoT platform layers (cf. Figure 4, p. 24). This refers on the one hand to the various options for integrating data from different machine PLCs, retrofitted sensors, and hardware via an edge device and the UMH

Factorycube. On the other hand, the possibility to roll out the solution on the cloud of the customer's choice or on-premise to address customers with data protection concerns is also vital. This applies not only to machine manufacturers themselves, but also to producing companies as end customers using the platforms. Scalability is guaranteed because the customer always has sovereignty over the data, algorithms, and apps through the open-source approach. This avoids the lock-in and ensures the flexibility to, for example, switch cloud providers without data or IP loss, in case they do not harmonize with the manufacturer’s upcoming plans or introduce a poorly scalable payment model.

Regarding the attribute “openness”, there is a consensus that common standards for communication and open interfaces must be developed on the infrastructure layer so that the basic modules can work together effortlessly. However, on the higher platform and application layers, there is some reticence in the conservative machine manufacturing industry, as some are concerned that they will lose the opportunity to differentiate themselves from the competition. While this is not viewed too critically by the manufacturers’ developers, there are doubts that management will agree to a completely open approach or even collaboration with the competition. However, respondents identified a trend toward openness, which is important for UMH because its concept relies on an actively collaborating B2B community that supports each other in forums, in the further development of applications in the app store, and with bounty-driven development projects. Thus, UMH raises this attribute as well. While infrastructure providers rely partly on open interfaces, system integrators tend to create specific ones for their customers' use cases and IIoT platforms are closed ecosystems in most cases, which positions them lowest.

As worked out together with the respondents, differentiation via infrastructure and apps that cover the smallest common multiple of the use cases of different industries offers only a short-term strategic advantage. Initially, a separate, self-contained platform may be a buying incentive for a customer if it offers attractive advantages and functions. However, as soon as several machine manufacturers in an industry offer such platforms to stay competitive, those with open and compatible interfaces will have a strong advantage in the market, as customers can integrate them into their production lines seamlessly. At this point, differentiation will take place via quality and functionality differences of the machine hardware again but additionally via manufacturer- or machine-specific apps on the common platform and related servitization business models (cf. chapter 5.2.1.2). As UMH pursues this long-term vision, the attribute "differentiation via infrastructure" is deliberately reduced for both versions, and an independent platform offering the corresponding interfaces and standards is provided.

The app store as a source of universally applicable algorithms and visualization methods was rated useful, but it was emphasized that the apps provided must on the one hand fit a variety of industries to become successful, and on the other hand, they must be proven to be functional and reliable. As with the platform itself, there will presumably be an adoption life cycle for each promising app (see chapter 2.3.2), with market penetration of apps accelerated by a rating and review system in the store.

The next hypothesis confirmed in the interviews is that there is a strong need among machine manufacturers for programming services in IIoT platforms (H2). However, contrary to the original assumption, the reason for this is not the manufacturers' initial underestimation of the effort, but rather that it is viewed with great respect and in most cases, it quickly becomes clear that in-house programming is not feasible. As most machine manufacturers lack the necessary programming skills to professionally implement a software solution such as an IIoT platform, like assumed in H2, comprehensive "service support" must be offered to keep the implementation effort low for the customer. Due to the manufacturers' lack of expertise, the Python SDK was hardly discussed in the interviews, as it is rather the service providers who work with it. Many machine manufacturers interviewed work together with software companies as technology partners to create their IIoT platform. Thus, even though UMH already positions itself in the top quarter of the competition regarding services, it should be evaluated whether the needs of machine manufacturers can be better met if the business model and communications are even more focused on services which would raise this attribute closer to system integrators.

Since such consultation, programming, or implementation services are not scalable, they can only be provided as a paid premium offer. However, it is possible to switch from in-house development to paid services at any time, which is important for SMEs that get started with the stack but then, like most respondents, find that they lack the time or expertise to continue from that point and would otherwise look for a third-party service provider. On the other hand, there are also large variances in the IT capabilities of large companies, which can use their resources optimally via such flexible services. Such a "safety net", which enables companies to begin without obligation and to receive support at any time, was consistently appreciated by the respondents as assumed in H2. On the strategy canvas (see Figure 16), any in-between value can be gradually set between the open-core and premium curves for the attributes price, service support, and implementation effort.

Users of the free open-core version can still take advantage of scalable services, such as the wiki providing information and examples of best practices and the ability to interact with the community on forums and by placing bounty-driven development orders. In combination with the preconfigured modules, this also enables non-technical users to get started with digitization smoothly and without obligation which was rated helpful in the interviews. Those features rise the service support level even of the open-core version above infrastructure providers. As some IIoT platforms offer consultancy, implementation, or maintenance services, they are ranked above UMH open core. UMH premium competes with system integrators, who have a broader service offer, e.g., to develop customer-specific apps like a micro-MES system but are more cost-intensive because they tailor each solution and cannot make use of existing components and modules. UMH's service offering is, therefore, more in the middle of the competition, but it can compensate for this with both reduced prices and implementation effort. In addition, there is the possibility of external service providers offering their services as soon as the platform achieves sufficient market penetration.

This leads to hypothesis three, which states that it is difficult for machine manufacturers to start digitization because the information available on the market is very limited and they are often unable to estimate the scope of the project. The approach of showing non-technical people how to use IIoT components and the platform through tutorials and examples of best practices was highly appreciated by the respondents. As found in the interviews, this free and publicly available material would help machine manufacturers estimate project effort and, in the case of external development, clearly formulate the specifications. For users with more IT knowledge, the well-documented open-source code is a further incentive, which was not evaluated in the context of the thesis, as the target group for this is also more likely to be service providers and app developers.

For both in-house and external development with UMH open core, these offerings ensure a reduction in “implementation effort” compared to implementation with an infrastructure provider. Whether UMH premium can undercut system integrators in implementation effort through its standardized interfaces and thus procedures, as indicated in H3, must be evaluated as part of its future marketing activities, and will vary on a case-by-case basis, which is why both competitors are positioned close to each other in that attribute.

The final hypothesis, that there are concerns about storing data on platforms that also have direct competitors as customers or collaborate with them (H4), was validated from the perspective of machine manufacturers for producing companies. On the machine manufacturer side, however, this is viewed less critically and collaboration with the competition is even sought in one case. Regardless of this, data protection is a top priority. Here, global companies provided new insights into GDPR-relevant topics, for example in China or the USA, where the code disclosed by the open-source approach helps to build trust, as users can understand what is happening with their data and how it is processed and stored.

6 Conclusions and Outlook

Concluding, the initial research questions are answered based on the previous findings. Subsequently, the procedure and methodology used are critically discussed and finally an outlook on future research topics is given.

SQ1: *What functionalities do the manufacturers' platforms include and how were they implemented? Why have machine manufacturers decided to develop their own platform?*

A variety of functionalities are currently implemented in machine manufacturers' IIoT platforms. Predominantly, these are remote maintenance, condition monitoring, and OEE analysis. The implemented functions are constantly being improved and expanded, for example through predictive maintenance. Motivations for digitization include curiosity about the added value that can be created or fixed goals such as fulfilling customer demand for functions or increasing the internal efficiency, e.g., of servicing. Every manufacturer interviewed started their projects by gathering information about the needed competencies and components through external sources like companies, research consortia, or events. Next, machine manufacturers implement their solution either by outsourcing the development to a software company, co-working with technology partners or other machine manufacturers, or building on existing infrastructure and IIoT platforms.

SQ2: *What functions or features are currently missing from existing platforms on the market? Which attributes must be raised to fulfill the desired customer benefits?*

The key attributes identified as missing in the market are flexibility, adaptability, independence, scalability, as well as openness. Since the use cases vary from industry to industry and each manufacturer has different requirements for the solution, the IIoT platform must be as flexible as possible. At the same time, it is important particularly for SMEs to keep the costs of such a solution as low as possible since its implementation inevitably entails additional costs to build IT capabilities and the servitization of the business model. To unite low prices and flexibility, modularization of the IIoT stack is necessary. Additionally, internal and external interfaces should use open standards to reduce duplication costs. It follows that manufacturers cannot meaningfully differentiate themselves on a platform via the deployed infrastructure, as this must be compatible for end customers with heterogeneous equipment. From the application level upwards, unique selling points can be generated by machine- or domain-specific applications. However, this is currently still met with reluctance by the mostly conservative machine manufacturers. Since machine manufacturers cannot currently estimate how demand for their IIoT solutions will develop, they need to build on scalable infrastructure which flexibly adapts to their further development and does not make them dependent on the provider.

SQ3: *How does an open-source approach affect the value curve and how is it perceived by machine manufacturers?*

UMH's open-source approach is perceived positively by most of the machine manufacturers interviewed, as it provides the necessary independence and flexibility. Many who have recognized these advantages are already using open-source components in their own solutions. The big hurdle they face is the required expertise in IT and programming, which particularly SMEs have difficulty building up. It is therefore important to offer complementary programming services. For some, there are concerns that an open-source solution has a "tinkering nature" that does not meet their requirements or those of their customers. It is emphasized that to reach the mass market, each of the open-source components must be reliable and proven, e.g., through demonstrated use cases (cf. Moore 1991, p. 9ff).

PQ: *Which blue ocean strategy has the best potential to set industry standards and establish an IIoT platform in the manufacturing sector?*

On the part of the machine manufacturers, the IIoT market faces a trade-off between low prices, low implementation effort, and maximum flexibility. While flexibility can be aligned with low prices through modularization and high standardization, customers can only gradually adjust their preferred effort-to-cost ratio. This is made possible by

UMH's flexible service offering, which can be included at any stage of development. Thus, the attributes price, service, and effort can be raised or reduced according to customer needs. The open-source approach and modular toolbox set the offering apart from the competition through its openness, flexibility, and independence. To achieve broad market acceptance on the part of producing companies as end customers, it is important to build on common standards in the platform infrastructure and to dismantle the conservative patterns of thinking in terms of differentiation. Figure 17 shows the defined measures of the four actions framework (Kim & Mauborgne 2015, p. 51), which enable a promising positioning in the IIoT market for machine manufacturers.

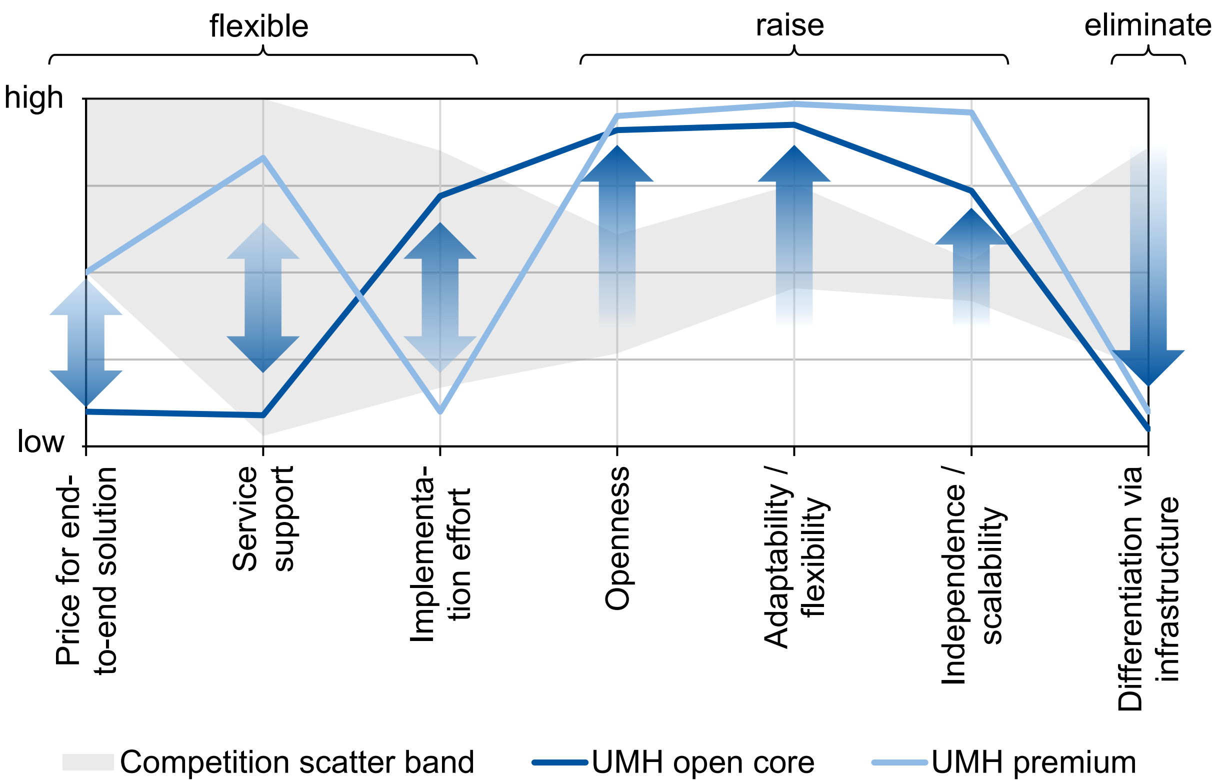

Figure 17: Final blue ocean strategy and competitive positioning of UMH

However, this strategy is only based on qualitative interviews with one customer group. Although there is presumably a certain overlap with other groups such as producing companies, consultants, or universities, the solution approaches, and thus the strategy, must be evaluated by them as well. Since the result is derived from statements made by only eight machine manufacturers, it must be constantly reassessed and expanded to include further insights into companies' needs in the future.

The approach chosen is well suited to get to know the customer group and the competitors on the market in detail and to derive a promising strategy from this. Studying and classifying the competition before the interviews and formulating hypotheses about important market attributes promotes the generation of important insights from the first interview on. The blue ocean framework allows the findings to be broken down to the essentials and to be presented clearly in paper form. Ranking the competition by evaluating weighted sub-attributes which are averaged across the customer segment also results in an insightful assessment as objective as possible.

However, the evaluation of five separate business models quickly makes the presentation confusing. In addition, the selected competitor clusters mainly target producing companies and can thus be used for further analyses of that group. On the machine manufacturer side, UMH competes mainly with software technology partners, which are closest to the system integrators described in this thesis. In the future, this competitor group needs to be examined more closely and it needs to be determined whether UMH's service offering is sufficient to enter non-exclusive technology partnerships with machine manufacturers as a software service provider.

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Statutory Declaration

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Thesis title: Design and Evaluation of a Blue Ocean Strategy for an Open-Core IIoT Platform Provider in the Manufacturing Sector

Hereby I assure that I wrote the present work by my own without usage of other as the given aids and appliances. All parts which are literally or roughly taken out of published or not published works are marked as those. The work in an equal or similar form has not be handed in as examination paper yet.

Aachen, 09.07.2021

Nicolas Altenhofen