INDUSTRY4.0 TECHNOLOGY BATTLES
IN MANUFACTURING OPERATIONS MANAGEMENT

non-technical dominance factors for IIoT & MES

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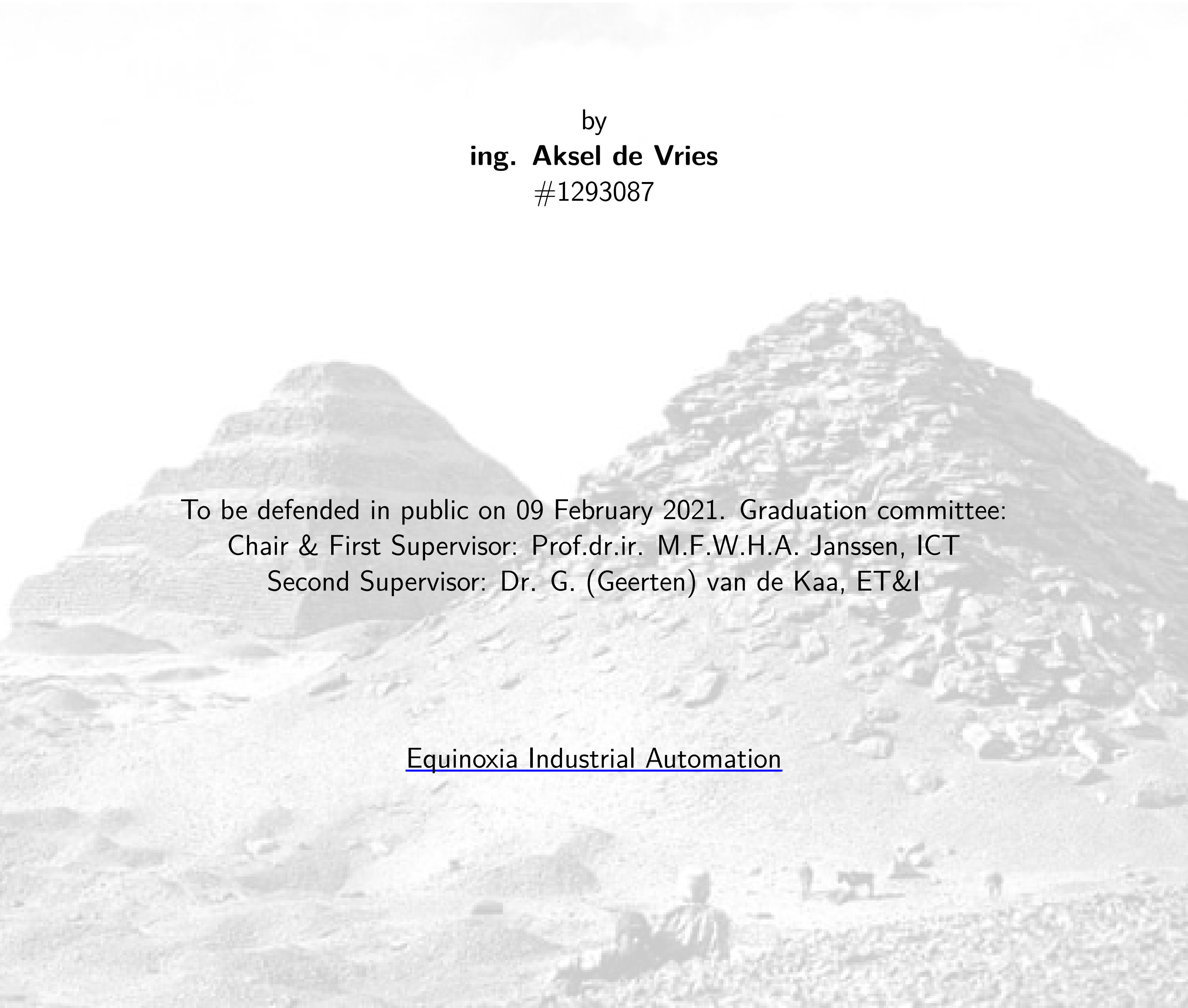
Equinoxia Industrial Automation



Impressum

The cover photo shows the Djoser step pyramid. It was once high-tech and replaced old-school pyramid technology; the ruin in the front. The analogy is to the once high-tech Automation Pyramid:

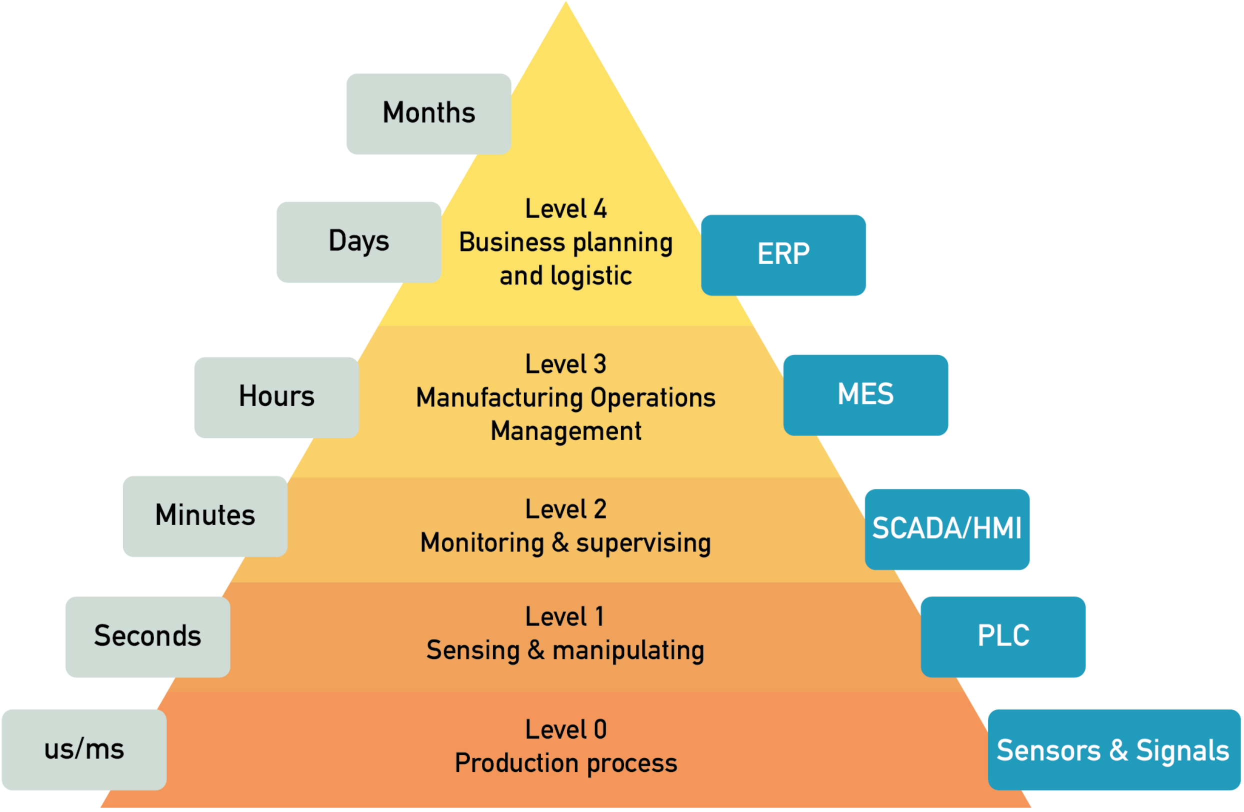


Figure 1: Automation Pyramid as advocated by MESA.org and ISA.org since 1986 A.D.

About the author

Aksel de Vries (1973) is a Chemical Process Engineer and has been working in the field of Manufacturing Operations Management since 1998. At AspenTech Europe, Aksel delivered training and consultancy during the transition from Computer Integrated Manufacturing (CIM/21, Batch/21, SetCIM, etc.) to Industry4.0 on corporate vertical and horizontal integration, fully leveraging ISA-88 and ISA-95.

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EXECUTIVE SUMMARY

In 2011, the fourth industrial revolution was announced at the German Hannover Messe. Claims followed that old Industrial Automation (MES) would soon be replaced by Industrial Internet of Things (IIoT). The re-industrialisation of Europe was promised, with re-shoring of jobs lost to Asia. Since then, more than 180 billion euro is being subsidised for the IIoT technology push. However, the promises are not materialising. The industry is reluctant to invest in IIoT technologies. Also, the future of MES is unclear.

This study focuses on the technology evolutionary processes around MES and IIoT.

IIoT technology itself is prosperous, but non-technical aspects remain vague and ambiguous. In particular; scope and cost/benefit of IIoT remains intangible, resource capacity is problematic, readiness and reference architecture models seem incomplete, and an IIoT system perspective is lacking. Also, it is unclear whether MES vendors will adopt IIoT or whether IIoT vendors will substitute MES. Indecisiveness is observed.

These are symptoms of the economic principle of *Knightian uncertainty*. Uncertainty is worse than risk, as knowledge is lacking, and as it is impossible to measure, calculate or plan around uncertainty. Besides indecisiveness, the theory also describes the phenomenon of sticking to known business partners.

Research Methodology Although the high-level principle is known, a research gap exists on MES/IIoT-specific socio-technical evolution. This further increases Market Uncertainty. The purpose of this study is to fill this gap by employing theories of evolutionary economics. The scope is broader than problem-solving-thinking, as that would introduce a bias to the problem framework. Instead, a *Creation of Meaning* perspective is chosen. The produced knowledge - socio-technical meanings - can decrease the uncertainty, direct MES/IIoT stakeholders out of the stalemate, enable the industry to build the *Factory of the Future*, and (eventually) deliver the promised re-industrialization.

The Market Uncertainty is analysed from a socio-technical lens of Technology Battles. It is a proven model in evolutionary economics to analyse emerging and competing technologies. A well-known example is the video format war. Not the technical superior design achieved market dominance (Sony's Betamax), but the collaborative supply chain of the videotape vendor (JVC's VHS), together with video rental shops and the film industry. It is a simple example, though, as it was a duel between two companies in a homogeneous consumer market. The MES/IIoT battle is much more complex.

Given the complexity, this study starts with exploratory research on the Industrial Automation market, along with an exploratory literature review on Technology Evolution processes and Technology Battles. Afterwards, the problem can be defined by challenging theory with the market analysis. Based on that, a number of possible market dominance factors is intuitively selected by scholars. To further remove *Researcher Bias*, the dominance factors are verified by a broad selection of Industry Experts.

My analysis confirms the Market Uncertainty as an exhibit of a Technology Battle. It is a common symptom in Technology Battles literature. The uncertainty is enormous as it is about three clusters of vendors in a business ecosystem, with various customers and vendors being reluctant to invest in IIoT and/or MES.

During the synthesis of Technology Battles literature, a hiatus was found. Most articles focus on duels, between vendors offering a single new product, in a business-to-consumer market. For such scenario's, literature prescribes 29 possible market dominance factors. However, these only partially cover business ecosystems with integrated product portfolio's. To fill that research gap, this study introduces four new dominance factors to existing theory.

A second hiatus was found. Scholars use a model with five battle phases. After a decisive battle, a final phase starts with as characteristics momentum and competitor lock-out. The accomplished large *Installed Base* is claimed to defend against competitors. In case a new battle occurs, it is assumed to start over at the first phase. My research found that too technical and simple. So, I introduce a sixth phase - *System* -

which further protects against competitors with socio-technical factors. For MES, this is observed in the two decades after the year 2000. MES became internalised to a paradigm, impacting organisational structures and work-culture, and entrenched into a *System* along with other technologies and social developments. This *System* phenomenon is fundamental in this study, in particular on how to de-entrench from it.

Findings My stakeholder and business ecosystem analysis show that the battle is not purely about MES and IIoT technologies themselves. Three nontechnical battle-fronts are observed.

Firstly, Irrevocable Technical Evolution is observed, driven by new software architectures from *Big Fish* Microsoft, Google, Amazon. Traditional architectures will soon become legacy, such as having a relational database server for each factory. MES vendors and IIoT vendors have no other choice than to fully adopt.

Secondly, misinterpretations and political framing are observed. It is often claimed that MES standards prescribe (legacy) architecture, but that is incorrect. The standards prescribe data models. MES vendors have chosen (legacy) architecture, independently from the standards. MES can be migrated to *Big Fish* architectures, while still adhering to existing data models. Another framing echoed frequently is that IIoT standards cover the full spectrum of MES, which is also not correct. Only machine-to-machine communications are prescribed. The IIoT standard does not prescribe Functional elements nor Business Intelligence. In other words, there is no competition between IIoT and MES standards; these can co-exist.

Vice-versa it is claimed that MES is a comprehensive system, a methodology to improve manufacturing, denouncing IIoT to „just a technology". From my analysis' technology evolution perspective, I confirm that MES has *become* a *Large Technical System*. It took 50 years. MES once started as a technology too. Now, also IIoT can *become* a Manufacturing *Cyber-Physical System*.

Thirdly, my analysis points out that the technical battle is limited to complementary functionalities. IIoT vendors are trying to conquer some existing MES market-share, with new technology standards, but do not substitute the core MES technical system. MES vendors can adopt the same new technology standard and offer the same complementary functionalities. The battle is, in essence, nontechnical.

During my analysis of MES/IIoT from the lens of Technology Evolution & Battle literature, nontechnical characteristics were confirmed yet another time. MES/IIoT is a *Platform Battle* with minimal *Dominant Design* aspects. The platforms are two-sided; MES/IIoT engineers (sellers) and Business (buyers). MES platforms and IIoT platforms can co-exist; however, nontechnical aspects cause market uncertainty. This is typical for the battle phases; IIoT is developing from *Technical Feasibility* to *Creating the Market*. MES reached *Momentum* two decades ago and is currently a *Large Technical System*, with many socio-technical lock-ins. Liberating MES (vendor) architectures from the lock-in is relatively simple, at least technically.

However, MES is institutionalised (by vendors and end-users) into paradigms, ways-of-working, organisational structures and operations culture. We can appoint strategy consultants, but as Peter Drucker said: „Culture eats strategy. For breakfast."

Dominance factors are prescribed by academic literature, linked to technological battle characteristics. As part of this study, more than forty factors were reviewed. After an abduction by three scholars, eleven factors seem feasible; the already mentioned *Big Fish*, and ten other nontechnical dominance factors.

Limitation; Verification versus Validation The eleven possible dominance factors were presented to twelve industry experts, at senior executive level or higher, with the question: „Assume it is 2030. Some players are out of business, and others gained market dominance. What strategy factors have been critical?" Each of the eleven factors was rated for each of the three clusters of software vendors; MES, SCADA to IIoT, and BigData to IIoT. The Imprecise Multi-Attribute Evaluation (IMP) method was used as verification. It was applied given the market uncertainty and likely inconsistent views on root causes. The IMP model allows for this. In fact, the IMP semantic process of description, dialogue and discussion were much valued.

The respondents found semantics more important than mathematical best and worst prescription. The trade-off of such a qualitative research method is a lack of quantitative validation. Therefore, the outcomes of this study are not 'hard', which is inherent to qualitative research. This is opposed to other scholars in the field of Technology Battles, who frequent the quantitative Best Worst Method. That leads to very precise validation. However, it has as prerequisite a (semantic) consensus on the dominance factors and assumes a linear hierarchical structure of dominance factors. Both of these prerequisites cannot be met for the subject of this study. Due to Knigtherian uncertainty, quantitatively validated research is impossible by definition. The outcomes of this study have been successfully verified, though.

Conclusions The *Big Fish* dominance factor was confirmed unanimously. MES vendors have no other choice than to adopt modern software architectures. MES as a methodology is a well-established standard. If MES vendors adopt modern architectures, then and only then, MES will likely continue to exist. Besides this dominance factor, each of the ten other nontechnical dominance factors was unanimously verified as important or critical. Therefore, it is concluded that the battle is not about MES or IIoT technologies or functions, but about a socio-technical paradigm change.

Whereas most recent literature describes Technology Battles from a deterministic lens (strategic management of innovation), that lens is only partially applicable for MES/IIoT. Evolutionary economics and social constructs are predominant. Multiple social constructs were found:

First, whereas the dominance factors are typically prescribed to be loosely correlated to each other, a strong concordant pairing was raised by the industry experts. This is caused by market uncertainty on the scarcity of skilled engineers. Dominance factors leading to higher installed base with lesser engineers are concordant. In other words, the battle is not only about market share but also about engineers.

This is a step beyond (vendor) pre-emption of scarce assets. The MES/IIoT battle leads to a system where all stakeholders are optimising themselves to needing fewer (IT) engineers. This implies an essential 4IR paradigm chance. In the *Factory of the Future* MES engineers become either IT engineers maintaining the platform, or Manufacturing Experts configuring and using the platform.

Secondly, a discordant pairing was observed on SCADA attempting to substitute MES. Experts either negatively associated the *Red Ocean Strategy* with poor self-reflection on lacking qualifications, or vice-versa, waived away the attack and suggested to exploit SCADA adepts to address the enormous market of IIoT devices. Again, the scarcity of engineers is a key factor. One way or the other, not a single respondent considers the IIoT threat from SCADA mission-critical for MES: „SCADA4.0 orchestration will go to MES anyway!“

A third phenomenon was found on MES versus Big Data IIoT. Technically, Big Data only offers complimentary functions. However, when evaluating the dominance factors on *Have & Exploit* versus *Lack & Develop*, these were unexpectedly found to be alternating on 8 out of 11 factors. What MES is lacking is what BigData possesses, and vice versa. Not just the battle is on complementary functions; the players are complementary. This is a perfect starting position for a *Blue Ocean* collaborative supply chain.

Contribution & Recommendations The conclusion of this study suggests that MES and IIoT can co-exist with a *Blue Ocean Strategy*. Further research is recommended to validate this claim. Nevertheless, it is an unexpected but prosperous outcome. An IIoT *Red Ocean* is a red herring, not a threat for MES. The only factor feeding the market uncertainty is disinformation and political framing. This originates from political and governmental institutes. These parties are too much technically focused on IIoT and lack a business perspective. 4IR is not about technically connecting devices. We need a *System Builder* who also connects businesses, who builds a collaborative supply chain, creates a *Large Technical System*.

As proven in this study, this *Creation of Meaning* is key to re-industrialisation and re-shoring lost jobs.

Besides the contribution of this study to society, further academic contributions to theory are; a sixth battle phase *System* with socio-technical aspects, and six dominance factors for business ecosystem battles. Industry experts have confirmed these in interviews. Another contribution is the pairing of dominance factors for technology battles. Analysis of concordant and discordant pairs was found valuable, particularly the correlation with socio-technical constraints and stimuli. Further research is recommended on this subject.

As final recommendation, I would like to advocate using positive and peaceful wording. The masculine and militaristic linguistics in this field of science (Format Wars, Technology Battles, Reverse Salient, Entrenchment, Dominance) may lead to overlooking outcomes like settling, Joint Venturing, Collaborative Supply Chain, and Blue Ocean Strategy.

Keywords: Technology Battle, Format War, MOM, MES, IIoT, Industry 4.0, Factory of the Future, ISA-95, RAMI4.0, B2MML, MAAS, Manufacturing as a Service, System Builder, Collaborative Supply Chain, Smart, Creation of Meaning.

Definitions - Glossary

- **Industry4.0 (4IR)** Fourth Industrial Revolution. Refers to advanced industrial automation and electronics, incorporating a system of; Horizontal integration through value networks, Vertical integration of networked manufacturing systems, and End-to-end digital integration of engineering across the entire value chain. Industry4.0 is driven by IoT and is also known as IIoT.
- **Automation** Industrial Automation is defined as the automation of complex industrial processes and functions, beyond conventional data manipulation and record-keeping activities. It focuses on 'run the business' opposed to 'count the business' types of automation efforts. Automation handles transactional, event-driven, mission-critical, core processes. Industrial Automation supports enterprises knowledge workers in satisfying the needs of its many constituencies.
- **Automation Pyramid** is a schematic representation of Industrial Automation activities and technology [ORourke, 1986], as shown in figure 1. The step-pyramid has five levels, from fast data processing of terabytes per second up to monthly aggregates of kilobytes of information. The ground level is the production process with as technology sensors and actuators. Level 1-4 are respectively sensing and manipulating with PLC and DCS, Monitoring & Supervising with SCADA, Manufacturing Operations Management with MES, and Business Planning & Logistics with as technology ERP.
- **Business to Manufacturing Mark-up Language (B2MML)** is a semantic interface, following ISA-95 standards. B2MML consists of semantic schemes using XML Schema language (XSD).
- **Data Lake** Data Storage of raw data, including context and meta-data
- **Data Swamp** Data Lake with poor data quality and/or lacking meta-data (attributes).
- **Data Warehouse** Data storage following de-normalised data model (deassociated from specific applications, optimised for data-mining, not for real-time transactions) in IoT architecture. Typically stores a fraction of raw data, whilst adding meta-data, events and other derived data.
- **ERP** Enterprise resource planning (ERP) tool sharing a common process and data model, covering broad and deep operational end-to-end processes, such as those found in finance, HR, distribution, manufacturing, service and the supply chain [Gartner, 2021].
- **Internet of Things (IOT)**; *"a computer network of physical objects (things) equipped with embedded technologies for interacting with each other or with the external environment"* [IEC/ISO 20924:2018].
- **Industrial Internet of Things (IIOT)** 4IR synonym. In this paper, 'IIoT' refers to post-2011 MES. Gartner defines IIoT as a set of integrated software capabilities. These capabilities span efforts to improve asset management decision making, as well as operational visibility and control for plants, depots, infrastructure and equipment within asset-intensive industries. These efforts also occur within related operating environments of those industries [Gartner, 2021].
- **ISA-88 / ISA-95** also known as IEC/ISO 61512 and IEC/ISO 62264 are Industry standards on Manufacturing Operations Management, including reference architecture models and B2MML (xml) semantic interface. The International Society of Automation (ISA) was founded in 1945 and currently unites more than 40,000 Industry experts serving more than 400,000 customers.
- **Lifecycle Management** for manufacturing is from R&D to factories, equipment, recipes, orders and continuous improvements. MES/IIoT must be agile and scalable to support this.
- **Manufacturing as a Service (MAAS)** refers to contract-manufacturing. A company focuses on product development and outsources Manufacturing Operations Management. A disruptive effect is the servitization of MES/IIoT IT aspects and empowerment of process experts.

- **Manufacturing Execution System (MES)** manages, monitors and synchronizes the execution of real-time, physical processes involved in transforming raw materials into intermediate and/or finished goods. They coordinate this execution of work orders with production scheduling and enterprise-level systems. MES applications also provide feedback on process performance, and support component- and material-level traceability, genealogy, and integration with process history, where required [Gartner, 2021]. In this paper 'MES' refers to pre-2011 MES.
  - *Higher MES* refers to Manufacturing Operations activities, such as detailed scheduling, performance review, batch track & trace, recipe & material management, (predictive) maintenance, as defined in the standard ISA-95.
  - *Lower MES* refers to equipment activities on-premise, often per work cell, see SCADA.
- **MESA** Industry experts community (since 1992) focus on MES & 4IR. Active in >40 countries. Published industry standards, B2MML, peer-reviewed white papers and research on MOM/MES.
- **Manufacturing Operations Management (MOM)**, covering Manufacturing & Production Operations, Business Operations, and Manufacturing Strategic Initiatives, see figure 10.
- **OPC** Communication standard between equipment and MES/IIoT; raw data with basic context. OPC is the interoperability standard for the secure and reliable exchange of data in the industrial automation space and in other industries. It is platform independent and ensures the seamless flow of information among devices from multiple vendors. Initially, the acronym OPC was borne from OLE (object linking and embedding) for Process Control. These specifications, have enjoyed widespread adoption across multiple industries, including manufacturing [OPC Foundation].
- **Programmable Logic Controller (PLC)** the fundamental building block of factory automation. A specialty purpose computer, including input/output processing and serial communications, used for executing control programs, e.g. control logic and complex interlock sequences. [Gartner, 2021].
- **Platform** two-sides service, bringing together two groups of users; a group of service/product providers and a group of service/product consumers. The platform services are standardised, which empowers the contents and functionalities of the service/product provider.
- **RAMI4.0** IIoT reference architecture model (see figure 7 and sections 3.2.7, 3.2.6).
- **Smart** Prefix label for 4IR, like smart sensor, "smart Industry", "smart manufacturing", etc.
- **SCADA or SCADA4.0** Supervisory Control and Data Acquisition over equipment (on-premise). A system used in manufacturing for acquiring measurements of process variables and machine states, and for performing regulatory or machine control across a process area [Gartner, 2021]. Traditionally SCADA excluded long-term (MES) Data Historians. SCADA4.0 may include it though.
- **Service-Oriented Architecture (SOA)** is a design paradigm and discipline that reduces redundancy and increases usability, maintainability and value. This produces interoperable, modular systems that are easier to use and maintain. [Gartner, 2021].
- **Uncertainty** is worse than risk, as knowledge is lacking, and as it is impossible to measure, calculate or plan around uncertainty [Knight, 1921]. Typical effects are uncertainty avoidance, and sticking to known business partners [Podolny, 1994]. Radical e.g. unsolvable uncertainty is also due to information being insufficient for action [Kay and King, 2020].

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1 Introduction

1.1 Industrial Automation and the Factory of the Future

Industrial automation exists since the early 1970s. Over the years, factories became more and more automated. Also, Industrial Automation technologies have expanded steadily over the past 50 years. With the recent introduction of *Industrial Internet of Things* (IIoT), this can further increase. However, the new technologies are not readily accepted. Even though new standards have been released, and hundreds of studies explain the benefits of digitalisation of the Fa*ctory the Future*, the industry is hesitant to implement IIoT. Why? This precarious situation is researched in this paper. The scope is the market of old and new Industrial Automation technologies, particularly around vendors and their IIoT products, which may or may not replace existing Industrial Automation solutions.

1.2 Technology Battles

The problem is that the Market Uncertainty is enormous. Industrial End-Users, as well as software houses, are reluctant to invest. The situation looks like a stalemate. The risk is high for all stakeholders; complete loss of investment, loss of reputation, and permanent market share loss. Just think about the simple example of the Technology Battle between the video formats Betamax, VHS and Video2000. When VHS established the standard, Sony and Philips lost their investment. Also, end-users lost money as they had to replace their equipment and copy old tapes to the new format. The video format case is a well-researched and straightforward example.

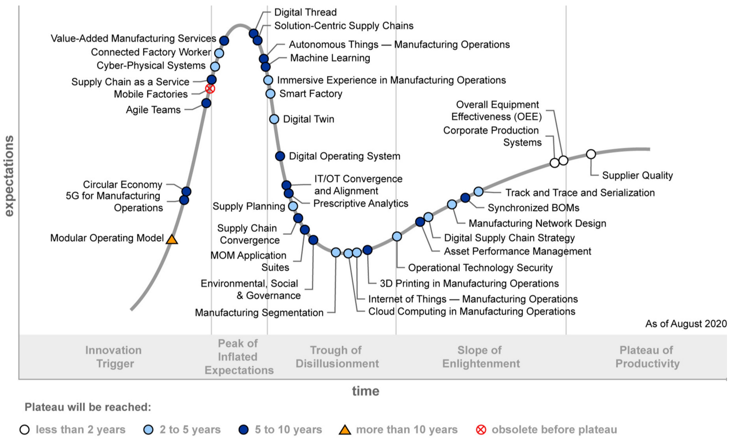

Figure 2: Hype Cycle for Manufacturing Operations Strategy [Gartner, 2020]

The situation in Industrial Automation is much more complex, see figure 2. It is not about a duel or truel, but about clusters of vendors competing between an old technology standard and a new standard. For multinationals, the impact is enormous. Just imagine that every Industrial Automation system in every factory needs to be migrated. How long will that take? Are sufficient engineers available, even globally? Moreover, what if a migration is prepared to a promising new technology, and it becomes non-standard after some years? Or even worse; what if a vendor loses the Technology Battle and files for bankruptcy?

These are symptoms of the economic principle of *Knightian uncertainty*. Uncertainty is worse than risk, as knowledge is lacking, and as it is impossible to measure, calculate or plan around uncertainty [Knight, 1921]. Typical effects are uncertainty avoidance, and sticking to known business partners [Podolny, 1994].

1.3 Research Gap and Techno-Societal Contribution

These symptoms of *Uncertainty in the Market* are confirmed in my market analysis, see Appendix A. This corresponds with Van de Kaa et al. [2011, p.1406] „When uncertainty in the market gets too high, firms and customers are not willing to take the risks attached to choosing one particular format and postpone their decision. This decreases both the likelihood that dominance of one format will be reached and the speed at which this format will achieve dominance. This negative effect was suggested in nine studies."

However, for Industrial Automation, no studies are known on this economic phenomenon. No indicators are known on early recognising or inducing a dominant technology. This research gap further worsens the Market Uncertainty. [Cividino et al., 2019; Magruk et al., 2016].

This study is to fill the research gap.

The contribution to theory is threefold; (1) extending the theory on Technology Battles, from duel/truel in the Business-to-Consumer market, to multi-cluster battle in the Industrial Automation Business-to-Business market, (2) researching Technology Battles in an *asynchronous* market where one cluster started two decades earlier than the other, and (3) reducing the Market Uncertainty, by producing knowledge and meaning, in order to direct MES and IIoT stakeholders out of the stalemate, to (eventually) accomplish re-industrialization and re-shoring of lost jobs.

Radical Market Uncertainty

To prevent an ambiguous or vague scope, the predicate *Market Uncertainty* is de-scoped to *Radical Market Uncertainty*. The assumption is that the fourth industrial revolution is considered radical and that *information is insufficient for action*. This is defined by Kay and King [2020] and based upon Knightian Uncertainty 1921. In fact, the assumption is that the uncertainty is resolvable because it is knowable but unknown due to various factors. By providing information - this study - the uncertainty becomes more resolvable. This is illustrated below. The assumptions will be verified at the end of this study.

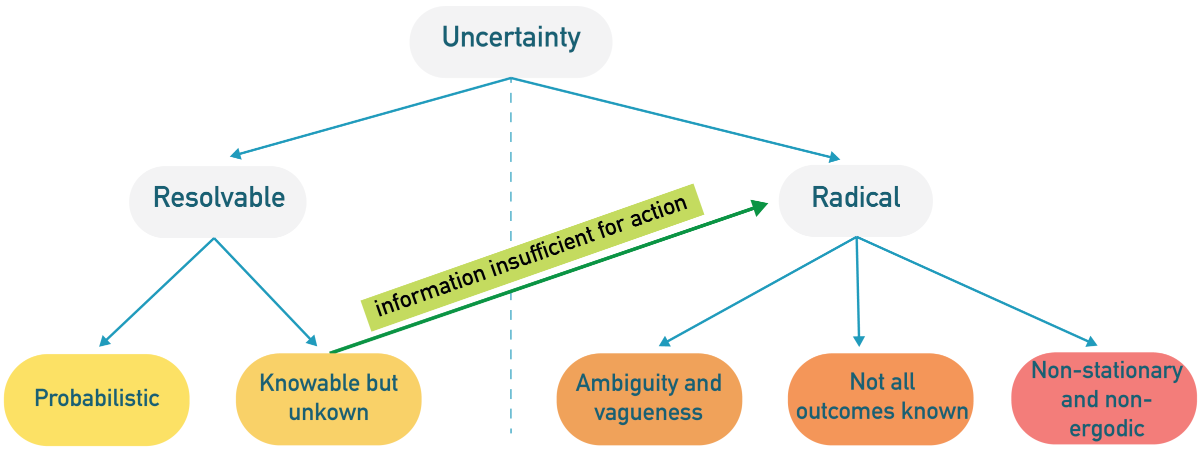

Figure 3: Radical & Resolvable Uncertainty (free to Kay and King [2020])

2 Research Methodology

2.1 Introduction

Given the complexity of the situation, Market Uncertainty is likely a symptom of a wicked problem [Buchanan, 1992]. Traditional research approaches would 'therefore' reduce the scope to a known context where stationary or ergodic analysis is possible. Such research approaches are well-described by Gregor and Hevner [2013] as *Exaptation* and *Improvement*, for respectively low application domain maturity with high solution maturity and vice versa. Such research produces (extended) known solutions for new problems or vice versa new solutions for known problems. Lastly, Gregor and Hevner [2013] describe a research approach for invention e.g. designing new solutions for new problems.

However, for 4IR Market Uncertainty no clear problem exists - only symptoms are described in academic and professional literature - and therefore problem-solution type of research is not applicable.

First, the underlying problem must be uncovered, and therefore an exploratory research methodology is suggested. The *Double Diamond* is chosen for that, as it is a proven model for exploratory research for wicked problems [Conway et al., 2017]. It leaves symptoms as-is, to prevent *Researcher Bias* jumping to solutions e.g. to prevent *Bias* within an alleged problem framework. As 4IR involves linguistic and semantic disruptions, the Double Diamond method is feasible, as it allows for Designerly Thinking as Creation of Meaning (rather than problem-solution Artefacts) [Krippendorff, 2005].

The Double Diamond consists of seven steps, which are described in the next seven paragraphs.

2.2 Double Diamond method, Researcher Bias and Research Questions

The Research Methodology is the Double Diamond, see figure 4. The Double Diamond is originally a design process model popularised by the British Design Council in 2005 and adapted from the divergence-convergence model from social systems linguist Banathy [1996]. Instead of a *Researcher-Biased* problem-solution framework, the focus is on Creation of Meaning [Krippendorff, 2005], with four phases; Discover, Explore & Define, Develop & Test, Deliver & Listen, as depicted below.

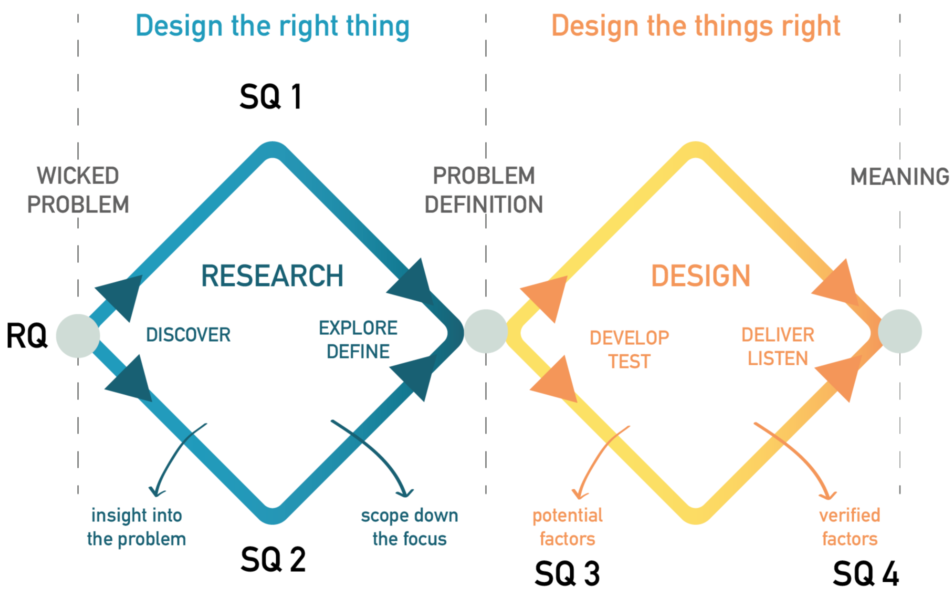

Figure 4: Double Diamond method (free to BritishDesignCouncil [2016])

The model controls *Researcher Bias*, by delaying the Problem Definition phase and by review from scholars and industry experts. First, insights are discovered, then the model moves to explore themes and patterns in the data, only afterwards the Problem Definition follows [Soiferman, 2010, p.7]; „This allows the researcher to develop an early tentative hypothesis that can be explored. The results of the exploration may later lead to general conclusions or theories" which is the second diamond's output.

The qualitative methodology is chosen as the research area is unexplored territory. In fact, a well-defined scope and problem can only be deducted after literature research. The Double Diamond supports this explorative process [BritishDesignCouncil, 2016]; It guides to a clear problem definition mid-way and formulates a design solution based on qualitative and quantitative expert input. This answers the main Research Question (RQ). So, let us first define the main Research Question:

(RQ) „What are the key dominance factors in the Industrial Automation technology battle?" Obtaining that knowledge will reduce the problem: Market Uncertainty. The knowledge will be produced based on four further research sub-questions:

- (SQ1) „What is the Market Uncertainty about?" to identify the stakeholders, what is at stake, what precise technology is being battled about, and the relation to the Business EcoSystem. This will drive the first part of the inductive research, after which the second part follows:
- (SQ2) „What type of battle is observed and in what stage?" will classify the Battle according to theory such as Suárez [2004].
- (SQ3) „What dominance factors are relevant?" to achieve a high market share.
- (SQ4) is to verify (SQ3) „Which of these market dominance factors are important?"
- This will qualify and quantify the key dominance factors, as requested in the RQ.

The used research methods for the Double Diamond are outlined in the following paragraphs.

2.3 Literature research to provide insight in the MES/IIoT realm

First, a diverting literature research was executed, to analyse the Market Uncertainty.

The literature was selected employing computerised searches of scientific literature in Scopus and Google Scholar in January 2020. The *snowball* approach was chosen, as that is a proven method for explorative research. However, initial search queries provided unsatisfactory results. The problem turned out to be that the Technology Battle does not have settled-in terminology for the Technology Battle. Various countries and even companies use their own terminology: Industrie4.0, Industry4.0, Smart Manufacturing, Smart Industry, Factory of the Future, Industry X.0, and Intelligent Industry, as used in respectively Germany, International, International, Netherlands, France, Italy, Accenture, GE. This ambiguity confirms the rationale for using the double diamond model and the need for an explorative snowball research. Afterwards, a problem statement can be formulated.

For the reader who is not used to the terminology and jargon, section 3.2 explains step by step the background, path-dependencies and meaning of Industrial Automation artefacts.

As no definite terminology exists, a wide range of search criteria was used to pinpoint the subject. As that would find too many articles, an initial sub-selection narrowed down search results to readiness, maturity, system perspective and reference architectures. The primary search criteria were: (Industry 4.0 OR Industrie 4.0 OR Smart Manufacturing OR Factory of the Future OR Smart Industry) AND (Readiness OR Maturity OR Business Ecosystem OR Large Technological System OR RAMI 4.0 OR MESA).

This search-round resulted in an initial set of 324 articles. The references of relevant articles were checked and subsequently included if they contained relevant information. In other words, the snowballing approach was used. Another search-round was added. Although many articles were gathered already, the coverage on the fourth industrial revolution initiation was light.

Further articles were selected around Industrie 4.0 initiation from the scholar Kagermann, as he coined *Industrie 4.0*. Articles referencing Kagermann, or referenced by Kagermann, were used as the basis of the Research Proposal on the initiation of Industrie 4.0 in Germany. Again, this is a snowballing technique and valid, given the fact that Kagermann is in the centre of Industrie 4.0.

The fact that an adjustment is literature search strategy was required is a finding on its own. It was noticed that a significant number of articles is written in German, appearing to form a bubble mainly referencing articles in its own bubble. This could be interesting for further research. After an initial quick scan with Google Translate, a dozen articles were reviewed in detail in German. The contents were of high value, but due to its isolated position, the academic objectiveness is questionable.

Last but not least, it was researched whether MES and IIoT players can be categorised as MES, PLC/SCADA and BigData players [Vries, 2020].

The detailed literature research is included in Appendix A, and reviewed in Chapter 3. That chapter assesses the technical and non-technical aspects of the Technology Battles, including a stakeholder analysis, both from a path-dependency perspective, as well as the current Acceptance and Readiness aspects. The chapter's outcomes are; irrevocable technological evolutions, misinterpretations & framing, and most importantly; the actual technology battle.

2.4 Literature review to gain insight on Technology Battles & Transitions theory

Following the Double Diamond, a secondary literature study was conducted, which is again diverting. Whereas the first literature review analysis the practice, this literature reviews the theory. Relevant theories were selected, based on the teachings of TUDelft scholars Karel Mulder and Geerten van de Kaa, experts on respectively *The production of new technology* and *Technology battles*.

2.5 Deductive challenging of theory with practice

The outcomes of the literature reviews on theory and practice are challenged against each other. By doing so, the first tangible contribution of this study is formulated, a precise problem definition of the battle, including scope and classification of the Technology Battle into type and stage [Suárez, 2004].

2.6 Abductive design development of Dominance Factors

Chapter 6 further reduces *Researcher Bias* by employing schholars to define a hypothetical design framework [McKaughan, 2008]. From a long list of potential dominance factors derived from literature (see appendix B), industry experts cross-out factors that the experts find intuitively irrelevant.

2.7 Verification

The Double Diamond process continues by verifying the previous intuitive selection of dominance factors. This further reduces potential *Researcher Bias*. The selected dominance factors are *qualitatively* verified for feasibility in practice, by interviewing Industry Experts.

This *qualitative* approach is novel, in this field of research, resulting from a learning during this study. For validating Technology Battles dominance factors, many scholars employ the Best Worst Method (BWM). It is a proven model to quantitatively validate key dominance factors in Technology Battles [Van de Kaa et al., 2011]. It was coined by Rezaei [2015] as a pairwise comparison matrix in the Analytical Hierarchy Process [Srdjevic, 2005]. BWM leverages a mathematical vector optimisation, to remove linguistic inconsistencies in determining the weight of the dominance factors. To quote Rezaei [2015, p.50]: „When executing a pairwise comparison, the decision-maker expresses both the direction and the strength of the preference i over j. In most situations, the decision-maker has no problem in expressing the direction. However, expressing the strength of the preference is a difficult task that is almost the main source of inconsistency.“

However, the BWM approach was objected against. The following feedback was received:

- **Tabula Rasa** The dominance factors provide novel insights, but they do not apply universally to all stakeholders. The MES versus IIoT battle is not a *Tabula Rasa* with identical starting positions. Path dependencies imply different starting positions and therefore different strategy directions - for the same factor. This impacts the BWM prioritisation. As Rezaei [2015] implied, the decision-maker has problems expressing the direction. So, BWM vector calculation will provide very precise results, which are inaccurate though. The differences in the vector directions are not taken into account.
- **Discrete** The questionnaire seems biased to a discrete winner-take-it-all scenario, whereas co-existence and continuous improvements are expected. Surely some players will drop-out, but a single winner is not expected. Even standards will co-exist. Also, *concordant* and *discordant* factors are not taken into account, neither for a single player nor between players.
- **Non-cardinal**. The focus is too much on translating words into numbers. Some cardinality is assumed, which is highly questionable, given the current Market Uncertainty. Introducing the eleven Dominance Factors was welcomed, but BWM was rated as over-simplification.

As first response to the feedback, it was proposed to execute three concurrent BWM calculations, one for each path dependency. However, a root cause analysis of the objections solved the issue.

A prerequisite for applying BWM was missed. Before rating dominance factors, first consensus on the factors needs to be reached. Also, it is questionable whether quantitative analysis and actual decision-making is feasible at this stage. The objective of this study is 'just' to reduce Market Uncertainty. We should not overplay our hand and pretend to be able to resolve the Technology Battle. This is confirmed by respondents appreciating the insights of dominance factors, without mathematics.

A short literature study was conducted for alternative approaches; alternative AHP (Analytic Hierarchy Process), ANP (Analytic Network Process), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), ELECTRE (ELimination Et Choix Traduisant la REalité), VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje), PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations), superiority and inferiority ranking (SIR), and multi-attribute evaluation using imprecise weight estimates (IMP).

The latter method was selected, as it seems perfectly applicable given the Market Uncertainty and reluctance on decision making. The method allows for imprecise descriptions, inconsistency, vagueness, and imprecision. It very carefully translates words into numbers [Jessop, 2011]. In fact, the linguistic process of description, dialogue and discussion is valued more important than mathematical best and worst prescription [Sun and Ma, 2015].

Two Dirichlet distributions were set up to accommodate the verification, for each path dependency; 2000s MES, SCADA to IIoT and Big Data to IIoT. The full adoption of IIoT is defined as *Mission Critical* without much compromise.

Then two branches can be followed; adapt to what is currently lacking and develop it, or adept what is already possessed and exploit it. Low importance is the weaker version of these, respectively *Monitor* and *Keep satisfied*. These are weighed with respectively 10, 5 plus/minus 1, and 1 or zero. Also the modus is determined and a count of high importance and critical.

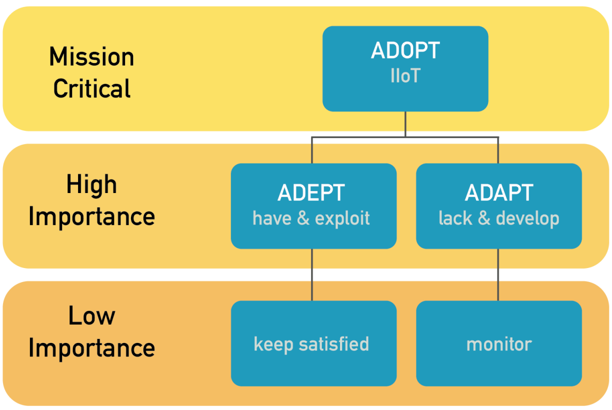

Figure 5: Path Dependency options for IMP

With this adjustment, the interviews continued. The objective remains to identify key dominance factors. But quantitative methods were dropped, as linguistic *Fresh Wording*, dialogue and discussions are more valuable in this battle stage [Jessop, 2011; Sun and Ma, 2015; Suárez, 2004].

2.8 Conclusion

Based on the qualitative and quantitative outcomes of SQ3 and SQ4, the previous section answers the main research question: What are the key dominance factors in the Industrial Automation technology battle? The conclusion chapter 8 will summarise the process to come to the Conclusion.

Afterwards, the research's value and limitations will be reviewed; What is the contribution to science and society? Finally, (research) recommendations will be given to position strategically for the Technology Battle's future development. The overall approach is listed in the table below.

Table 1: Overview of Research Methods, as defined in this chapter

Section	**Research Method**	**Purpose**
Chapter 2	Double Diamond	Overall research methodology
Chapter 3.2	Exploratory literature review	Historical innovation waves in Industrial Automation
Chapter 3.3	Power Interest Grid	Stakeholder Analysis
Chapter 3.3	Verification of assumption used throughout this study	Verify Vendor Solution Portfolio matching Automation Pyramid Solution Definition
Chapter 4.2	Exploratory literature review	Evolutionary economics
Chapter 4.3, 4.4, 4.9	Exploratory literature review	Network economics
Chapter 4.5 - 4.8	Exploratory literature review	Format & Platform Wars
Chapter 4.10 - 4.11	Exploratory literature review	Strategic Management of Innovations
Chapter 5	Deduction & Problem Definition using Double Diamond	Challenging of theory (chapter 4) with actual business ecosystem (chapter 3).
Chapter 6	Abduction & model development using Double Diamond	Interviewing scholars to cross-out non-applicable dominance factors and selecting possible dominance factors
Chapter 7.2	Verification with IMP	Interviewing 12 industry experts
Chapter 7.3 - 7.7	Verification	Discussing results from an academic perspective
Chapter 8	Conclusion	Conclusion
Chapter 9.1	Reflection	Limitations of research
Chapter 9.2 - 9.3	Reflection	Contribution to theory and society

3 Analysis of the Business EcoSystem

3.1 Introduction

This chapter is a market analysis of the stakeholder positions and historical innovation waves in the Industrial Automation realm. In paragraph 3.2, seven innovation waves are described, followed by an in-depth stakeholder analysis in paragraph 3.3. It concludes with a definition of the Technology Battle.

In general, Industrial Automation is considered a Business EcoSystem [Moore, 1993] given the tight network and coevolve of the stakeholders; Industrial End-Users, Service Providers, and Automation Vendors providing hardware and software products. All players provide services and custom software.

Industrial End-Users use industrial Automation hardware and software for their work in factories in discrete manufacturing and the continuous process industry. Some typical roles are; operator, engineer, data analyst, scientist, quality officer, production supervisor/executive, planner, controller and COO.

Service Providers support the Supply Chain Network of both vendors and the industry, by offering System Integration, Consulting and Training, as well as User Group activities and standardisation.

Automation Vendors sell automation products, hardware and software, both Commercial of the Shelf (COTS) and project-engineered. Just like Rome was not built in one day [li proverbe au vilain, 1190], the solutions have co-evolved during 50 years of Industrial Automation.

3.2 Historical innovation waves in Industrial Automation

Automation (Greek = self dictated) is the use of electronics to guide, control and improve processes. It is a step beyond mechanisation, where humans use machinery to optimise their work. Automation provides information and communication to optimise work. It offers a *decision support system* [Turban, 1988].

Triggered by the 1913 Ford Assembly Line, many industrial processes have become automated. In the 1930s, the Japanese car and war-industry followed. Equipment got electrical controls; its data got available for operators, orders were managed electronically, etc. Since the 1970's Industrial automation became prominent, and these can be classified into three historical innovation waves, see figure 6.

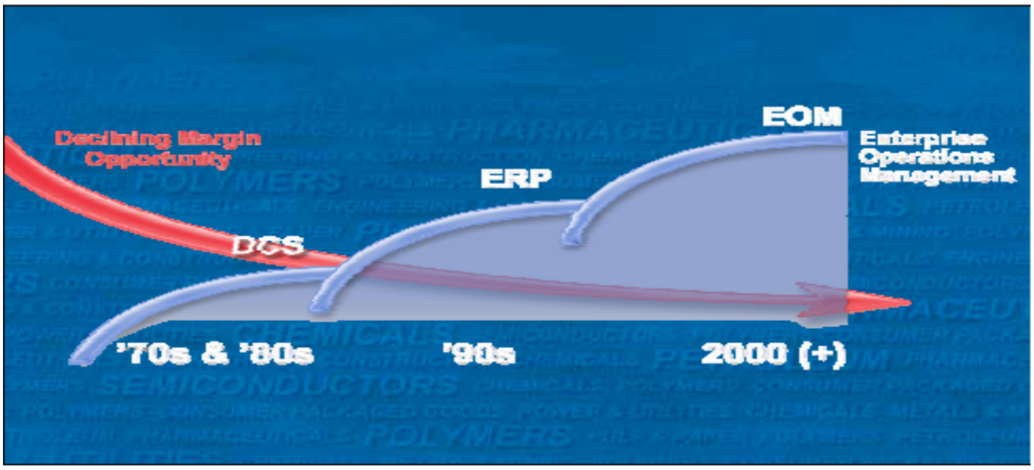

Figure 6: AspenWorld Conference on Industrial Automation niches, AspenTech CEO McQuillen 2002. Showing Decreasing Margin Opportunity (in red) versus historical Industrial Automation Waves (in blue). Please note that EOM is nowadays called Manufacturing Operations Management (MOM). As stated in the Glossary, the difference between MES and MOM is basically verb and noun: "MES is doing MOM".

3.2.1 1970's innovation wave: Equipment Automation (PLC, DCS, SCADA)

Under the denominator Equipment Automation fall all factory shop-floor automation, using Distributed Control Systems (DCS), Programmable Logic Control (PLC) and Supervisory Control & Data Acquisition systems (SCADA). This jargon will be explained in the following sections. Typical is that many vendors have dominated the Industrial Automation market. To name some early players: Bedford (1964), Allen-Bradley (1971), Honeywell, Elsag-Bailey, GE, AEG, ABB, Fisher-Rosemount, Yokogawa, Rockwell.

Whereas the concept of equipment-automation was functionally identical, data-interfacing between them was a significant challenge across these vendors. Interfaces were proprietary, and standards were lacking at all levels of the OSI 7-layer model. This was accepted since the focus of automation - back then - was on standalone equipment anyhow. The operator and process engineers, who were interpreting the data, executed data-integration employing 'walking networks', e.g. exporting data-sets to a floppy disk and walking it to each-other. Data was processed in spreadsheet applications such as *Lotus 1-2-3*.

In the 80s the usage of the automation system grew further. Where initially only the process itself or the operators were supported, now (quality) supervisors and planners could benefit as well. Software layers were added to offer 'Process Information Management System' (PIMS) functionality, and various equipment got integrated. This was typically limited to using one software package per factory, and a corporation could have a cacophony of hundreds of automation software deployments worldwide. Because of the lack of standardisation, the effort to gather and historise data was more complex than the effort to analyse the data. For instance, the development team of the software vendors Setpoint and ISI (later merged to AspenTech) Data Historian software package consisted of about 10 core developers and about 20 interface developers. Their integration software portfolio (gathering data from various DCS/PLC/SCADA systems) consisted of more than 200 products. However, the core portfolio was limited to five applications; a Data Historian, Batch Track & Trace, SQL+ interface kit, Statistical Process Control and Human Interfaces for data (trend) analysing.

A reference model was introduced for Computer Based Manufacturing (CIM), including an equipment model, a procedural/recipe model, and a process model. In practice, data was lacking as interfacing failed.

When in the 90s the standard OPC was introduced (OLE for Process Control) this *entrenchment* (of having to stick to one vendors automation infrastructure) was opened up. Entrenchment is a technological stalemate, which Egyedi and Verwater-Lukszo [2005, p.2] defines as „changes to a technical infrastructure are only possible at the cost of re-adjusting the socio-technical arrangements that surround it.“ Now, integration became easier, and the market for MES was transparent. However, the second innovative wave of industrial automation was present: Enterprise Resource Planning. Moreover, since the margin opportunity of DCS reached its maximum and ERP offered new prospects, the industry focus had already shifted to this new automation field. This is a classic example of a technology-push into an existing market.

3.2.2 1990's innovation wave: Enterprise Resource Planning (MRP, ERP)

ERP stands for Enterprise Resource Planning. These are automation activities focusing on decision support for business processes overarching the shop floor. For example; Order Processing, Product Cost Accounting, Supply Chain Management, Inventory, Maintenance, Procurement.

ERP became an Automation Wave in the '90s. In fact, it originates from 1960's mainframe systems to optimise Material Requirements Planning (MRP) [Orlicki, 1975]. Around the year 1972, IBM introduced Communication-Oriented Production Information and Control System (COPICS), which was used at Philips until 1990. When IBM disinvested in the programme, ex-employees continued the legacy and started *System Analysis and Program Development* (SAP). Initially, SAP only overlooked Material Planning, and it was extended in the 1990s with Procurement, Inventory Control, Planning, and Production, all in one application and one central database. SAP became a big success.

These (sub) innovations have influenced Industrial Automation, either by lack of budget (because of the CFO prioritising ERP) or by the demand to integrate PLC/DCS/SCADA data with ERP.

3.2.3 2000's innovation wave: Manufacturing Execution System (MES)

Contrarily to the previous two technology-pushing waves, the next innovation wave is technology-pulling.

A Manufacturing Execution System (MES), as Seeley [1997, para.1] stated; „makes it possible to pass information back and forth between an MRP/ERP system and programmable logic controllers (PLCs), distributed control systems, and supervisory control and data acquisition (SCADA) systems on the floor of a manufacturing facility." [Seeley, 1997] To achieve this, fixed point-to-point connections are made with data-streams, to streamline these. MES follows the *Automation pyramid*. In the lower layers, terabytes of real-time production-data are gathered per second. These are then processed to kilobytes of steady performance data, for the ERP system. In return, some data flows down from the ERP business-layer to the production-layers, to plan and trace produced items with a batch number.

MES arose after a market demand to automate the processes in between DCS & ERP. This led to a new way of operating and even thinking that several business processes were managed, which neither DCS nor ERP people were previously aware of. Already in 1997, MES looked very prospective [MESA, 1997]: „66% of the manufacturers responding reported a reduction in manufacturing time of >45% and a reduction in entry time of >75%. 57% reported a reduction in Work-In-Progress of >25%. 63% reported a reduction in paperwork between shifts of >50%, and a reduction in Lead Time of >35%."

While the MES concept indeed looked prospective, the MES market did not grow to its True Potential (pun intended, this was the marketing slogan of AspenTech). One or more reverse salients caused this. The first reverse salient is diffusion since many MES projects were sticking to old technology or old style of working, which was not applicable in the new market: Too factory / production-line focused on a high-level system. Because the MES was often implemented very specific to one local factory or production line, it was challenging to integrate between factories and production lines. Too much vendor-focused, ineffective integration with competitors. When different vendors had done the automation at different factories, it was challenging to integrate the systems. Again, an MES implementation is always specific. Often built upon DCS or ERP technology, which either have a real-time or a steady concept and not the required object-oriented concept. The second reverse salient is that the existing companies were blocking innovations because they already had saturated the market and customers were locked-in. A couple of companies arose which had a correct vision for the MES market. Still, it was too difficult for them to penetrate the existing DCS and ERP market for multinationals. Therefore, most MES projects were only successful at small or mediocre enterprises.

As solution, market leaders acquired the MES entrants and integrated their software. The following MES players were acquired around 2000: M2R (offering eBRS) by AspenTech, Compex by Siemens, Base Ten by ABB and INCODE (offering POMS) by Honeywell. An interesting phenomenon is described by Brandl [2000, p.17]: „as traditional control vendors and enterprise resource planning vendors are adding manufacturing operations through the purchase of manufacturing execution system (MES) companies and MES-level software solutions, they are using the ISA-S95.00.01 models for internal organisation."

3.2.4 2010's innovation wave: The Fourth Industrial Revolution (4IR)

At the 2011 Hannover Messe, the German research institute DFKI claimed that we are in the Fourth Industrial Revolution (4IR). Whereas the third industrial revolution was driven by electronics and industrial automation, e.g. limited to factories, 4IR is claimed to be driven by Cyber-Physical Systems.

A new industrial revolution is compelling. Within five years after coining 4IR, already 130 relevant articles were published; 37 in English and 12 in German academic journals or conference proceedings; 52 in English and 29 in German practical journals or books [Hermann et al., 2016]. The 4IR focus is merely on components, equipment, devices and impact thereof on society and economy. The literature on overarching concepts and standards seems scarce, which is surprising for an Industrial Revolution.

A second observation is on the announcement of the industrial revolution, a-priori instead of ex-post [Drath and Horch, 2014]. Re-industrialisation is the envisioned goal of 4IR, de facto a planned policy for re-shoring jobs lost to Asia. 4IR was branded in Germany with an intensive campaign. It was government-funded for 200 million, with a market-push for re-industrialization of Germany [Bundesregierung, 2012]. The EU also funds 80 billion as part of the Horizon 2020 program for re-industrialization. Still ongoing is the Seventh Framework initiative ICT Innovation for Manufacturing SMEs (I4MS) which aimed to help SMEs and mid-cap manufacturing companies master the digital transformation in cloud computing, robotics and simulation (77 million). Also, at least 100 billion from the European Structural and Investment Funds (ESIF) are available to the Member States to make investments in *smart specialisation* innovation, which encourages regions to concentrate on their comparative advantages and to create pan-European value changes [Davies, 2015].

Bauer and Horváth [2015] estimated an economic growth for Germany induced by 4IR of 78 billion up to 2025. Price Waterhouse Coopers expected; „within five years after the 4IR introduction, productivity increases of ca. 18%, and sales growth per year of 2-3%, with projections of yearly sales growth of 30 billion for the entire industrial sector“ [Reischauer, 2018, p.7]. Moreover, the key driver is the competitive threat from large international digital concerns and development efforts in Asia-Pacific and the USA, which already pushed further the frontiers of digitisation. Billions of euros are spent to prepare for the 4IR readiness and transitioning, both public and private.

However, the announced re-shoring effects are not (yet) significant. A vast number of re-shoring activities are ongoing in Europe, but the target of 20% is not quantified in actual results [Nassimbeni et al., 2019]. In the US, the decline of Manufacturing Employment was halted since 2009 which was not attributed to 4IR [Moser, 2019]. Research on re-shoring, specifically related to 4IR, found limited to new product development only [Ancarani and Di Mauro, 2018].

Nevertheless, 4IR is pushing disruptive technologies, also to Manufacturing Operations Management. In the factory is where new *Industry4.0* technologies get introduced, both tangible IoT technologies (such as robots and IoT devices), as well as intangible architectures (such as cloud, data lakes, NoSQL interfaces, LowCode applications and concepts such as servitisation and platformization). A technology-push is observed on *Industrial* Internet of Things (IIoT), attempting to surrogate MES.

The functional scope of IIoT is often summarised in three points [Henning, 2013]: (1) Horizontal integration through value networks; (2) Vertical integration and networked manufacturing systems, see figure 1; (3) End-to-end digital integration of engineering across the entire value chain. This is quite identical to MES; therefore, a more in-depth comparison needs to be produced.

3.2.5 2020's MES versus IIoT: Functional and Non-Functional Components

Based on the literature study, MES and IIoT can be distinguished as listed in table 2. Obviously, hybrid architectures exist, but these are out of scope for this study. This study uses *either-or* denominators to distinguish between MES and IIoT. These are, in fact, an interpretation and shall be validated.

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Table 2: MES versus IIoT differences as found in literature

Characteristic	**MES software**	**IIoT software**
Description	MES has business intelligence **functions**. In this paper, the predicate MES refers to pre-2011 MES, as detailed in this column.	IIoT is a data **technology** for equipment. In this paper the predicate IIoT refers to post-2011 MES architecture(s).
Horizontal Integration	Horizontal orchestrating PLCs via OPC. Horizontal integration with other MES-SCM-PLM systems, leveraging B2MML.	Horizontal orchestrating PLCs via OPC, using RAMI4.0 *admin shell*. Indirectly integrates other systems via Data Lake.
Vertical Integration	PLC via OPC to MES to ERP and BI as live Manufacturing Operational System	PLC via OPC to Data Lake (indirectly to BI as ad-hoc off-line Lakeshore Mart)
Architecture	Three-tier client/server with on-premise DataBase (one for each site or factory) and B2MML interface.	On-premise *Admin Shell* IIoT gateway, feeding Data Lake / Data Warehouse / Data Marts and cloud apps.
Data Models	Based on ISA-88 / ISA-95 designed prior deployment. Data model fully entrenched in DataBase and interface design.	bottom-up data model, NosQL/Hadoop potentially not version-controlled nor standardised across the enterprise.
Data Storage	Relational DataBase with normalised (embedded) data model, one for each site or factory, based on ISA-88 and ISA-95. Often multiple databases for multiple sub-solutions. Raw data gets altered (structured) in proprietary formats.	Network databases (Data Lake) Raw data stored without data (altering) structures. Data Warehouse Marts are denormalised relational databases but do alter (structure) data. Hybrid solution to achieve acceptable performance [VDI3714-1, 2020].
Semantic interface	<AutomationML/>and ISA-95 XML (B2MML) semantic business interface.	<AutomationML/>. No semantics for functional or business intelligence layers.
Operational Efficiency	Solutions are often *off the shelve* with templates covering market-typical requirements. Low need for customer's resources.	Emerging, solution is often introduced to the market whilst not fully mature, often struggling with resource capacity.
Market size	Full market coverage.	Emerging, often next to MES.
Market Covariance	Well-developed network of (strategy) consultants, engineers, project managers, support, training, etc. Spanning horizontal and vertical markets.	Often single-market focus, only partially covering MOM activities. In other words, when replacing one MES system, multiple IIoT systems are to be implemented.

Now that MES, IIoT and their differences are defined, we can distinguish between irrevocable technological evolution and actual technology battles. Four battlefronts can be derived; one on functionalities and three non-functional, e.g. on architecture and design.

Non-Functional Battlefront: Fixed Monolithic Architecture versus flexible SOA@Cloud

This is not a true Technology Battle, as old technology of monolithic Application Servers (physical or virtual) is simply replaced by new technology. The industry has decided to move into the cloud and adhere to Service-Oriented architectures. Current estimates predict that by 2021 more than half of the global companies currently leading in the adoption of cloud solutions will have moved all of their systems to a cloud-based infrastructure [Laney and Jain, 2017]. On-premise server rooms will become musea with legacy systems. MOM architectures must move away from Monolithic site-based server architecture to distributed components in an SOA architecture. Leading is the *Vaart der Volkeren* (Dutch for Golden Horde) technological progress.

Functional Battlefront: Standardised versus Bottom-Up Data Models

A stronghold in MOM is the ISA-88 and ISA-95 data models [Meyer et al., 2009; Thiel et al., 2008]. Although these are proven models, a constraint is the data model's design before data processing, also called *schema-on-write*. The processed, e.g. derived data becomes meaningless for other purposes than the designed purpose, meaning that raw data always needs to remain accessible for future usage. On the contrary, IIoT ad-hoc data models also risk that data sets cannot be deemed complete and will therefore always need data-scientists [Janssen et al., 2020], even more than with traditional data models. To prevent *Data-Swamp* or a *Data-Graveyard*, every ad-hoc data model must be stored along with raw data to allow future evaluations. Therefore, ad-hoc versus standard data models is a non-discussion, or at least not a Technology Battle, as in both cases raw data access remains fundamental. This is a critical functionality.

AI models, says Manzano and Langer [2018, p.4], „can analyze huge volumes of non-structured data using algorithms such as K-Means, Random Forest, or K-Nearest Neighbors. While these methods are not new (1960s), they become useful when combined with cloud computing power and a vast amount of data."

Non-Functional Battlefront: Relational Databases (tables with foreign key Identifiers) versus Network/Hierarchical databases (Data Warehouses & Data Lakes)

A path dependency exists in current MOM client/server/database architectures, backdating to the '80s. The data model is embedded in the database design. The data model determines the design of database tables, and often, data engines are found hard-coded to the data model. The data models are often so entangled in three-tier architectures (presentation-application/logic-data) that these become *de facto* two-tier (without logic, as the data tier is too rigidly structured), making data-migration to Data Warehouses and especially Data Lakes virtually impossible. Some MES solutions even still *compile* static and live data models into their proprietary data engine.

Secondly, database servers are historically on-premise meaning that systems architecture is further entrenched to *local* client/server models. Communication between systems is on-premise data tier to on-premise application tier to on-premise database data tier, both for systems on-premise with different functionalities (supply chain, LIMS, MES, Scada, Planning, Maintenance, etc.) as well as between systems at other physical locations. Many MOM software packages backdate to the '90s when the MES design was *cutting edge*; however, it turned out to be a *reverse salient* over time. Many of the successful MOM software of the '90s have not seen fundamental design optimisations ever since.

One way or the other, current relational MOM databases will have to be migrated to Data Lakes, Data Warehouses or both (with a hybrid solution).The migration decision is out of control for MOM software vendors, as IT and IoT suppliers are more powerful. MES vendors migrating their current relational databases to a dedicated Data Warehouse may survive if a single central repository is offered. The Industry4.0 momentum must be adhered to. Otherwise, MES loses the techno battle.

Non-Functional Battlefront: Raw Data Interfaces versus Semantic Mark-Up Interfaces

The fourth battle is on the interface. As shown in Table 3 NOSQL and OPC battles against semantic mark-up interfaces like ISA-95's B2MML and *<AutomationML/>*. Specifically, the ISA-88 and ISA-95 data models are being battled. A strong argument against B2MML is that data models are built based upon user requirements and implemented as a locked-in system. This may lead to a reverse salient with a stronghold of advanced data models, but limited opportunities for progressive insights at other fronts. An observed risk is that solutions are becoming too complex at IT level. This leads to the introduction of large Manufacturing IT teams, who may focus on IT aspects of the solution, and overrule the business requirements from actual Process Experts.

Table 3: Differences between MES and IIoT following RAMI4.0 layers

Characteristic	**MES**	**IIoT**
Business	Offers Business Intelligence	-
Functional	Most vendors fully cover the MOM activity model, see figure 10.	Limited to Supervisory Control, Data Acquisition and performance analysis.
Information	Enriched with events and transactional info, e.g. trace-ability between equipment, procedure and process.	Raw data with unstructured meta-data.
Comms	Machine to Business (ISA-95)	Machine to Machine (RAMI4.0)
Integration	OPC, B2MML, ERP	OPC, NoSQL, Hadoop
Assets	-	Sensors, actuators

3.2.6 2020's MES versus IIoT: Acceptance & Readiness of the Standards

The global market share of IIoT was USD 2.57 billion in 2017 and is projected to reach USD 13.82 billion by 2023 [Markets, 2018]. The most commonly used standard is still MES with a global market share of USD 11 billion in 2020 to USD 14.9 - 24.3 billion by 2025 [Bloomberg, 2020; Reports, 2020].

MES is well-established. It has been advocated since the 90s by Software Houses, System Integrators and industry-users, joined in the International Society of Automation (ISA) and Manufacturing Enterprise Solutions Association (MESA) with more than 400,000 affiliates worldwide.

MES consists of well-accepted concepts such as the *Automation Pyramid* (see figure 1), the MOM model (see figure 10), and reference architecture models defined in industry standards ISA-88 and ISA-95 [IEC61512-1, 1997; IEC61512-2, 2001; IEC61512-3, 2008; IEC61512-4, 2009; IEC62264-1, 2013; IEC62264-2, 2013; IEC62264-3, 2016; IEC62264-4, 2015; IEC62264-5, 2016; IEC62264-6, 2020]. The reference architecture models define terminology, standard data models and a semantic interface *Business To Manufacturing Markup Language* (B2MML), an XML implementation of the ISA-95 family of standards. The MES standard is both *de Jure* and *de Facto* [Gallagher and Park, 2002].

Whereas MES is currently a well-established standard, literature research (as detailed in Appendix A) found that IIoT is suffering from acceptance and readiness problems, causing Market Uncertainty:

1. **Definition of 4IR is ambiguous** especially the scope, cost & benefit remains unclear. This is typical for emerging technologies or an industrial revolution. Only the disruption is clear.
2. **Capacity issues on investing in 4IR** investments for 4IR are high and are difficult to fund. Skilled personnel lacks the market for software architect/developer, solution architect/implementors, and even for end-users and maintenance. And many resources are needed, as costly tailor-made solutions are required. Corporations and service providers lack personnel-resources as the market resource pool is limited, and customised solutions are labour-intensive. This is caused by lacking standards (company and market) and/or templates.
3. **Make or Buy Hobsons Choice; IIoT will always be tailormade** because of lack of resources and lack of mature technology, System Integrators and vendors implement fully custom projects. Templates, reference architecture models and subsequent application-platforms are lacking.
4. **Conflicting reference architecture standards/models; IIRA, IDSA-RAM, RAMI4.0** Multiple reference architecture models exist, as if IIoT is battling with itself to come to a standard. The contents are hardly conflicting, though. Each claims that the *Automation Pyramid* must be redefined and only redefine the lower layers; SCADA and Equipment-automation. Also, the models are not adopted by MOM end-users. RAMI4.0 seems more advanced and is *de Jure* ICE-registered, but the

question remains whether it will become a standard *de Facto*?

5. **The IIoT reference architecture model RAMI4.0 is non-adopted and non-functional** The German government has funded a *de Jure* IIoT reference architecture model. Most parts are only available in German language or behind a pay-wall. No non-German speakers were invited for establishing the standard. The industry-representation is marginal; the RAMI4.0 contents are mostly authored from the Ivory Tower of the German electronics equipment user-group ZVEI (Zentralverband Elektrotechnik- und Elektronikindustrie or in English: Central Association of the Electrical and Electronics Industry). Upon closer inspection, the RAMI4.0 model is a copycat from the Electrical Smartgrid model SAGM [Englert and Uslar, 2012] and has not been adapted to other industries. The standard is not peer-reviewed by process-industry experts outside the ZVEI electricians network. Having said that, RAMI4.0 excellently covers Machine-to-Machine (M2M) automation for asset communication, and information interfacing. Nevertheless, the Functional Layer and Business layer are not defined by RAMI4.0, see figure 7. It is also not planned in the Industrie4.0 standards roadmap [DIN, 2020]. But a MESA smart manufacturing model is announced [Richardson, 2020]. RAMI4.0 remains limited to *horizontal* equipment automation. Not a single functionality for MOM is IIoT-standardised or even IIoT-defined. Also, the Lifecycle Management that RAMI4.0 is said to prescribe turns out to be an empty shell. This would be a niche market for MES or IIoT to orchestrate. It is definitely in need of a meaningful standard.

6. **Cim-Salabim: spelling magic words instead of integrating technology** IIoT is functionally identical to the 1980's CIM (Computer Integrated Manufacturing), and MES. CIM failed as only buzzwords were used in magazines and conference, whilst proper data-interfaces and centralised architectures of CIM applications were lacking. IIoT may make the same mistake. Just offering IIoT data-mining applications (without data-models or data-integrity) is trusting on CIM-Salabim [Jacobi, 2013].

7. **Are the readiness models ready for 4IR?** The 4IR readiness models are CMMi models backdating to the third industrial revolution (MES). The models are excellent but may be outdated. Although some 4IR artefacts have been added, the CMMi framework remains identical. The CMMi model framework likely needs a total makeover to incorporate new concepts such as platformisation, servitisation, and lifecycle management.

8. **4IR is a cacophony of products; lacks a systems perspective** Under the denominator 4IR a cacophony of products are marketed: Augmented Reality, Internet of Things, Multi-Agent Systems, Artificial Intelligence, Big Data Analysis, Simulation, Cyber Security, Cloud Computing, Additive Manufacturing, and IIoT. What is missing is a systems perspective. In particular, IIoT is currently not leveraging the situation by offering a System-of-Systems approach. Having said that, it does fit in with Service Oriented Architectures as long as there is a common ground for data models.

9. **No abundance of resources to fuel 4IR** previous industrial leaps had a strong momentum leveraged by relatively unlimited energy sources (fire, animal-power, wind-power, coal, oil, nuclear energy, etc.), often in conjunction with an economic boom.

3.2.7 2020's IoT re-introduction of SCADA as SCADA4.0

Whereas 4IR and IIoT have broad problems with readiness and acceptance, one specific solution is well-perceived: the IoT re-introduction of SCADA. The functionality is identical to traditional SCADA, but with a scalable asset administrative shell. This is defined in the RAMI4.0 standard and allows for de-centralised I4.0 components to work more or less independently within a Production Recipe's lifecycle whilst being orchestrated centrally [Fuchs et al., 2019; Leeuw, 2019; Pisching et al., 2018].

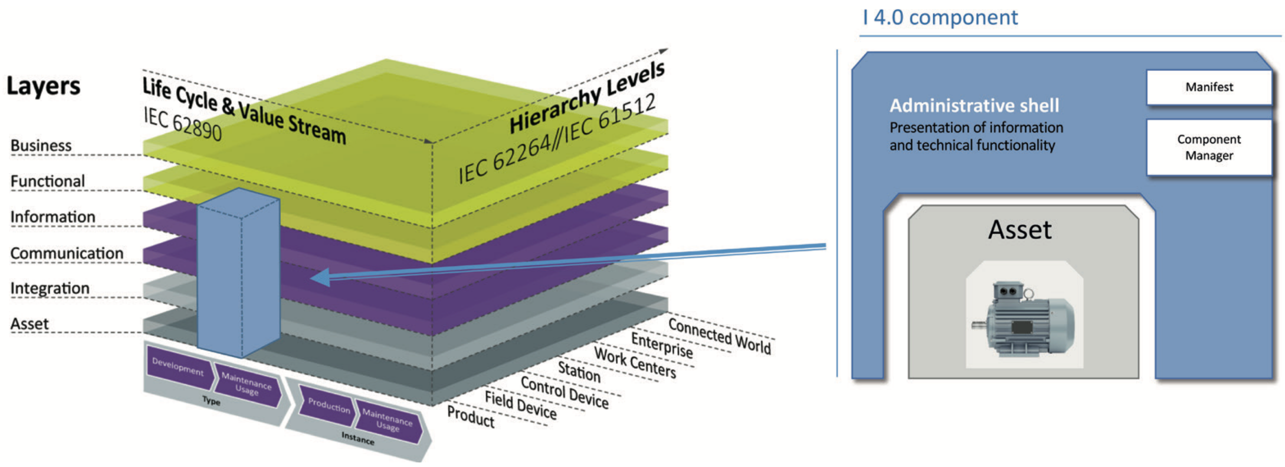

Figure 7: RAMI4.0 model with Asset Administration Shell for SCADA4.0

PLC vendors typically offer SCADA4.0. Some claim that SCADA4.0 will replace MES. However, SCADA4.0 functionality is limited to *lower-MES*, see figure 10, literally Supervisory Control and Data Acquisition. That is only 5% of the functionality of MES/MOM. For example, it lacks the functionality of production recipe control orchestrating the modern SCADA. Also, Business Intelligence functions lack SCADA4.0, which can only be offered by an orchestrating MES or IIoT solution.

The new RAMI4.0 standard for the Asset Administration Shell is excellent, and it will seamlessly integrate with MES/IIoT orchestrating multiple lines and sites. The conclusion is that RAMI4.0 is limited to IoT communication protocols; RAMI4.0 does not cover IIoT functionalities nor business intelligence.

3.3 Stakeholder Analysis; how IIoT is disrupting the entrenched market positions

The stakeholders are visualised in a Power Interest Matrix [Mendelow, 1981], See figure 8.

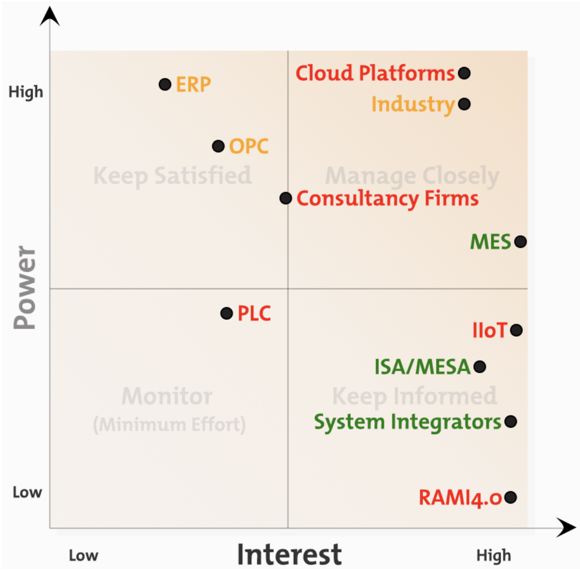

Figure 8: Power Interest Matrix for stakeholders in the MES/IIoT Technology Battle (MES advocates and supporters in green, blockers and critics in red, and neutral in orange)

The stakeholders as found in the literature are: **MES** vendors of 3IR MOM products, who are still the market leaders but struggling with IIoT market entrants and SCADA4.0 disinformation from PLC vendors; **IIoT** new market entrants selling MES functionalities on modern architectures; **PLC** maintaining their installed-base and full-on on pushing new IoT equipment automation and SCADA4.0; **ISA-MESA** user groups still advocating for MES, with 40.000 affiliates worldwide, offering *de facto* MOM standardisation, but not affiliating or modernising with RAMI4.0; **RAMI4.0** is the new IIoT standard, struggling to get a foot on the ground outside of Germany, not co-operating with ISA-MESA. In Germany, it is a *de Jure* MOM standard but *de Facto* only covering SCADA4.0 (in other words, in terms of the *Automation Pyramid* it is NOT covering MOT but only SCADA); **System Integrators** are profit-driven, following industry needs whilst partnering with booth MES and IIoT, System Integrators are influential but tend not to choose sides; **Consultancy Firms** independent but biased on anything *cutting edge or bleeding edge*, they may make a hype as marketing for their own profitability; **Cloud Platform** and Data Lake / Data Warehouse suppliers, pushing irrevocable technological evolution for the entire market. The industry, ERP, MES and IIoT has no choice but to follow; **ERP** defending its stronghold ERP installed base and trying to enter the MES/IIoT market with their own proprietary standards; **OPC** formally a standard for PLC to MES communication but jumping on the SCADA40/IIoT bandwagon claiming that their flat-data standard can bypass MES/MOM semantics and functionality. This is considered disinformation, but is a threat for MES; **Industry** end-user looking after reliability, cost reduction and other profitabilities. Is confused and merely awaiting the outcome of the MES/IIoT Technology Battle.

Entrenched positions

The market positions of the stakeholders is currently entrenched. A recent Global Business Research [Vries, 2020] study compared 100 automation products to vendors, using the *Automation Pyramid* technologies as the denominator. The classification fits remarkably well, as shown in figure 9 on page 18. The classification was validated by confirming whether the *Automation Pyramid* standard interface technologies were actually in place (OPC, B2MML).

It was found that 97% of the established vendors offer one single type of product (MES, DCS/PLC/SCADA, BigData), which perfectly fits the *Automation Pyramid* standard. Only 3% of the vendors have a product portfolio expansion outside of its trench. Now that IIoT market entrants are ignoring the old standards, in which the existing vendors are locked-in, IIoT has more degrees of freedom. It is a classic example of a *reverse salient* [Collingridge, 1982] in which 97% of the stakeholders are stuck.

The 3% of software vendors that are not entrenched may hold the best position (to be confirmed).

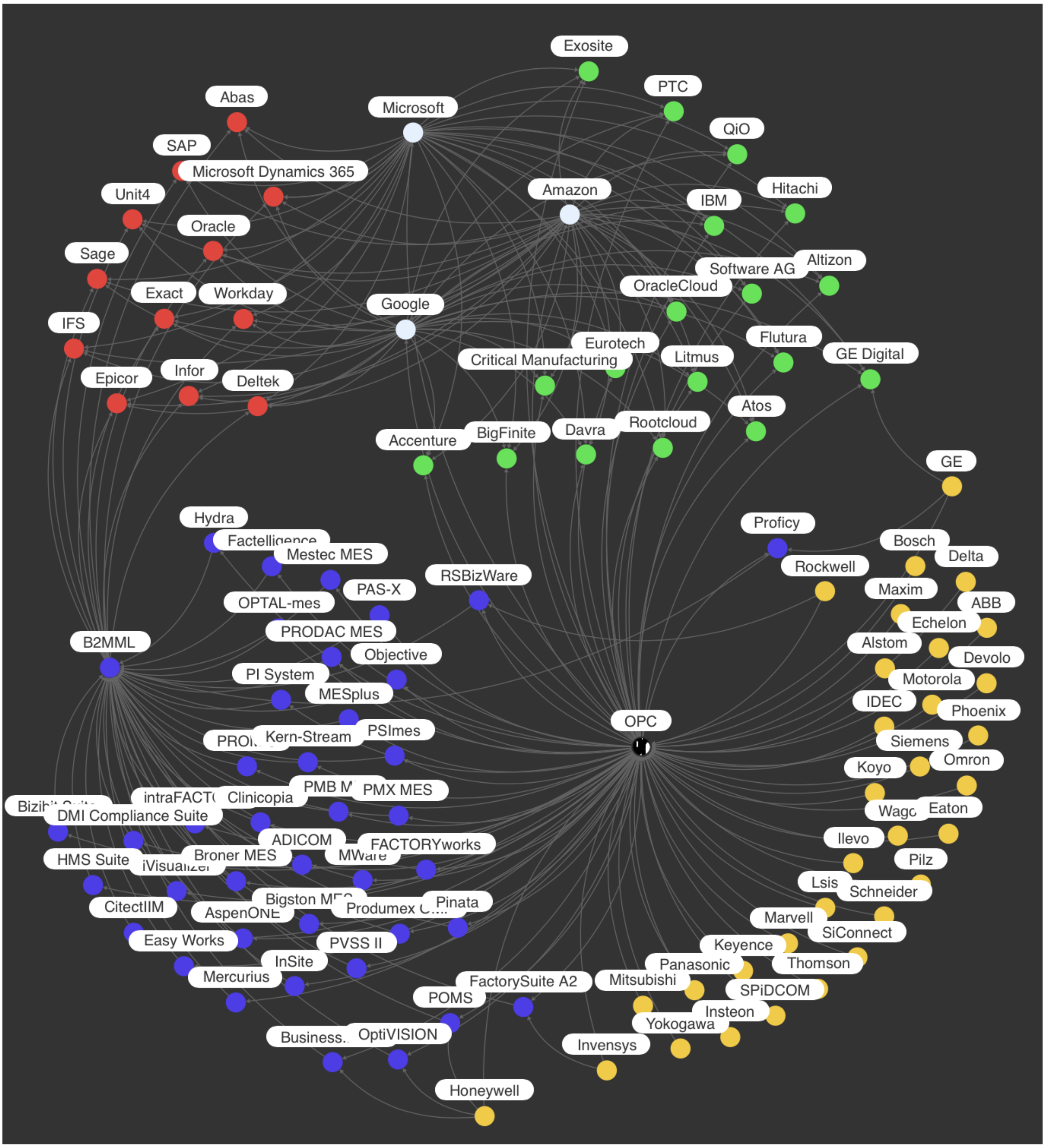

Figure 9: Vendor Solution Portfolio versus Automation Pyramid solution definition. Showing 97% of vendors locked-in to a single product. The Business EcoSystem revolves around the interface standards OPC, B2MML and NoSQL (Amazon, Google, Microsoft). In red are ERP vendors, blue MES vendors, yellow PLC/SCADA vendors, and in green IIoT vendors.

3.4 Conclusions

As abstraction from literature, it was found that clearly identifying a fourth industrial revolution is not possible for Industrial Automation. Multiple innovation waves have occurred in the past decades, and are still ongoing. From a techno-functional perspective none of these can be classified as revolution. In fact, organisational structures and product portfolio's are still structured following the 1986 Automation Pyramid. Only 3% of software houses is disrupting this traditional constellation.

The innovation waves are summarised in the table below.

Table 4: Historical Events in Industrial Automation

Event	**Started**	**Description**
PLC, DCS, SCADA	1964	Equipment automation, often standalone or local orchestration
MRP, ERP	1972	Business Intelligence automation (planning & reporting)
CIM	1973	Failed attempt to system-integrate; interface-standard lacked
Automation Pyramid	1986	Hierarchy model, coined by CEO of Allen-Bradley (Rockwell)
OPC	1994	Market-push of interface standard for PLC/DCS/SCADA
ISA-88	1995	Data-model standard for Discrete (Batch) Manufacturing
MES	1990's	Successful revamp of CIM, leveraging OPC, ISA-88, ISA-95
ISA-95	2000	Data-model standard Manufacturing Operations Management
B2MML	2002	Semantic XML standard for Batch Manufacturing (MES)
4IR, IIoT	2011	Market-push of Internet of Things (1999) for the industry
RAMI4.0	2015	Market-push of IIoT reference architecture model

Above and beyond these artefacts, the literature review confirmed the market uncertainty. In particular, ambiguity and vagueness is observed, not all possible outcomes are known or quantifiable, with as effects unwillingness to invest.

Further abstraction from literature identified that the MES/IIoT technology battle has three subjects:

Irrevocable Technological Evolution

First of all, an irrevocable technological evolution is observed, on modern IT architectures. This is driven by the market's biggest players who have set an overall ICT standard for the next decade. Traditional monolithic three-tier architecture - with multiple human interface clients, an application server and a database server - will disappear. Legacy support may remain available, but that is a risk. Also, nobody should want to be cornered as having a solution for laggard infrastructure. Modern IT landscapes consist of Cloud & Service Oriented Architecture, in other words, Modular applications, decentralised opposed to monolithic servers on-premise for each physical site, and as monolithic databases will be replaced by Data Lakes and Data Warehouses. The major challenge for MES will be a de-entrenchment of Data Models from Monolithic Architectures and migrating these to Service-Oriented architectures.

Misinterpretations and Framing

Secondly, multiple misinterpretations and/or framing [Fairhurst and Sarr, 1996] were found. It is often stated that ISA-95 prescribes a monolithic hierarchical architecture, but that is incorrect [Moghaddam et al., 2018]. In fact, MES vendors offer laggard architectures. In contrast, the ISA-95 standard covers data models at the level of Business Intelligence, functions, and semantic interfaces, all of which are fully compliant with SOA architectures.

Another incorrect statement is that RAMI4.0 covers all MOM activities. It is only a modern interpretation of the OSI 7 layer model; defining data links, networking, transport, communication, and presentation of information for system administration purposes. RAMI4.0 excludes Business Intelligence and does not offer a single MOM end-user functionality. Closely related to the RAMI4.0 confusion, many PLC vendors claim that their modern SCADA solutions can replace MES. However, fact is that SCADA4.0 only partially offers

Production Execution and Production Data Collection, whereas the other ten MOM activities are simply not offered by SCADA (see figure 10).

These three pieces of disinformation originate from the IIoT front. Obviously, it could be misinterpretations, as the matter is quite complex, but these statements are often found in articles where the author has conflicts of interest. A similar framing is found from the MES front, claiming that IIoT is a not a system but a scattered cacophony of loose products. That makes sense, seen from the ivory tower of monolithic MES. But in fact, IIoT offers Service Oriented Architecture, which is by definition 'scattered'.

Actual Technology Battle

The actual Technology battle is between MES and IIoT vendors on the following fronts:

- MES data platform versus IIoT bottom-up data miners, with respectively B2MML semantic interface versus IIoT RAMI4.0 NoSQL interface;
- Will MES or IIoT orchestrate SCADA4.0, e.g. the RAMI4.0 Asset Admin Shell?
- Will MES or IIoT orchestrate Life Cycle Management at functional and Business Intelligence level? That is from R&D to (pilot or launch) factories, recipes, orders and continuous improvements.

From a techno-functional perspective, the question is which vendor will address the functional requirements and offer business intelligence. In other words, which vendor will cover all Manufacturing Operations Management activities, as shown in fugure 10 below.

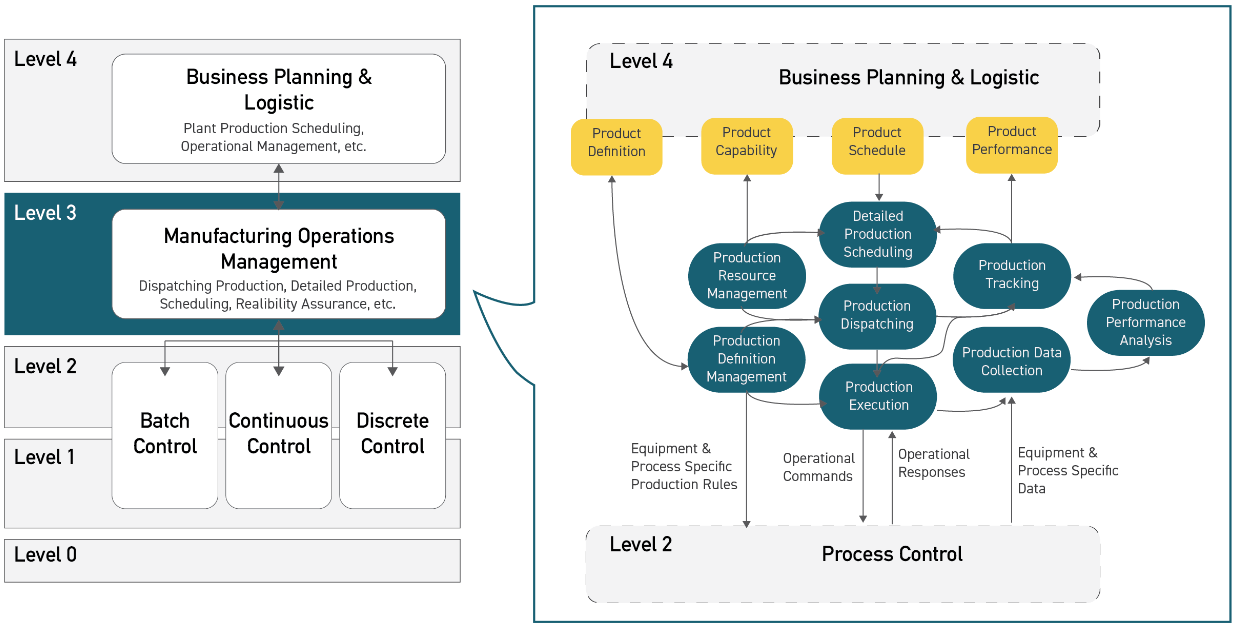

*Figure 10: Scope of **Manufacturing Operations Management** as defined in ISA-95*

The above techno-functional artefacts address *Dominant Design* factors [Fernández and Valle, 2019].

However, this chapter's literature abstraction also found non-technical aspects of the battle. At implementation level, readiness and business change are non-technical factors. At techno-societal level, new work ethics or culture is often described, as well as a disruption in the business ecosystem. Looking above and beyond, the MES/IIoT evolution remains vague and ambiguous on these non-technical artefacts. This stalls the market uncertainty.

4 Technology Evolution & Battles Literature Review

4.1 Introduction

The previous chapter concluded with the technical details of the Technology Battle. But also, non-technical factors were found. These are likely to have a significant impact on the Technology Battle and require further analysis. Therefore, exploratory literature research is conducted, on Technology Battles and related theories such as technological evolution processes.

The literature review starts with *Evolutionary Economics* the early work of Thomas P. Hughes in paragraph 4.2. His theorem is selected, as it is a proven model for retrospective analysis of mature system-of-systems. It assesses reverse salients and entrenchment, which were observed in the previous chapter [Hughes, 1987].

From the same era is the 1984 Social Construction Of Technology (SCOT framework) where Pinch and Bijker assess the Social Construction of Facts and Artifacts: Or how the Sociology of Science and the Sociology of Technology Might Benefit Each Other. In 2016 Baalen et al. wrote an article on extending the SCOT framework to the digital world, which will be reviewed in paragraph 4.3.

Thirdly, in paragraph 4.4, the Sailing Ships case is reviewed as this is an example of old technology getting a boost due to the introduction of new technology. The theorem of Technological Transitions and appreciative theory is applied, with the specific case study [Geels, 2002; Mendonça, 2013].

In paragraph 4.5 the basics of Format Wars is reviewed [Shapiro and Varian, 1999]. A format war is a specific technology Battle on standardisation in two-sided markets [Rochet and Tirole, 2003]. The purpose of this paragraph is to determine whether MES and IIoT can be seen as two-sided markets and whether Format Wars apply.

In the previous chapter is was discovered that the establishment of MES was, in fact, the outcome of a Technology Battle with SCADA. This is analysed in paragraph 4.6 using the theorem of Suárez and Gallagher and Park. The purpose is to determine the established characteristics of MES in the IIoT technology battle.

The technology battle between MES and IIoT is an asynchronous phenomenon, as MES started more than 20 years ago and IIoT is new. The literature on this phenomenon is reviewed in paragraph 4.7.

Although the literature suggests a platform Battle, neither MES nor IIoT positions themselves as a platform. This is further researched on theorems about Platforms and Pipelines in paragraph 4.10 [Eisenmann et al., 2011; Van Alstyne et al., 2016].

Another outcome of the previous chapter is further researched: the ISA standards' co-existence versus the RAMI4.0 standard. Paragraph 4.8 analyses the possible multi-mode standardisation battle [Wiegmann et al., 2017].

Most of the recent literature addresses duels and truels in the Business-to-Consumer market. However, the MES versus IIoT technology battle is between business clusters in a business to business market. Relevant research could be the work of den Hartigh et al., which is reviewed in paragraph .4.9

Last but not least, paragraph 4.11 challenges the framing that IIoT is a substitute for MES [Fairhurst and Sarr, 1996]. IIoT may well be a complementary good next to MES. In that case, a Blue Ocean strategy may be wiser than a Red Ocean strategy [Kim and Mauborgne, 2005]. Would it be possible to create uncontested market space and make the competition irrelevant?

4.2 Large Technical Systems; reverse salient, entrenchment, system builder

The production of new technology can be interpreted as following a deterministic path, pushing socio-technical changes towards establishing a system. Hughes [1987] described innovation as creations of Large Technological Systems. The current definition describes multiple socio-technological phases, which may overlap; invention-development adapting a radical invention to economic, political and social characteristics, innovation phase adding complementary components for production and services, transfer *commercialisation* to other markets, consolidation where a system has gained so much momentum and path dependency that a *systems culture* has been created that is difficult to change, up to further system growth with *institutionalisation* and standardisation. Each of these phases has its own characteristics.

Typical for early system growth is reverse salients. That is a part of the initially successful system, falling behind in its development, like in a front line. In this state of unevenness, the underperforming component may act as a retardant hampering the development of the overall system. The systems innovative capabilities can become exhausted due to the reverse salient. The solution is defining it as a 'critical problem' [Hughes, 1987] and resolving it with a multi-disciplinary socio-technical approach.

Another typical artefact for system growth are catalysts of entrenchment, as coined by Egyedi [2001]. During system growth, various dependencies and design choices crystallise, solidify and make manifest a process of socio-technical entrenchment [Egyedi and Verwater-Lukszo, 2005, p.2]: „changes to a technical infrastructure are only possible at the cost of re-adjusting the socio-technical arrangements that surround it." Egyedi enhances the definition with *catalyst for entrenchment*, in particular around standardisation. Standardisation is the outcome of a path-dependency of technical and political design choices, which fix initial technology development [Hanseth et al., 1996] parameters. Also, standards coordinate further technology development [Schmidt et al., 1998]. Standards provide the reference architecture to develop compatible products, stimulating new market entrants, which increases the number of actors and products, which leads to momentum, e.g. rigidity of the system and difficulty to change it [Egyedi, 2001]. The solution is designing for system flexibility, for example, OPC or XML interfaces.

Typical for momentum is Institutionalising the technology into a belief system, employment norms and values, impact on politics, organisations and further entrenchment between other technologies and social development. As an example, many companies have separate departments for equipment automation and MES. Also, IIoT is often found in a different department.

During later research, the artefact of System Building was added. It refers to actors that merge and align technical and non-technical elements into a socio-technical whole system. The concept suggests studying the key actors not as heroic inventors, but as dedicated builders of socio-technical systems [Van der Vleuten, 2009, ch.39]: „Thomas Edison was not so much concerned with 'inventing' the light bulb as with designing and selling entire electricity supply systems, which demanded simultaneous work on a commercial vision, contracts with local governments and financiers, setting up new companies, marketing, and new generator, distribution network and lightbulb designs."

In the previous chapter, three historical waves of innovations are described. Following Hughes LTS theory, PLC and ERP innovations are similar in nature, since existing processes are automated.

The third wave MES is very different. New functionalities are invented and developed in between the existing processes of DCS and ERP. Before MES, only ad-hoc business processes existed in this area, and no multidisciplinary efforts were in place to increase efficiency between the shopfloor and the enterprise-level. Because DCS and ERP automation reached momentum, the the business processes' hidden factory was revealed [Miller and Vollmann, 1985]. MES was able to overcome the organisational silence [Slade, 2008] in this area. Therefore, a new market evolved to improve multi-disciplinary business processes.

That was in the early 2000s. Anno 2020, MES is beyond momentum and fully institutionalised. MES vendors are often found fully entrenched and suffer from path-dependencies (catalysts for entrenchment), namely its design on 1990's software and hardware architecture. As detailed in chapter 3, MES vendors have chosen monolithic client/server architecture with entrenched relational databases, as a standard, which fixes the parameters of technology development (Hanseth et al., 1996). Some scholars believe that a Large

Technical System cannot change anymore at this stage; others believe it can still evolve. Perhaps the solution is again *System Building* and re-gaining *System Flexibility*.

4.3 Extending the Social Construction of Technology Framework to Industry4.0

Baalen et al. [2016] suggests to extend the social construction of technology (SCOT) framework to the digital world. It was proposed to modernise four dimensions for digitisation: (1) Technology focus towards digital technologies, (2) Interaction focus on interpersonal, person-technology, technology-technology and technology-physical environment interactions (3) Social Groups focus on networked individualism, and (4) Context focus on socio-digital context [Baalen et al., 2016]. Whereas the article provides valuable insights, it validates the analysis in this chapter. Two artefacts that are suggested in the article are already covered by *System Building* from the previous paragraph, and by *platforms* in paragraph 4.10.

4.4 Technological Transition and the Sailing-Ship effect

The battle between MES and IIoT has an asynchronous factor of twenty years. Still, it does not seem like a technological evolution but as a true Technology Battle. In a search for analogy and previous research, the Sailing ship effect was reviewed.

The anecdote is that the speed of sailing ships had remained unchanged for centuries, up to the moment that steamships were introduced. Steamships were faster especially with low winds, and were substituting sailing ships.

This allegedly triggered further research and development on sailing ships, after centuries of non-progress: „what is often overlooked is that the sailing ship developed fastest while it was being supplanted.“ [Ward, 1967, p.1]

Even after the first world war hundreds of sailing ships transported passengers and cargo, An example is the Preussian; „Built of steel between 1902 and 1904 this German barque was square-rigged on all masts. She measured 5081 tonnes gross, had 5560 m2 of sail area, and could run up to speeds of 18 knots with a relatively small crew. In 1907, exactly one hundred years after the economic introduction of the steamer, she could be found on a round-the-world voyage, one of the very last performed by a wind-powered cargo square-rigger.“ [Mendonça, 2013, p.1].

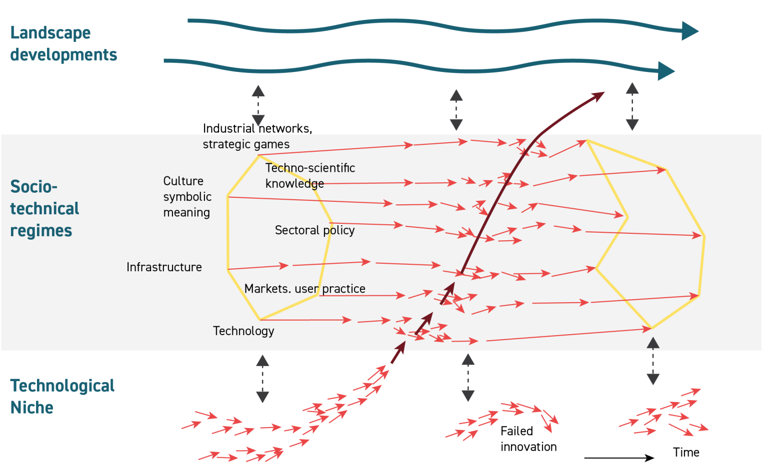

Figure 11: Multi Level Perspective (free to Geels [2002])

Ward's anecdote is debunked. A cause of the sailing ships not developing was a monopoly ocean carrier which had standardised sailing ship designs [Geels, 2002]. Furthermore, the change in speed was not directly triggered by steamship technology. Instead, the SCOT model applies. Multiple stakeholders were aware that sailing ships could improve. With the frustration of engineers and customers, entrepreneurs saw a niche, resources became available, and technology further evolved.

Evidence points to strong complementarities between sail and steam for most of the century, to steamship learning from the older technology of sail, and to the role of new global infrastructures [Mendonça, 2013].

The transition from sailing ships to steamships was not just about the propulsion technology, it was a complete technological transitions and can be seen as a evolutionary reconfiguration processes [Geels, 2002]. Also see figure 11 to the right with Geels theory.

In light of this study, Geels' theorem partly applies. For the interesting parts a significant overlap is observed with Hughes' Large Technical Systems. It was therefore decided to leave Geels' theory as is.

4.5 Two-sided markets; Format & Platforms Wars

An interesting view on Technology Battles are the economic principles of *two-sided markets* and *Network Economics*. It encompasses delivering a product or service to two concurrent user markets. Examples are the video player, with household end-users at one side and video shops and film industry as the other side. Typically, format wars exist on the platform technology [Rochet and Tirole, 2006]. Dominance is often achieved not by the technical superiority of dominant design, but by network externalities e.g. leveraging the collaborative supply chain such as video shops, film industry, video recording from television, handheld video recording, documentaries and other learning activities, etc, etc. [Parker and Van Alstyne, 2005].

An excellent meta-study on the subject synthesised 29 possible dominance factors for Format Wars [Van de Kaa et al., 2011]. These factors are evaluated in Appendix B.

A more modern variant of Format Wars is Platform Wars. This is described by Rochet and Tirole [2003] as: „To succeed, platforms in industries such as software, portals and media, payment systems and the Internet, must 'get both sides of the market on board.'" For platform wars, not just the platform itself has network externalities and increasing returns, but also the two-sided users benefit from each-others network externalities and increasing returns.

IIoT is clearly a platform. On one side is the MOM end-user e.g. the operational factory. On the other side are the (Data) Scientist and Process Experts configuring and maintaining IIoT. As a rule of thumb, the first *side* reports to the COO in a company with most end-users having a staffed position in the manufacturing organisation. For the other *side* the end-users reports to the CFO-CIO-CTO and work in the Process Development or IT organisation. This can be staffed or outsourced.

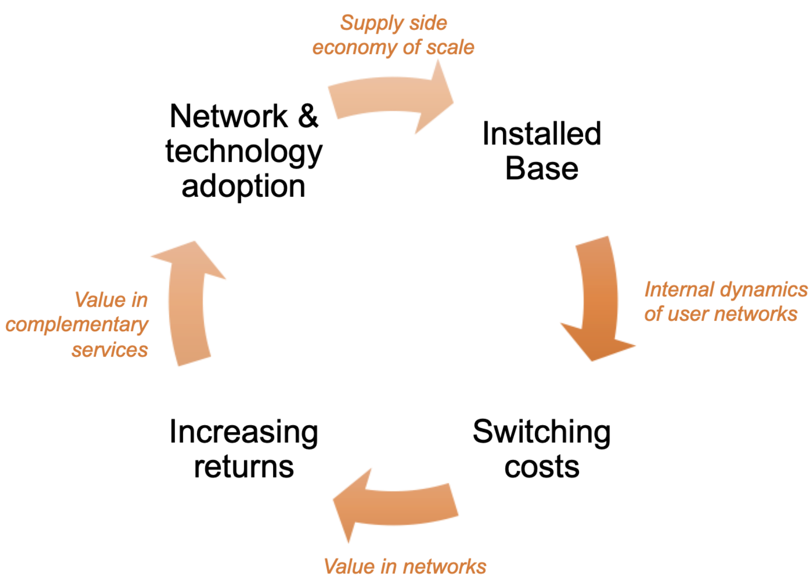

Figure 12: Network Externalities & Increasing Returns (free to McGee and Sammut-Bonnici [2014])

A difference with literature is that *seller* and *buyer* cannot be easily identified. Cost streams are intra-company, between departments. Financial factor is the Total Cost of Ownership (TCO), often split-up into Capital Expenditures (CaPex) and Operational Expenditures (OpEx). An implicit financial factor exists on value offered; for process optimisation, quality assurance, safety, faster time to market, etc.

MES has all the characteristics to be a platform with similar two-sided users. However, it has grown traditionally with both sides of users reporting into the COO e.g. the manufacturing organisation with mostly staffed positions. And the engineering or manufacturing IT organisation (apart from CFO/CIO organisation) also reporting into the COO. The IT staff implementing, configuring and maintaining MES is typically partly staffed and partly associated with the MES vendor or system integrator.

An essential difference between IIot and MES is the dominance of MES engineers over Process Experts. This is caused by a path dependency as MES engineers had the automation knowledge, consultancy skills, and therefore designed a custom solution, implemented it and then transitioned to maintaining it. This is the profit model from the MES vendor.

MES generates more income from implementation projects and solution maintenance than from license costs. A conflict of interest exist during the projects, because a Minimal Viable Product generates more income than a plug & play implementation with standard templates. Also during the operational phase a path dependency is observed that MES engineers maintain the MES solution, just like automation engineers maintain automation solutions and mechanical engineers maintain equipment. Data Scientists and Process Experts are outnumbered by MES engineers.

The MES/IIoT platform battle is evident. Differences exist on design aspects, but the key difference is the different philosophy on IIoT/MES users and to which organisation these report e.g. are funded by.

An special phenomenon is that MES vendors and System Integrators build-up knowledge from different customers and implicitly share this. However, their profit is inversely proportional to operational efficiency. For IIoT this applies to a lesser extent, as less customisation is required by vendors and System Integrators.

4.6 Theory in Practice: 2000's Historic Battlefield of SCADA versus MES

As written in the previous chapter, the current battle MES versus IIoT takes place at the scorched earth of the 1990's battlefield of SCADA versus MES. Therefore we first analyse this historical battle; What type of battle took place then? In which phase is it now?

In the early 1990s, SCADA had not reached standardisation. Various SCADA suppliers had their own proprietary standard and no standardisation institutes have publishing governing standards. On the other hand, well-established standards exist for MES itself and for the OPC interface between MES and SCADA.

MES leveraged its earlier design from the days of CIM in the 1970s. Data models were re-used and architectures were migrated to modern operating systems such as UNIX and VMS. This path dependency was key for the success of MES. In the 1970s computer memory space was exponentially more expensive than storage space. As a result, CIM/MES applications were very memory-efficient both for the application itself as for (historical) data-processing. Traditional MES Data Historians OSI PI and Aspen Infoplus.21 are still claimed to be faster than Oracle and SQLserver databases.

Moreover, the introduction of the OPC interface to PLC, DCS, SCADA was a *coupe de grace*. When MES incorporated the standard, or in fact when MES leveraged the OPC minimal viable product to a full blown standard, SCADA left the battle field.

These standard have been defined employing large-scale cooperation and consensus in committees, and therefore it seems that SCADA versus MES is a Standards-battle with a *De Jure* outcome [Gallagher and Park, 2002]. However, the technology battle took place in the '90s, and the standards were not established until the 2000s. In fact, the standard was only established after a market-based technology battle resulted in MES (and OPC) as the winner. In other words, the standard came into existence Market-Based and is therefore considered *De Facto* [David and Greenstein, 1990].

The technology battle itself was on Dominant Design [Suárez and Utterback, 1995; Utterback and Abernathy, 1975].

It is the outcome of a specific path, along an industry's design hierarchy, which establishes dominance among competing design paths.

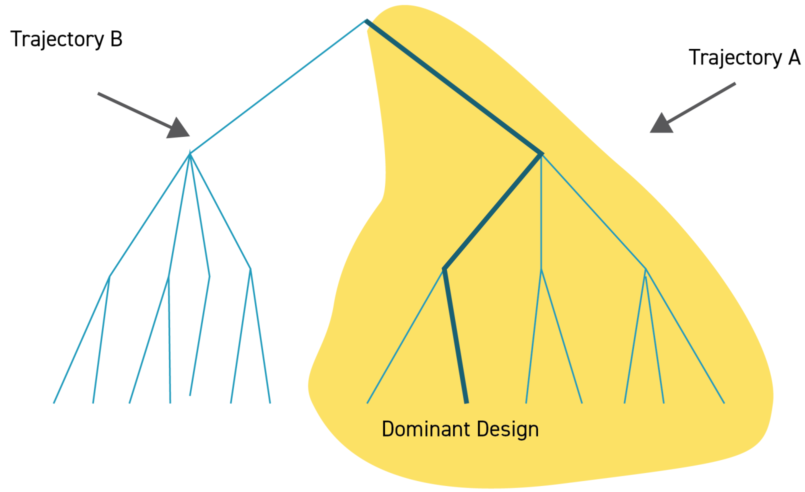

Figure 13: Design hierarchies & Dominant Design [Suárez, 1995]

The conclusion that the MES versus SCADA was a Dominant Design battle can be challenged. Firstly, the functionalities of MES and SCADA could be interpreted as platforms, so would a platform-battle have occurred? Not likely, as in those days there was no such thing as a platform. A prerequisite for a platform-battle is inter-connectivity, and the technical design was lacking for that in the '90s. Secondly, the battle could have been about *complementary goods* [Hill, 1997; Suárez, 2004], as SCADA was a complementary good from PLC vendors. However, the key dominance factor was inter-connectivity, e.g. dominant design-based as described above.

When analysing the battle phases, it is clear that MES had better technical feasibility. Although it costed major R&D costs, MES was able to interface multiple SCADA systems. The decisive battle was the arrival of the OPC standard. This standard diminished R&D (interface) costs for MES, which was a *coupe-de-grace* for SCADA. In the post-dominance market, MES vendors (and the market) have de facto established multiple standards, leaving a minimal market share for SCADA. SCADA remains proprietary software for PLC vendors, which is often bypassed by MES directly connecting to PLCs.

Therefore, the conclusion is that the MES versus SCADA battle was a dominant design battle. Given the fact that MES is currently in a post-dominance market, with competitor lock-out of SCADA (for MES functionalities), it is concluded that MES is in or beyond stage V [Suárez and Utterback, 1995].

4.7 Twenty years MES post-dominance; introducing Suarez phase VI

According to Suárez [2004], five phases exist in Technology Battles: R&D build-up, Technical Feasibility, Creating the Market, Decisive Battle, Post-Dominance, which was confirmed by Den Uijl [2015]. Suarez defines phase V based on the characteristics; clear dominant technology, large installed base, within-standard competition, lasts until a discontinuous technology starts a new dominance cycle [Suárez, 2004].

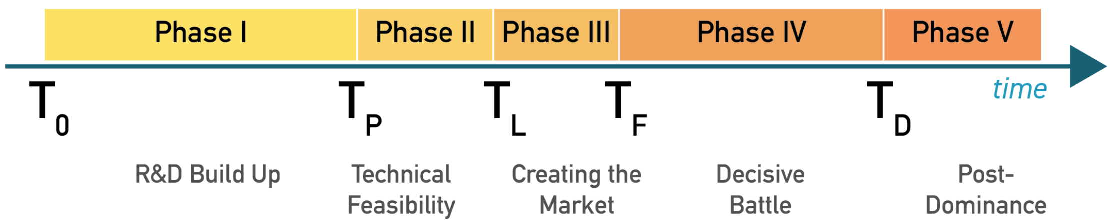

Figure 14: Technology Battle five phases (free to [Suárez, 2004])

This is more or less in line with Hughes' Large Technical System framework; invention - development - innovation - transfer - consolidation - institutionalisation. The significant difference is that Suarez only describes the immediate period of Post Dominance after a technology battle, whereas Hughes adds a long-term sixth phase; Institutionalization [Hughes, 1987].

This matches the socio-technical position of MES after 20 years of MES post-dominance. Phase V *post dominance* was accomplished around 2000, when SCADA got locked-out [Hill, 1997].

Afterwards, Phase VI started, where MES became institutionalised. Observed are: Internalising the technology into belief systems, impact on organisational structures and work-culture, changing social norms and values, impact on politics and legislation. Furthermore lower budgets on innovation, pioneers and visionaries leaving the company, and deeper entrenchment between other technologies and social developments.

MES itself is locked-in with a well-established Business EcoSystem with Standards defining the data-models, interfaces, professional education and certification even to the extent of the MESA institute delivering training courses on *How to select an MES vendor*.

R&D effort has shifted from software vendors to delivery teams and system integrators. Some successful market players have not had a major update on their core architecture since the late 1990s (data model, interfaces, database, application). Competition exists between MES vendors, but merely over projects and not over license costs. The lack of R&D focus of MES vendors may be troublesome in the technology battle with the market entrant IIoT. And that's not limited to resources, after 20 years of dominance the will to innovate has left the company culture. Even a significant monetary injection may not revert the company culture to innovative. As Peter Drucker said: „Culture eats strategy. For breakfast."

4.8 Multi-mode standardisation battles

For the MES/IIoT market, all three modes of standardisation are found, as identified in literature: committee-based, market-based and government-based.

Also multi-mode standardisations are observed [Wiegmann et al., 2017]. All ISA norms originate from the market, are formalised by the ISA committee and are often adopted by other committees and government institutes. The renowned ISA-95 standards has been adopted by International Electrotechnical Commission (IEC 62264) and also by NEN-EN-IEC 62264 (Dutch government institute NEN). Itis a good example of Network centrality: A standard that is supported by a standards organisation that has a more influential position in an industry-wide standards network has a higher chance of achieving dominance.

RAMI4.0 is committee-based but heavily government-subsidised. Network diversity is lacking: A standard that is supported by a diverse network (in which stakeholders represent each relevant product market in which the standard can be used) will have a high chance of achieving dominance.

Specifically on MES versus IIoT some characteristics can be seen on a format war on B2MML semantic interface versus NoSQL or Hadoop. However, the format war is an exhibit of the dominant design battle, which on its turn originates from the Platform War.

4.9 An alternative view: Business Ecosystem Health factors

Whereas the Van de Kaa et al. [2011] list of Dominance Factors is complete and validated multiple times, the focus is on Business-to-Consumer duels/truels. As part of this research, we check whether new Business-to-Business dominance factors are required, or whether existing dominance factors may need adjustment. During the literature research, it was observed that Network Externalities are crucial for the complex environment of MOM suppliers, consulting firms, systems integrators, standardisation institutes, SME's and corporations. Also, the *Van de Kaa* methodologies only reference one article on an industry-standard battle. Therefore it was decided to perform additional literature research on cluster to cluster battles. One methodology was selected on Business EcoSystem Health. Four complimentary dominance factors were taken into account, as detailed in Appendix 3. One Dominance Factor is suggested: Covariance with the market. As den Hartigh et al. [2013] says; „this indicates the variety of different partners a company has.

Partners were by their characteristics classified into species. We first calculated the proportions of the species in the entire market as a reference point. We also calculated for each company the proportions of different species that it is related to. We then calculated the covariance between those the company proportions and the market proportions."

Although closely related to *Suppliers* and *Number of Partnerships* [Van de Kaa et al., 2011], the cooperation with the market is crucial; willingness to partner and in having access to the workforce from (local) system integrators, engineering firms, flex pools with contractors, recruiting agencies, university-graduates, etc.

4.10 Red Ocean Strategy: Platform Envelopment Attack

The terms 'Red Oceans' and 'Blue Oceans' was coined by Kim and Mauborgne in 2004. Red oceans refer to the known market space, where companies compete on existing demand e.g. profit and growth are limited [Kim and Mauborgne, 2005].

Whereas the effectiveness of the red and blue oceans theory is disputed (it was successful, though, in creating uncontested market space for their 3.5 million copies book) a more academic position is from Prahalad on white space [Hamel and Prahalad, 1994]. That underlying concept is similar (blue ocean = white space) and can be applied for the MES-IIoT technology battle.

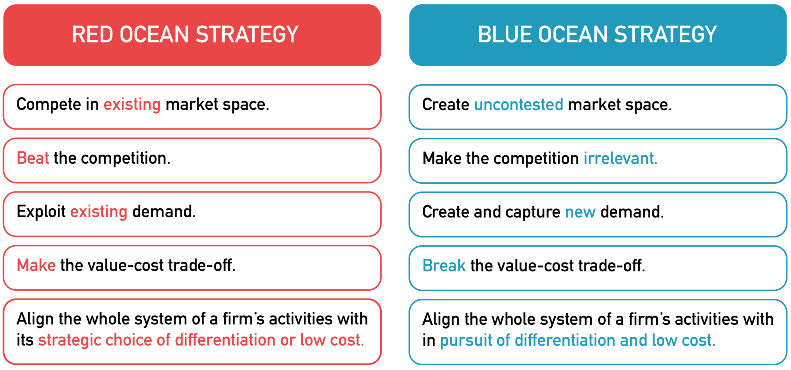

Figure 15: Red and Blue Ocean Strategies (free to Kim and Mauborgne [2005])

Envelopment is the hijacking of a market, by enveloping its services into your own platform. For example, Microsoft conquering the Real player market, by substituting with the MediaPlayer. Launching an envelopment attack requires a high level of cross-unit coordination. Engineers must integrate two platforms' functionality (in a modern architecture) and marketers must formulate joint pricing and targeting strategies [Eisenmann et al., 2011].

Given its installed base, MES can launch envelopment attacks on IIoT. For example envelopment of the SCADA4.0 orchestration 'weak substitute', or envelopment of IIoT Data Mining 'complementary goods'.

4.11 Blue Ocean Strategy

Blue Oceans are the opposite of Red Oceans: „Blue oceans, in contrast, are defined by untapped market space, demand creation, and the opportunity for highly profitable growth. Although some blue oceans are created well beyond existing industry boundaries, most are created from within red oceans by expanding existing industry boundaries, as [yellow tail] did. In blue oceans, competition is irrelevant because the rules of the game are waiting to be set."[Kim and Mauborgne, 2005, p.4]

The very first sentence in the renowned article of Shapiro and Varian [1999] defines standards wars as: „battles for market dominance between incompatible technologies."

That's a clear statement, but what if we could make MES and IIoT compatible? Already in 1988, David and Bunn, p.170 wrote about „Gateway technology is some means (a device, or a convention) for effectuating whatever technical connections between distinct production sub-systems are required for them to be utilised in conjunction, within a larger integrated production system" concluding: „they make it technically feasible to utilise two or more components/subsystems as compatible complements or compatible substitutes in an integrated system of production."

Anno 2020 an interface between MES and IIoT could certainly be a solution. Also a functional interface - a platform - could be a nice as both MES and IIoT address double-sides markets.

4.12 Conclusion

The literature study confirms that the MES/IIoT battle is not a set of random events influencing the outcome. Several events can be pin-pointed as precursors to factors for standard dominance [Schilling, 2002; Suárez, 2004; Van de Kaa et al., 2011]. This implies that the outcome of the technology battle can (more or less) be predicted by examining the battle characteristics and dominance factors.

The literature research's first outcome is that Technology Battles in Manufacturing Operations Management are on compatibility standards and dominant design.

However, after more profound literature research, the standards battle between ISA and RAMI4.0 turned out to be a red herring. The ISA standards are *de facto* well-accepted industry standards that are retrospectively documented by standardisation institutes. RAMI4.0 is a *de jure* standard heavily subsidies by the German government for political reasons, e.g. re-shoring and re-industrialisation. The standard is poorly accepted outside of Germany, most literature is in the German language, and the standard does not even have an entry at Wikipedia. Moreover, although RAMI4.0 claims to cover the full 4IR spectrum, replacing MES monolithic architectures with IIoT, *de facto* only SCADA4.0 is specified with the Asset Admin Shell specification. This has zero to no impact on MES. In fact, MES can easily take the role of orchestrating SCADA4.0 given the current MES installed base orchestrating SCADA3.0 and given MES' complimentary ISA-95 functionalities. As *coup de grace*, the MESA Institute is currently developing a MESA smart manufacturing model, whereas RAMI4.0 does not have any plans to cover the full IIoT spectrum.

The technology battle on dominant design is more vivid, between vendors of MES and vendors of IIoT solutions. MES had already reached momentum and is now institutionalised. IIoT is in the transfer phase of technical feasibility and market creation. It focuses on complementary goods, namely data-mining across platforms. IIoT is in phase III/IV, and MES is in phase VI.

A phase VI 'system' is proposed as the final phase in Suarez' model. After a decisive battle, first momentum and competitor lock-out occur, as currently described in phase V. Afterwards, institutionalisation follows; Internalising the technology into belief systems, impact on organisational structures and work-culture, changing social norms and values, impact on politics and legislation. Furthermore lower budgets on innovation, pioneers and visionaries leaving the company, and deeper entrenchment between other technologies and social developments.

To confirm the Dominant Design battle's conclusion, literature was also reviewed on Platform Battles. This led to a precious conclusion that although the technology battle is fought on the fronts of standards and dominant design, intrinsically the battle should be on platforms. Both MES and IIoT are in theory platforms, with R&D process development on one side, Operations on the other side, and service providers maintaining and supporting the platform. However entrenchment and institutionalisation is currently limiting the platform function to IT engineers and Operations. This insight may lead to a niche market.

Above and beyond these conclusions, two literature streams seem predominant. From one hand side deterministic literature applies, leading to the conclusion that the technology battle can be (more or less) controlled as strategic innovation management. Leveraging Van de Kaa et al. [2011] dominance factors is likely to lead to reducing market uncertainty and setting a new platform standard by means of network economics. From the other hand side, evolutionary economics are observed, in particular on the social construct of MES as a Large Technical System. It is assumed that leveraging business ecosystem health factors will overcome this.

5 Problem Definition & 5-WHY Approach

'Market Uncertainty' was introduced in chapter 1. It is a symptom of a wicked problem [Knight, 1921]. The Double Diamond research method was chosen to determine the Problem Definition, but only after a thorough analysis. This was executed in the previous chapters, therefore the problem can be defined (only now). Afterwards the research questions will be updated accordingly, retrospectively.

The exploratory literature studies have confirmed the Market Uncertainty. Specifically, it was found that the technical aspects are more or less evident in the market, although misinterpretations and political framing is observed. Biased governmental subsidies of more than 180 billion euro are causing market uncertainty on top of the disruptive technology. Still, the problem remains vague. The technical aspect of the Technology Battle is not as complex as it seems. The technical root cause is MES having some entrenched design constraints, which modern architectures are uncovering. These modern architectures are pushed irrevocably by *Big Fish* What does remain complex, though, are non-technical factors and how to respond to these. There is a research gap in this field.

Based upon this, the problem can now be uncovered with a 5-why approach [Ohno, 1988]; The promised re-industrialization and re-shoring of jobs lost to Asia are not materialising; The market is not willing to take the risk attached to choosing old or new Industrial Automation technologies and postpones their decision; This is caused by market uncertainty [Van de Kaa et al., 2011]; Knowledge is lacking and measuring, calculating or planning is not possible [Knight, 1921]. Disinformation and political framing stalls *informed decisions*; A research gap is observed; Knowledge is required on the non-technical factors in the MES/IIoT market.

The problem is defined as follows: In the realm of the Radical Market Uncertainty around MES/IIoT, **it is unclear which non-technical factors are relevant and important.**

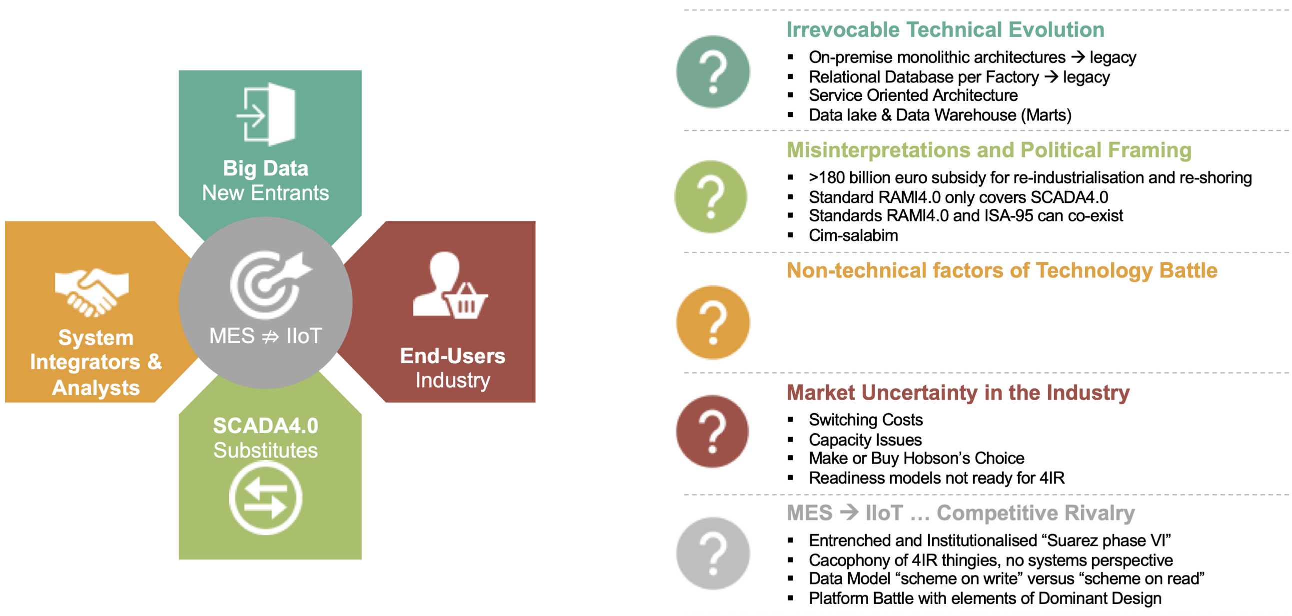

Figure 16: It is unclear which non-technical factors are relevant and important

6 Possible Dominance Factors

6.1 Introduction

Knowledge is required on which non-technical factors are relevant and important.

Based on the literature research a raw list of dominance factors has been constructed, see appendix B. It was evaluated with four industry experts: An independent, previously senior director of a big consultancy firm that offers MES and IIoT system integration services. An independent strategy consultant, who published numerous professional literature on MES. An industry analysts co-authoring RAMI4.0 and related standards. And a seasoned Software Architecture Academic lecturer & researcher on requirements modelling, domain integration, and model-driven development. As outcome, eleven dominance factors are selected, as listed in the next paragraphs. Each factor is worded specifically for MES/IIoT including an academic rational. The first factor is an MES knock-out criterion for Irrevocable Technological Evolution (Big Fish). The following ten dominance factors are expected to play a key role in the MES/IIoT technology battle.

6.2 Dominance Factors in the Business EcoSystem

6.2.1 Big Fish

Big Fish refers to mayor players such as Google, Amazon, Microsoft. Bigger forces will shape the future on standard software architectures. This is out of control for MES and IIoT vendors. MES vendors will have to adopt their architecture, such as abandoning relational databases (Oracle, MS SQLserver) and move to Data Warehouse (Marts) and move to Service-Oriented Architectures.

Academically, this dominance factor originates from Suárez and Utterback [1995] and was further detailed by Van de Kaa et al. [2011]. He found 20 studies that suggest that a format supported by a Big Fish will increase the chances to achieve dominance. In the MES/IIoT context, this is post-factum, the Big Fish already have set a new standard on software architecture. Smaller fish such as MES and IIoT software houses have no other choice than to fully adopt. Even partially adapting the existing solution with workaround is likely to decrease the chances to achieve dominance. For example; migrating ten on-premise relational databases to a central cloud, still means having ten legacy relational databases.

6.2.2 Installed Base & Switching Costs

Installed Base is the influence of currently installed systems e.g. existing business relations and switching costs when moving to/from MES/IIoT. For end-users, it includes lock-in such as trained personnel, technical and procedural integration within the business, and capital expenditures amortised. For vendors, it includes momentum (increased economic returns but challenging to manoeuvre) and institutionalisation (technical solution and company culture intermingled).

Academically, installed base as used in this study is a concatenation of previous installed base, current installed base, switching costs as defined by Van de Kaa et al. [2011] together with factors from Large Technological System on entrenchment and institutionalisation [Hughes, 1987]. The rationale for combining these factors is found in Table 2 where MES is defined as having full market coverage and IIoT as an emerging player. Obviously, further granularity exists, and it is likely to be interesting for future research, but it is out of scope for this study.

6.2.3 Market Covariance

Market Covariance covers partnerships, co-learning and cross-marketing with system integrators, consultancy firms, job agencies, consultants, standardisation institutes, universities, etc. Academically this stretches 'Network of Stakeholders' as defined by Van de Kaa et al. [2011] and combines it with Business Ecosystem Health [den Hartigh et al., 2013]. Covariance originates from economics and measures the directional relationship between the returns on two assets. A positive covariance means that asset returns strengthen each-other. It is called a Positive Sum Game, or popularly: $1 + 1 = 3$.

6.2.4 System Builder

System Builder is extending Market Covariance, to building a collaborative supply chain [Camarinha-Matos and Afsarmanesh, 2005; Klibi et al., 2010], where vendors, integrators and end-users co-invest in a system much broader than software. By doing so, silo-thinking and high transaction costs in the (software) supply chain will be overcome [Williamson, 1981]. Instead of every player optimising its own business process, regardless whether this may cause inefficiency downstream the supply chain, all players collaborate and fairly share the pain and gain of investments [Janssen et al., 2016]. Typically one visionary leads this process, called the System Builder [Hughes, 1987]. Exemplary is: „Thomas Edison was not so much concerned with 'inventing' the light bulb as with designing and selling entire electricity supply systems, which demanded simultaneous work on a commercial vision, contracts with local governments and financiers, setting up new companies, marketing, and new generator, distribution network and lightbulb designs." [Van der Vleuten, 2009, ch.39]

Academically, the term was coined by Large Technical System scholars [Hughes, 1987]. The concept got dusted-off recently and is hyped as Collaborative Supply Chain 4.0. The fair sharing of gain and pain also correlates to a moral dominance factor for accepting new technologies [Milchram et al., 2018].

6.3 Dominance Factors of the Software House

6.3.1 Financial Strength

Financial Strength is required for investing in the Technology Battle. For MES vendors, adopting modern architecture will be costly. An updated portfolio is required and migration needs to be developed for the current installed base. For IIoT, developing a *full* Manufacturing Operations Management solution, from scratch to Commercial-off-the-Shelf, is roughly estimated to take 500 man-years. Even when market entrants share their investments with strategic customers, the question remains who is willing to take this market entry barrier. Offering a partial solution can be a workaround but has its pro's and con's, as detailed in the (new) dominance factor 'full service - comprehensive goods'.

Academically this dominance factor was coined as 'shake out' [Willard and Cooper, 1985]. It included the financial strength to invest and survive during the technological battle, and it also included pricing strategy. The first factor is taken into account for this study. The second factor is expected to take a smaller role, as pricing is mainly determined by project labour costs by third parties. Also, typically MES is funded from the COO office, whereas IIoT is often funded from the CFO office. In other words, the pricing strategy only applies between MES vendors and between IIoT vendors.

6.3.2 Operational Supremacy

Operational Supremacy is about the operations and services around the technology. Is a service network in place? Not just helpdesk, but also consultancy and implementation services with sufficient capacity, user community with band-with to incorporate feedback, documentation, etc. Bottom line is whether the MES/IIoT vendor can exploit its resources better than competitors.

The capacity factor is often found critical, what if a vendor is successful and receives an order to implement their solution at a multinational with 28 sites globally? Also, pre-emption of scarce assets is a fruitful strategy, as the vendor can build-up better operational supremacy. The resources are acquired at a lower cost, and competitors will have to pay the full price.

Academically, this factor was coined by Schilling [2002] and adopted by Van de Kaa et al. [2011].

6.3.3 Learning Orientation

Willingness to Learn is about the culture of learning from the Voice-of-the-Customer, the Voice-of-the-Process (your employees) and incorporating the latest technologies and insights. Failure to invest in learning can increase the likelihood of being locked out [Schilling, 2002]. Learning includes both technical know-how, as well as market pioneering know-how [Agarwal et al., 2004]. This may be difficult for MES vendors after twenty years of market dominance, when less learning orientation was required [Tripsas, 1997]. Also for IIoT vendors originating from the PLC era, it may be challenging to look beyond IoT Data Acquisition and Data Analysis, and learn about further IIoT requirements in the industry.

Academically this dominance factor originates from theory on organizational learning [Duncan, 1979]. The concepts of Voice-of-the-Customer and Voice-of-the-Process originate from Lean, and are particularly helpful to mitigate a lack of organizational learning; the Hidden Factory [Miller and Vollmann, 1985] and Organisational Silence [Slade, 2008].

6.4 Dominance Factors of the Solution

6.4.1 Full Service - Comprehensive Portfolio

Full Service - Comprehensive Goods or providing one-stop-shop MOM services. This allows the end-user to consolidate their internal portfolio of partial service applications. Often hundreds of applications are found in use, scattered over multiple sites. Reducing these to one or two vendors offering all required MOM functionalities will significantly diminish Total Cost of Ownership. This also means that MES vendors may have to offer modernised or complementary functionalities.

Technically, this would mean encompassing all ISA-95 activities (see figure 10), extended with IIoT data mining, Lean Six Sigma tools, Data Warehousing, supporting all interfaces; OPC, B2MML, AutomationML, RAMI4.0, also to ERP and data lakes and other data warehouses, etc.

The academic background of this factor is the *Complementary Goods* dominance factor [Hill, 1997] referring to add-ons to the main solution. For MES/IIoT we use the reciprocal of this, claiming that lacking functionality is stopping efficiency or even causes a showstopper. This is also called Economies of Scope: *An integrated design can reduce production costs by leveraging common components* [Eisenmann et al., 2011].

6.4.2 Capability Maturity - Plug&Play with industry templates

Capability Maturity refers to offering solutions commercial-off-the-shelf with industry templates. This is a leap beyond tailor-made projects on top of a solution that is only a Minimum Viable Product. End-users may prefer a mature solution, which is less flexible and more expensive (to invest), but can be deployed fast out of the box with high quality and much lower Total Cost of Ownership.

Academically, this is based on compatibility of MES/IIoT with the business processes and other Industrial Automation activities [Van de Kaa et al., 2011]. Even when MES/IIoT disrupts current business processes, offering optimization, it still needs to be backwards compatible at the time of initial implementation. The rationale for renaming the factor is the vast amount of literature on 4IR readiness which are referring to mare than twenty variances of capability maturity models.

6.4.3 Manufacturing as a Service (Platform)

According to Baines et al. [2017, p.2], servitization is „a process of building revenue streams for manufacturers from services.“ Three levels of services can be offered by manufacturers; (1) Base services goods and spare parts; (2) Intermediates services product repairs, maintenance, overhauls, helpdesks, training, condition monitoring; (3) Advanced services customer support agreements, outcome contracts also known as contract manufacturing.

Manufacturing as a Service (MAAS) means that a company focuses on product development and outsources its manufacturing activities to a contract-manufacturer [Moghaddam et al., 2015]. A technical prerequisite is a highly configurable and mature MES/IIoT platform [Lin-Gibson and Srinivasan, 2019; Mantravadi et al., 2020]. Traditionally, an MES project takes a minimum of three years. For a contract-manufacturer, their *raison d'être* is fast and flexible operations. So, MES/IIoT must offer life-cycle management synchronised to the life-cycle of the MAAS. This is not just a technical challenge of Configuration Management. Organizationally, an automation team often consists of a large number of IT engineers dominating a smaller number of process experts. This often leads to an IT solution, with business requirements compromised and entrenched with technical constraints.

With MAAS, IT engineers are to offer a platform function, with the following components:

- On one platform side: Functions and Business Intelligence for day-to-day execution and review of Manufacturing Operations Management. End-users are working in (contract) manufacturing.
- On the other platform side: LowCode functionality where Process Developers can build business solutions leveraging their R&D expertise. [Sanchis et al., 2020; Waszkowski, 2019]. This allows agile Process Lifecycle Management.
- internally multi-layer configurable components leveraging standards such as BPMN, ISA-88, ISA-95 and IEC-62890 on Lifecycle Management. Critical for the multi-layer configuration management is defining a lifecycle per layer and prevent rigid 'compiling' of data models. These concepts are well-documented as Design Patters [Brandl, 2006].

Platformization will enable faster Time To Market, with decreased Total Cost of Ownership (less IT capacity required), and increased Knowledge Productivity [Zegveld, 2004]. The standards ISA-88 and ISA-95 allow for such platformisation and existing MES products follow that theorem on Design Patterns. When adopting modern architectures, also platformisation is possible.

This concept is fairly new, in Technology Battles literature. It loosely correlates with flexibility [Van de Kaa et al., 2011] and the dynamics of standards [Egyedi, 2001; Egyedi and Blind, 2008]. Professional literature on Configuration Management and (implicitly) platformization is abundant [Brandl, 2006; Meyer et al., 2009; Moghaddam et al., 2015, 2018; Thiel et al., 2008]. Also, ISA standards build upon this concept.

6.4.4 Envelopment Attack

Given its installed base, MES can launch envelopment attacks on IIoT [Eisenmann et al., 2011]. For example an envelopment of the SCADA4.0 orchestration 'weak substitute', or an envelopment of IIoT Data Mining 'complementary goods'.

Firstly, the currently developed IIoT platforms for PLC orchestration can easily be substituted as an MES component. After all, an IIoT platform is often not a single platform but a range of platforms that remain on-premise, vendor-dependent and these vendors compete heavily. If two dogs fight over a bone, a third carries it away. IIoT platforms will continue to exist, but as a gateway without end-users. MES envelops all end-user functions. Or to phrase Eisenmann et al. [2007, p.7] (filled in for MES and IIoT): „Through bundling, MES can foreclose its target's IIoT access to overlapping customers and thereby diminish IIoT's scale. In particular, the attacker (MES) seeks to capture IIoT orchestration customers who were also previously purchasing MES by reciprocally tying the purchase of MES and IIoT orchestration in an MES' pure bundle. Now, customers who want to consume MES also get MES orchestration of IIoT and no longer needs to consume IIoT orchestration separately." This bundling of substitute services is called 'envelopment of weak substitutes'.

Secondly, MES can launch an envelopment attack on IIoT Data Mining, by building its own platform. MES can relatively easily offer a comprehensive platform, supporting both the legacy MES schema on write as well as IIoT's bottom-up schema on read data mining. Given the fact that IIoT struggles with performance issues [VDI3714-1, 2020] and MES is an expert on optimising internal data performance issues, the 'complementary goods' envelopment attack on IIoT may be feasible.

Academically, this dominance factor was triggered by reading the very first line of Shapiro and Varian [1999] renowned work: „Standards wars - battles for market dominance between incompatible technologies - are a fixture of the information age." So what happens if the incompatible technologies are made compatible or inclusive? An interface simply resolves the MES-IIoT battle. The vendor who offers such an interface may achieve market dominance.

6.5 Conclusion

Existing literature on Technology Battles [Van de Kaa et al., 2011] and business ecosystem health [den Hartigh et al., 2013] covered most of the required dominance factors.

As the MES/IIoT realm is a business eco system with a research gap on characteristics, four new dominance factors are proposed.

One new ecosystem factor was added 'system builder' [Hughes, 1987]. For the solution two factors were modified; comprehensive portfolio as reciprocal of complementary goods, and capability maturity as merger of compatibility and ICT maturity. Also, two brand new dominance factors were added; Manufacturing as a Service [Moghaddam et al., 2015] strongly related to platformization, and Envelopment Attack based on an excellent article [Eisenmann et al., 2011].

7 Verification

7.1 Introduction

Now that scholars reached a consensus on the relevant dominance factors by Scholars, the next phase is to test for feasibility in reality. The verification is performed by interviewing industry experts.

7.2 Selecting respondents by their characteristics

Respondents have been selected at executive level or higher, broadly across the industry, to remove potential role-bias. The rationale is to interview influencers and decision-makers, as they are most likely to determine the Technology Battle path. Fifteen respondents have been invited; twelve have participated, covering the roles as listed below.

Table 5: Influencers and Decision Makers roles covered in interviews

Category	**Amount**	**Roles**
2000's MES	3	Marketing & Sales at or to C-level
SCADA to IIoT	1	Marketing & Sales at or to C-level
BigData to IIoT	2	C-level
System Integrators & Analysts	4	Executives and C-level influencers
Standardisation	2	Authors
Industry end-users	3	MES & IIoT executives

7.3 Results

As outcome of the twelve interviews, see figure 17, the following dominance factors are confirmed:

- **Big Fish** is unanimously confirmed as a driving factor. For MES vendors, it is mission-critical to adopt modern software architectures. Not adaption is required - with workarounds - but full adoption. For the Big Data players, this factor is a unanimous *have and exploit*. Half of the respondents rate it as *have and exploit* for SCADA players, referring to the current IIoT platforms being offered. The other half of the respondents consider the IIoT platform just a gateway and still consider it mission-critical for SCADA players to adopt modern software architectures.
- **Market Covariance** is the second most important dominance factor, also unanimously rated important or critical. MES vendors already have partnerships and need to exploit these. respondents elaborated that this is both capacity-driven (lack of engineers) as well as knowledge-driven for a *Positive Sum Game* on network effects. PLC/SCADA vendors do have a network of partners, but typically too focused on equipment automation. Further development into MOM market covariance is required. For BigData vendors the orientation is typically product-focused and cooperating with system integrators, consultants and scientist is reckoned strategical.
- **Learning Orientation** is deemed mission-critical for MES, particularly in the late 2000s an exodus was observed from key knowledge workers and pioneers. New knowledge is to be acquired for Industry4.0 artefacts such as Artificial Intelligence, Virtual Reality, Predictive Maintenance, etc. For PLC/SCADA players, both in-depth technical knowledge is to be acquired (on Manufacturing Operations Management, ISA-95, etc.) as well as market-specific knowledge. Many respondents considered this a mission impossible, especially as PLC/SCADA players are expected to have capacity problems already with just staffing for IoT equipment automation. For BigData, crucial modern knowledge is at hand, which can be exploited. Industry-specific knowledge is to be acquired, though.
- **Operational Supremacy** is unanimously verified as most important dominance factor. It is rated'

adept' for the established players and mission-critical to develop for Big Data market entrants.

- **Capability Maturity** Is the final high-scoring dominance factor. This is key for all players. It allows for shorter project execution, meaning fewer engineers are required per project, meaning that more engineers are available for other projects.
- **Manufacturing as a Service** was welcomed by most respondents: „Spot on!“. Most respondents rated it as a future roadmap item, as first more import dominance factors need to be addressed. The Big Data respondents rate it as Mission Critical, though. They foresee a *paradigm change*. The MAAS principle was echoed; MES engineers will become either IT engineers maintaining the MAAS platform, or Process Experts configuring and exploiting the CyberPhysical System.
- **Red Ocean Strategy** was waived away by most respondents. SCADA is currently executing an envelopment attack to MES. However, it was considered „mission impossible“, a „waste of time“ or even „loss of face“ as SCADA players show a lack of understanding of what the business really needs. Not a single respondent considers the IIoT threat from SCADA players mission-critical for MES; *SCADA4.0 orchestration will go to MES anyway!*
- **Full Service** led to interesting discussions. Some respondents are *believers* in a central, standardised MOM tools portfolio, from one or two vendors. Others believe in Service Oriented Architecture which - according to them - should allow for multiple solutions, each covering a sub-section of MOM. Constructive feedback was that MES should extend its current MOM portfolio with Big Data complementary goods; Artificial Intelligence, Predictive Maintenance, multi-site trend analysis and recipe management, as well as multi-site real-time order tracking (at production unit level).

	Assume it's 2030. Some players are out of business, other gained market dominance. What strategy factors have been critical?	**COUNT**	**Weighed**	**Path Dependency**		
				2000s MES	SCADA -> IIoT	BigData -> IIoT
Dominance Factor	Big Fish (adopt modern architectures)	36	12%	Mission Critical	Have & Exploit	Have & Exploit
	Market Covariance	34	11%	Have & Exploit	Develop	Mission Critical
	Learning Orientation (techn & market)	34	10%	Mission Critical	Develop	Have & Exploit
	Operational Supremacy (capacity)	33	10%	Have & Exploit	Develop	Mission Critical
	Capability Maturity (plug&play+templates)	33	10%	Have & Exploit	Develop	Mission Critical
	Installed Base & Switching Costs	33	9%	Have & Exploit	Have & Exploit	Develop
	Financial Strength	30	9%	Develop	Develop	Have & Exploit
	Manufacturing as a Service (LowCode)	31	8%	Develop	Develop	Have & Exploit
	Blue ocean: System Builder	32	8%	Develop	Develop	Have & Exploit
	Full Service (cover all MOM functions)	26	7%	Have & Exploit	Develop	Develop
	Red ocean: Envelopment Attack/Defense	17	6%	Monitor	Mission Critical	Monitor

Figure 17: Results: Count, Weight, and Modus per path dependency

Further productive dialogues and discussions followed.

7.4 Discussion: can MES and IIoT be compared in the first place?

Two respondents completely disagreed with this study assumption and argued that MES and IIoT cannot be compared. It was vividly claimed that MES is a comprehensive system, a methodology to improve manufacturing, denouncing IIoT to „just a technology“. The feedback was well-argued in High-German; „MES ist ein Funktionsgebäude für die Produktion, während IIoT eine Technologie darstellt, die die Datenverarbeitung und Kommunikation unter den im Internet beteiligten Objekten regelt. Ob dies nun auf dem Regelwerk der ISA oder von RAMI 4.0 beruht, ist dem Anwender ziemlich egal. Es wird jene Technologie gewinnen, die die Realisierung des MES Funktionsgebäudes am besten löst.“. Also by the other respondent, all (underlying) technical aspects are rated irrelevant, as infrastructure will change anyhow, and technologies will be added (to MES) though time. MES is and will remain a methodology, or to quote; „a journey to improve the production process and organization.“

This view is often heard and is absolutely true from an MES perspective anno 2020. But does it consider evolutionary economics? MES took 50 years to develop from (CIM) technology to the current *system*. And, IIoT is in a similar evolutionary process now. It can indeed integrate with MES. But also, it can become a Dominant Design due to path dependency [Suárez and Utterback, 1995]. Interesting is that the latter respondent prefers BPMN for process modelling, but does not integrate LowCode .XML with MES. In general, both *believers* did verify the dominance factors, but only for MES to MES competition.

These views match Suárez [2004] phase V competitor lock-out and vivid competition within the standard.

7.5 Discussion: the concordant pairing of dominance factors

During the literature research, the concern was found on the worldwide capacity of skilled engineers. This was echoed during the interviews. It is also observed in the results, as a concordant pairing of Operational Supremacy, Technical Maturity, and Manufacturing as a Service (Platform). On the same subject, an interesting remark was made. Learning Orientation should be extended to offering training and coaching. This enforces a standard. Also, collaborating with Human Resource and Process Excellence departments will eliminate fears of becoming obsolete during the revolution. The collaboration can de-entrench old habits, and institutionalise new 4IR ways of working and corporate culture.

7.6 Discussion: discordant red ocean strategy for SCADA4.0

The opposite effect was raised around the red ocean strategy of SCADA, e.g. its envelopment attack on MES. It has adverse effects on Market Covariance, Technical Maturity, System Builder, and Learning Orientation. In fact, most respondents cornered SCADA to taking care of SCADA4.0 only, as they lack qualifications to enter the MES market. If the development only starts in 2021, the boat will be missed. The response is clearly observed in tables 17 and 18.

Frequency	2000s MES	SCADA -> IIoT	BigData -> IIoT
Mission Critical	39	26	34
Have & Exploit	42	22	39
Develop	30	65	42
Keep Satisfied	10	12	8
Monitor	11	7	9

Figure 18: Results: Frequency distribution

Again, not a single respondent considers the 'IIoT threat' from SCADA players mission-critical for MES; „"SCADA4.0 orchestration will go to MES anyway“. More productive than battling, for all players, is to adhere to a Blue Ocean Strategy. SCADA will be fully occupied with addressing the enormous market of IIoT devices. Instead of overplaying their hand on developing something they do not possess (on six fronts), SCADA can better focus on their Core Competence [Prahalad and Hamel, 1997].

MES is king in its castle. Obviously, MES must adopt modern architectures, but then and only then, it can exploit its current installed base. Now that the 'threat' from SCADA is off the radar, the focus can shift to the future. This applies to all stakeholders in the market, including SCADA. MES can offer more comprehensive MOM functions, partnerships with System Integrators and BigData players will leverage Market Covariance and Operational Supremacy. Perhaps some unexpected partnerships or mergers & acquisitions are possible.

7.7 Discussion: de-entrenched MES and PLC/SCADA vendors

Three respondents claimed to have successfully de-entrenched from old ways of working with either MES, PLC or SCADA. For confidentiality reasons, we cannot go in detail. However, takeaways for this study are: (1) investment costs are indeed in the range of 500 - 1,000 labour-years or equivalent value of merges & acquisitions, (2) these respondents filled-in a remarkably amount of *mission-critical* answers, (3) these respondents were the only ones who directly understood manufacturing-as-a-service including its ramifications and benefits, (4) eggs were not put in one basket; comprehensive services and collaborative supply chain are highly recommended. The 3% of software vendors that are not entrenched may hold the best position (confirmed).

7.8 Discussion: complimentary MES and BigData

One of the respondents made a critical remark: *"A lack of integration causes the battle."* In particular, integration by MES with new architectures and new functions is lacking. On the other hand, when observing the position of BigData, precisely the opposite is observed. The two players are alternating on their dominance factors and complement each other; what MES lacks is what BigData possesses and vice versa. This is a perfect starting position for a Blue Ocean collaborative supply chain [Camarinha-Matos and Afsarmanesh, 2005; Klibi et al., 2010].

This may make a dominance factor significant; Manufacturing as a Service. Finally, these concordant factors can be further leveraged by a crucial strength factor that Big Data does possess: direct access to end-user CFO funds.

7.9 Discussion: verification of "Radical Market Uncertainty"

As final verification, the assumption of "Radical Market Uncertainty" is discussed. The Double Diamond research methodology was chosen to leave the problem as-is. The rationale was that narrowing down a problem to a specific scope often leads to an outcome within the problem's framework [Buchanan, 1992]. As the subject is a disruptive change, a more creative approach seems better. Designerly Thinking as Creation of Meaning was chosen [Krippendorff, 2005]. The assumption of "Radical Market Uncertainty" needs a verification, though.

The economic principle of *Knightian uncertainty* rates uncertainty worse than risk [Knight, 1921]. Uncertainty implies a lack of knowledge and inability to measure, calculate or plan. It encompasses vagueness and ambiguity. Typical effects are uncertainty avoidance and sticking to the known [Podolny, 1994]. As written in chapter 2, the purpose of this study is to generate knowledge, to fill the research gap, in order to reduce market uncertainty.

These elements are found in the market study of Appendix A. After synthesis of hundreds of articles, nine acceptance and readiness artefacts were formulated, all around market uncertainty. As a point of critique, it could be considered as a *Petitio Principii* begging the question. Nevertheless, market uncertainty is a well-known factor in Technology Battles.

Van de Kaa et al. [2011] describes it as: „When uncertainty in the market gets too high, firms and customers are unwilling to take the risks attached to choosing one particular format and postpone their decision. This decreases both the likelihood that dominance of one format will be reached and the speed at which this format will achieve dominance. This negative effect was suggested in nine studies."

What Van de Kaa prescribes exactly matches the observations in the MES/IIoT market, as confirmed in the exploratory literature studies in chapters 3 and 4. Also, the interviewed Scholars and Industry Expert (decision-makers) all confirm the Market Uncertainty, even though their view on root causes, effects and solutions are fundamentally different. These differences obviously confirm the Market Uncertainty.

The observed disinformation, political framing, concordant and discordant effects further confirm the entrenchment causing the market uncertainty. In addition, the sixth Suarez phase also confirms the entrenchment, lack of agility and other socio-technical effects, reducing the willingness to decide soon.

Finally, the proposed non-technical dominance factors are verified by twelve Industry Experts, both on contents and on the impact. The dominance factors and the knowledge about these factors indeed reduce market uncertainty by providing information and insights.

Given the above arguments, the Market Uncertainty assumption is verified to be correct, as well as the "Radical" assumption based on Kay and King [2020]. Information was insufficient for action. And this study is confirmed to supply insights allowing to proceed. Whilst the assumption is verified in the case of MES/IIoT, further research is recommended on overall validity.

7.10 Conclusion

All dominance factors have been confirmed, with a preference for Big Fish, Market Covariance, Learning Orientation, Operational Supremacy, and Capability Maturity. As a secondary outcome, it was found that dialogues and linguistic descriptions in 'Fresh Wording' provide valuable insights that reduce market uncertainty. No mathematical prescription is needed on best and worst dominance factors. Thirdly, it was found that the technology battle has all potential for a Blue Ocean Strategy. If MES adopts modern architectures, then and only then, MES and Big Data are complementary and can collaborate as System Builder. This would relieve market uncertainty and is likely to resolve engineer-capacity issues.

8 Conclusion: Creation of Meaning

Following the *Double Diamond* model efficiently structured this study. In particular, it prevented jumping to a premature problem definition. Each of the previous chapters addressed a research question, which is summarised below:

SQ1 The market uncertainty is about three clusters of software houses; MES backdating to the 2000s, SCADA trying to substitute MES with SCADA4.0, and BigData as a new market entrant. Other main stakeholders are industrial end-users, system integrators, consultancy firms and standardisation institutes.

The technical aspect of the Technology Battle is not as complex as it seems. The technical root cause is MES having some entrenched design constraints, which modern technologies are uncovering.

The exploratory literature study confirmed the Market Uncertainty. Specifically, it was found that the technical aspects are more or less evident in the market, although misinterpretations and political framing is observed. Whereas usually this would be technically resolved under engineers, governmental subsidies of more than 180 billion euro are causing market uncertainty on top of the disruptive technology.

SQ2 The battle is a Platform War. The platform is between IT engineers (who configure data and information functions) at one side and for Manufacturing Operations at the other side. The engineers and their organisation add value to the operational organisations, who are therefore willing to invest in further automation using the same platform. The platform and its engineers become more experienced, offer complementary services - up to comprehensive services, and increase their reputation. This leads to a higher *Installed Base* within the network, e.g. increasing returns. The three clusters of players share standards, but each offers their own platform. Co-existence of multiple platforms is observed, within industrial corporation, with a demand to reduce the number of platforms, e.g. to reduce Total Cost of Ownership. Co-existence is caused by Switching Cost and lack of Comprehensive Services or vice-versa: offering of better Complimentary Services.

Less critical are two observed Dominant Design aspects. Firstly, Irrevocable Technical Evolution, driven by *Big Fish* such as Microsoft, Google, and Amazon. Traditional architectures will soon become legacy, such as having a relational database for each factory. Software vendors have no other choice than to adopt. Therefore this aspect is considered technological evolution and not a battle. Secondly, a dominant design battle is observed on database and data analysis. MES uses 'schema-on-write" using relational data models and semantic interfaces, all of which are *de facto* and *de juro* standardised. IIoT uses "schema-on-read" using Data Lakes and raw data interfaces, with developing *de facto* standards. The battle is influenced by government subsidies, political framing and disinformation on the Dominant design aspects. This causes a significant amount of confusion, along with other non-technical factors.

The battle is asynchronous. IIoT is an emerging standard in the phase of 'Technical Feasibility' and 'Creating the Market'. MES achieved momentum two decades ago and meanwhile it is wholly entrenched and institutionalised (by vendors and end-users) in operational standards, ways-of-working, organisational structures and culture. This is Suarez phase VI - System - as introduced in this study.

Still, it is unclear which non-technical factors are relevant and important, to the mES/IIoT battle.

SQ3 Eleven possible dominance factors have been identified as part of this study; Big Fish (adopt modern architectures), Installed Base & Switching Costs, Market Covariance, Blue ocean: System Builder, Financial Strength, Operational Supremacy (capacity), Learning Orientation (tech & market), Full Service (cover all MOM functions), Technical Maturity (plug & play + templates), Manufacturing as a Service (LowCode), and Red ocean: Envelopment Attack/Defense

SQ4 Each dominance factor was verified as critical or important. The twelve respondents were at executive level (or higher) across all stakeholders. The following dominance factors scored up to 50%: **Big Fish**

forcing all stakeholders to adopt modern architectures **Market Covariance** variety of partners for *Positive Sum Games* **Learning Orientation** on technology and markets **Operational Supremacy** efficient services **Capability Maturity** plug & play with templates.

RQ The findings of the sub-research questions adequately address the main research question. The respondents welcomed the insights from the technology battles perspective and confirmed that this decreases Market Uncertainty. In addition, three further *Creations of Meanings* were derived:

First, whereas the dominance factors were expected to be loosely correlated, the industry experts described a robust concordant pairing. This is caused by market uncertainty on the availability of skilled engineers. Dominance factors leading to higher Installed Base with lesser engineers are concordant. In other words, the battle is not only about market share but also about engineers. This is a step beyond (vendor) pre-emption of scarce assets. The MES/IIoT battle leads to a system where (all) stakeholders are optimising themselves to needing fewer engineers. This relates to an essential 4IR paradigm chance. In the *Factory of the Future* MES engineers will become either IT engineers maintaining the platform, or Manufacturing Process Experts configuring and using the system.

Secondly, a discordant pairing was observed on SCADA attempting to substitute MES. Experts either negatively associated the Red Ocean Strategy with poor self-reflection on lacking qualifications, or vice-versa, waived away the attack and suggested to exploit SCADA adepts to address the enormous market of IIoT devices. One way or the other, not a single interviewee considered the 'IIoT threat' from SCADA players mission-critical for MES: *"SCADA4.0 orchestration will go to MES anyway"*.

A third phenomenon was observed on MES versus Big Data IIoT. Technically, Big Data only offers complimentary functions. When evaluating the dominance factors on 'have & exploit' versus 'lack & develop' these were unexpectedly found to be alternating on most factors. What MES is lacking is what BigData possesses, and vice versa. Not the battle is on complementary functions; the players are complementary. This is a perfect starting position for a Blue Ocean collaborative supply chain.

The determined dominance factors and the three derived conclusions are confirmed to positively support re-industrialisation and re-shoring of lost jobs.

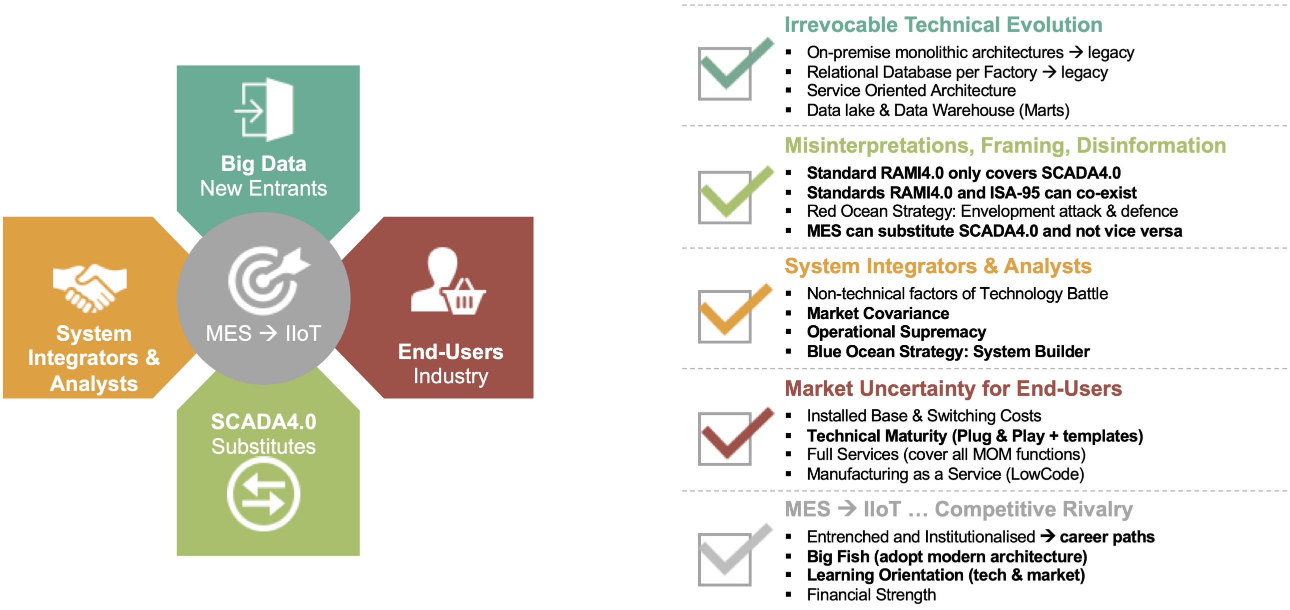

Figure 19: It is clear now which non-technical factors are relevant and important

9 Reflection

Reflection in design science research takes place on three levels [Gregor and Hevner, 2013]:

(i) The artefact itself, e.g. this study. What is novel? What lens or perspectives have been used? How 'hard' are the conclusions?

(ii) Theories: Which streams of theories have been applied? Which were useful and which may have led to limitations? What further research is recommended?

(iii) Research process and programme: How did the research process influence its outcome? Can we replicate the process for other types of artefacts or other domains? Furthermore, what was the influence of the TUDelft study programme on this research process?

These three levels of reflections are covered in the next paragraphs, including the reflection on whether design science was applicable for this study.

9.1 Limitations

9.1.1 Artefact: Research Novelty

The approach of this research is novel. In the field of 4IR, a research *lens* of technology battles has not been previously applied. Also, in the field of technology battles, a focus beyond duels is novel. The novelty was much appreciated by the scholars and respondents who participated in this study.

A limitation is observed, though. As steady ground is missing both from a theoretical and practical perspective, it may be that crucial artefacts have been missed out. As an analogy, Marco Polo missed-out the Chinese Wall during his exploratory 'research' to China. He may have missed the artefact, which is theoretically possible as the Chinese Wall is not continuous. He may have missed local literature on the artefact, simply because no-one had documented such research before in a Western language. He may even have described 'China' whilst in fact, having described another continent, just like Columbus did when discovering America. To reduce this limitation, specifically for this study, further exploratory research is strongly recommended.

9.1.2 Process: How 'hard' is Qualitative Research?

Thirdly, the qualitative approach is novel for researchers used to quantitative research. This implies that no 'hard' results can be claimed, which is typical for qualitative research [Soiferman, 2010]. The purpose was not to produce hard results, but to reduce *Market Uncertainty*, specifically by Creation of Meaning (semantics [Krippendorff, 2005]) to overcome the current 4IR ambiguity and vagueness.

Creswell [1998] defines qualitative study as (p. 39): „a type of educational research in which the researcher relies on the view of participants, asks broad, general questions, collects data consisting largely of words (or texts) from participants, describes and analyses these words for themes, and conducts the inquiry in a subjective, biased manner“.

This is opposed to dealing with *bias* in quantitative research, where *Researcher Bias* must be reduced as much as possible. In the field of qualitative research, bias is allowed and even encouraged. A restriction is that stubbornness must be prevented. In this study, *Researcher Bias* was controlled (e.g. open-mindedness was enforced) by employing the Diamond Model. Specifically, early jumping to a problem-solution framework was prevented. An extensive literature research was employed, together with open-minded interviews, which ensured getting knowledge from professionals and academics on-board [Soiferman, 2010].

A limitation is that the research outcomes could not be mathematically or deductively *validated*. Again this is inherent to qualitative research [Soiferman, 2010]. Nevertheless, the research outcomes have been *verified* by a broad selection of twelve Industry Experts. As the population size is relatively small, further research is recommended.

9.1.3 Theory (streams): Uncertainty, Random Events, and Determinism

This study follows and Innovative framework that added insights into the state-of-the-art, by leveraging theories from Business Eco-Systems, Technology Battles and Hughes' Large Technical Systems. In particular deterministic theories were proven successful in this study. This is in contracts of *Random Event* literature streams, such as the SCOTT, Digital Disruption, and Dominant Design research. It was found that random events may seem to occur when analysing in detail from a problem-solution *lens*. Nevertheless, when applying a socio-technical *lens*, e.g. focussing on Creation-of-Meaning [Krippendorff, 2005], then *Radical Market Uncertainty* can be determined as an artefact of *information being insufficient for action*, following the theorem of Kay and King [2020].

A limitation may be *begging the question* as the above was stated as the goal of this research. Further research is recommended from a *Random Event* lens but with a robust societal perspective. For example, the article on extending the Social Construction of Technology framework to Industry4.0 can be used as a starting point [Baalen et al., 2016]. Also, recent research in the field of Digital Disruptions may be interesting to leverage to the Technology Battle. In particular, a limitation could be that there may be no Technology Battle at all, but just emerging technologies replacing old technologies. MES may become so complex, that diminishing returns may occur, which allows for de-entrenchment when new technologies are cheaper.

9.1.4 Process: Problem-Solution framework versus Creation-of-Meaning

When preparing for this paper, I was very impressed by the abundance of research in the field of Technology Battles. In particular, the work of Van de Kaa et al. [2011] has been a guide in this study. Many students obtained their Master by following that theorem: Setup a problem-solution framework, a literature study follows on market and battle artefacts, make a selection of dominance factors (out of the standard 29 factors), and then validate with the Best Worst Method. Such outcomes are mathematically very precise.

While setting up my research for this paper, I started with that trajectory. I explored various possible scopes and problem statements. However, I intuitively objected against the problem-solution framework. For MES versus IIoT, already thousands of articles have been published – scientific and professional – from a problem-solution perspective. Nevertheless, most problems still perish. Therefore I concluded that a novel exploratory perspective is required. That started my research journey.

Employing Technology Battles' theory would certainly provide interesting socio-technical insights, I thought then, but the masculine bias feels intuitively unjust. It employs rational deterministic thinking styles, problem-solution frameworks, quantitative research, mathematical validation. It is characterised by masculine linguistics like; war, battle, entrenchment, reverse salient, dominance, winner-takes-it-all, etc.

Applying rational and mathematical methods may be very precise. However, it is likely not accurate in scenarios of wicked problems [Buchanan, 1992] and *Hidden Factory* [Miller and Vollmann, 1985], e.g. when the root cause is difficult to identify as workarounds have been implemented in silence. After all, problem-solution thinking does not overcome *organisational silence* [Slade, 2008]. A less masculine approach may be required, at least for the scenario addressed in this study.

I advocate for a more feminine approach: qualitative research on ongoing battles from a semantics lens (as we cannot quantitatively predict the future). So, instead of problem-solution [Buchanan, 1992] employ a Design and Designerly Thinking as Creation of Meaning (rather than Artefacts) [Krippendorff, 2005]. Focus on creativity and ideation instead of rationality, apply Blue Ocean Strategies instead of Red Ocean [Kim and Mauborgne, 2005], Use linguistics processes [Jessop, 2011; Sun and Ma, 2015]. Balance mathematics with intuition, and onboard emotional and (work) cultural aspects. I pledge for a more feminine socio-technical approach.

The proof is in the eating of the pudding.

The more feminine approach was successful in this study. For this study, the *Double Diamond* was used to enforce the creation of meaning. Only after a thorough literature study, the problem was defined. This added a value, as it prevented de-scoping the exploratory aspect, and as it prevented jumping to conclusions (and jumping to problems). Specifically, the socio-technical perspectives of Hughes [1987] Large Technical System theory was fundamental for this study. It laid the foundation for a sixth battle phase *System*, as well as for the *System Builder* dominance factor.

Designerly Thinking also allowed for taking another robust socio-technical dominance factor on-board; *Manufacturing as a Service*. The 4IR paradigm change is essential; from MES engineers, to either IT engineers maintaining the MES/IIoT platform, or to Process Experts configuring and exploiting it.

Last but not least, the linguistic approach of the IMP method was successful too. It was fundamental in providing *Fresh Wording* to induce creativity and meaningful design-thinking. The respondents welcomed this. The IMP method also (indirectly) allowed for the concordant and discordant analysis, which confirmed the criticality of capacity problems and reinforced the need for a paradigm change.

An essential point of self-critique is that full validation of the research outcome was not possible. However, that is intrinsic to the concept of qualitative research. The results were verified, though, by Industry Experts. All introduced dominance factors were rated as important and critical. Moreover, knowledge is produced, [Zegveld, 2004] and market uncertainty is significantly reduced. The study goal is accomplished.

9.1.5 Process: TUDelft Management of Technology programme

A significant limitation in this study is the influence from the Technical University Delft programme of *Management of Technology*. An important form of *Researcher Bias* is university grading. This study had to comply with exam regulation (bias) and criteria focused on *academic* research. A 4IR focus on *professional* research was not allowed, for instance from a 4IR standardisation institute perspective, regardless of its feasibility, academic quality and proven Knowledge Productivity [Zegveld, 2004].

As a second limitation, this study's approach and subject is an *ugly duckling* within the faculty of Technology, Policy and Management. The faculty is a little bit behind on Industry4.0 (2011) as no courses nor electives are offered on Digital Transformation, *System of Systems*, Engineering Paradigm Change, Data Integrity, or other *State-of-the-Art* research fields around 4IR innovation management. Most other technical universities, research institutes, and professional research organisations are *spot-on* 4IR.

Having said that, the MoT programme does offer an excellent academic foundation equivalent to a Technical MBA. Specifically useful for this study where courses like System Design (system-thinking), Production of Technology (Hughes' Large Technical System), Digital Business Process Management (process-thinking), Design Innovation 4.0 (Collaborative Supply Chain and Designerly Thinking, e.g. Creation of Meaning), and last but not least; Technology, Strategy and Entrepreneurship (strategy-thinking). These courses and in particular the associated TUDelft scholars are priceless!

9.2 Contribution to Society & Theory

The social impact of this study is high. A stalemate in 4IR progress is observed, despite more than 180 billion euro subsidies. Re-industrialisation of Europe and re-shoring of lost jobs to Asia is at stake. The stalemate is around Market Uncertainty, which this study significantly reduces, at least from a theoretical perspective. The respondents have confirmed this, also from a practical perspective.

Furthermore, this study contributes to five existing theories, as follows:

9.2.1 Hughes' Large Technical Systems

The theory on large Technical Systems (LTS) was coined by Hughes [1987] and describes the era of an earlier industrial revolution. The theory may seem outdated, as technology battles literature is more comprehensive and focused on modern technology battles. Nevertheless, LTS has an essential aspect of socio-technical change. As my academic contribution, it was proven to be capable of describing and prescribing processes around major techno-societal 4IR disruptions. I pledge to remove LTS from under the dust and recommend novel research on 4IR from an LTS perspective, see also section 9.2.4.

9.2.2 Business Ecosystem Health

The Business Ecosystem Health [den Hartigh et al., 2013] model may have been a bit too mathematical, but it highlights critical economic evolutionary processes. In particular, for technology battles within an ecosystem, it was proven very useful. Again, my contribution is a new use-case for the existing model, with further contribution to apply the model from a qualitative semantics perspective.

9.2.3 Best Worst Method for Technology Battles

This study contributes to the existing 'Best Worst Method for Technology Battles' framework with two artefacts, as described in section 2.7 on page 6. First, the prerequisites and application of the framework are further detailed. In case respondents disagree on "the direction" of dominance factors or its starting point, then the calculations will still produce very precise results, which are inaccurate. This is inherent to the used vector calculation. In practice, it implies that consensus must exist on the meaning and application of the dominance factors. Secondly, the BWM framework out-rules concordant and discordant pairing, as it assumes a linear hierarchy between dominance factors. It is recommended to mathematically model and verify such effects.

9.2.4 Sixth phase in Suarez' Technology Battles

As part of this study, Phase VI is introduced as the final; phase in the Suárez [2004] model. After the decisive battle, the next phase starts with as characteristics momentum and competitor lock-out. This is currently prescribed as final phase V [Hill, 1997]. The large *Installed Base* is claimed to defend against competitors. If nevertheless, a new battle occurs, it is assumed to start over at the first phase.

My research found that too technical and introduces a sixth phase - *System* - which further protects against competitors with socio-technical elements. The new phase is based on institutionalisation [Hughes, 1987]. For MES, this is observed from 2000-2020: internalising MES to a paradigm belief system, impacting organisational structures and work-culturechanging social norms and values, impact on legislation, and deeper entrenchment into a *System* with other technologies and social developments. Furthermore, lower budgets on innovation are sometimes observed, as well as pioneers and visionaries leaving the company.

Suárez states that the large installed base acts as a strong defence against potential challengers. In my phase VI, an extra stronghold is the socio-technical institutionalisation of the standard in society.

This phenomenon is fundamental for this study, particularly on how to de-entrench or reconfigure, e.g. how to reach a new phase VI after the MES/IIoT battle. After all, a paradigm change is paramount. The phenomenon should be interesting for further research, to validate the idea for other technology battles, and in general for the de-entrenchment of socio-technical path dependencies during 4IR.

Although out-of-scope for this paper, Sarvari et al. [2018] may point to a path forward, see Figure 20. Further research is recommended on the concepts of de-entrenchment, e.g. reconfiguration, stagnation and decline. This is critical for the MES/IIOT evolution.

9.2.5 Six new dominance factors

Six new dominance factors were introduced and well-perceived. Further research is recommended whether these factors are reproducible in other markets and technology battles. Four factors were defined based on literature research and feedback from scholars. These are listed below. A fifth and sixth factor were derived during the discussion of the interview results. An **external constraint** can be a factor, such as engineering availability. Also, a defensive stance to protect against an (envelopment) attack is a factor.

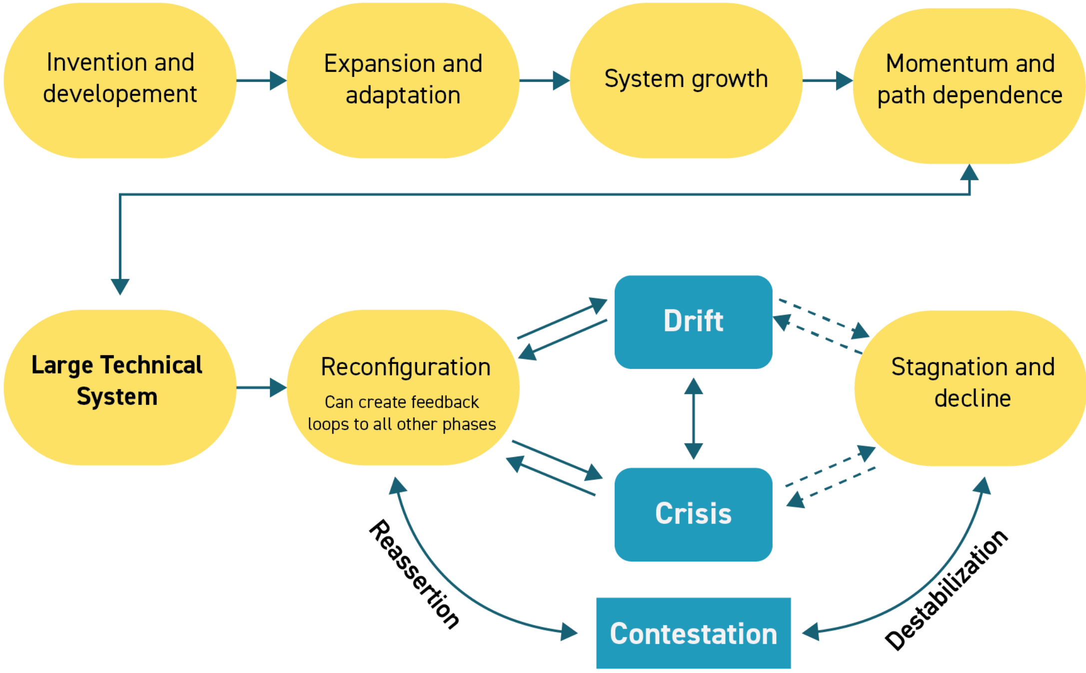

Figure 20: Phases of Large Technical Systems (free to Sarvari et al. [2018])

Both of these factors, five and six, or not static dominance factors from a deterministic literature stream perspective. Instead, these factors are reactive or pro-active, from a strategy management literature stream perspective. Further research is recommended, for example, from a Game Theory literature stream.

The four contributions to the Van de Kaa et al. [2011] theory of Dominance Factors are as follows:

Full (comprehensive) Service is the reciprocal of Complementary Goods; instead of stating that adding a good is good, I claim that removing a service from the complete package or offering a partial portfolio, is terrible. It leads to higher Total Cost of Ownership, prevents standardisation, and therefore the business cannot accomplish high Capability Maturity.

System Builder is entirely new in this field. It is based on Collaborative Supply Chain theory and coined initially by Hughes 1987.

Capability Maturity is new and refers to CMMi on vendor software product and services portfolio, as described in Appendix A.7.

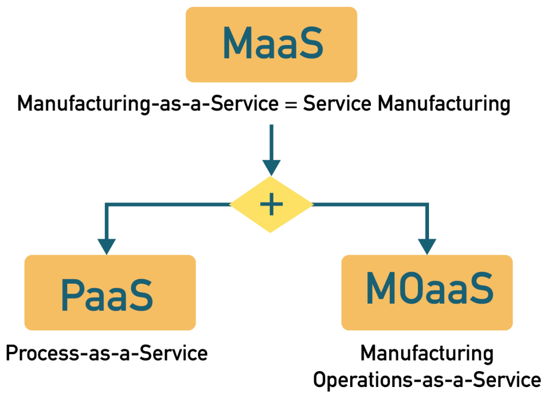

Figure 21: Manufacturing as a Service platform [Kusiak, 2020]

Manufacturing as a Service is, in fact, servitisation, in the context of the MES/IIoT platform. Both relate to a paradigm change. Vendors and IT engineers have dominated solution design, which does not make sense, as all Process Expertise is in the Business. It can be better defined, and further research is recommended. Figures 21 and 22 show the two user-sides of my proposed MAAS platform as inspiration.

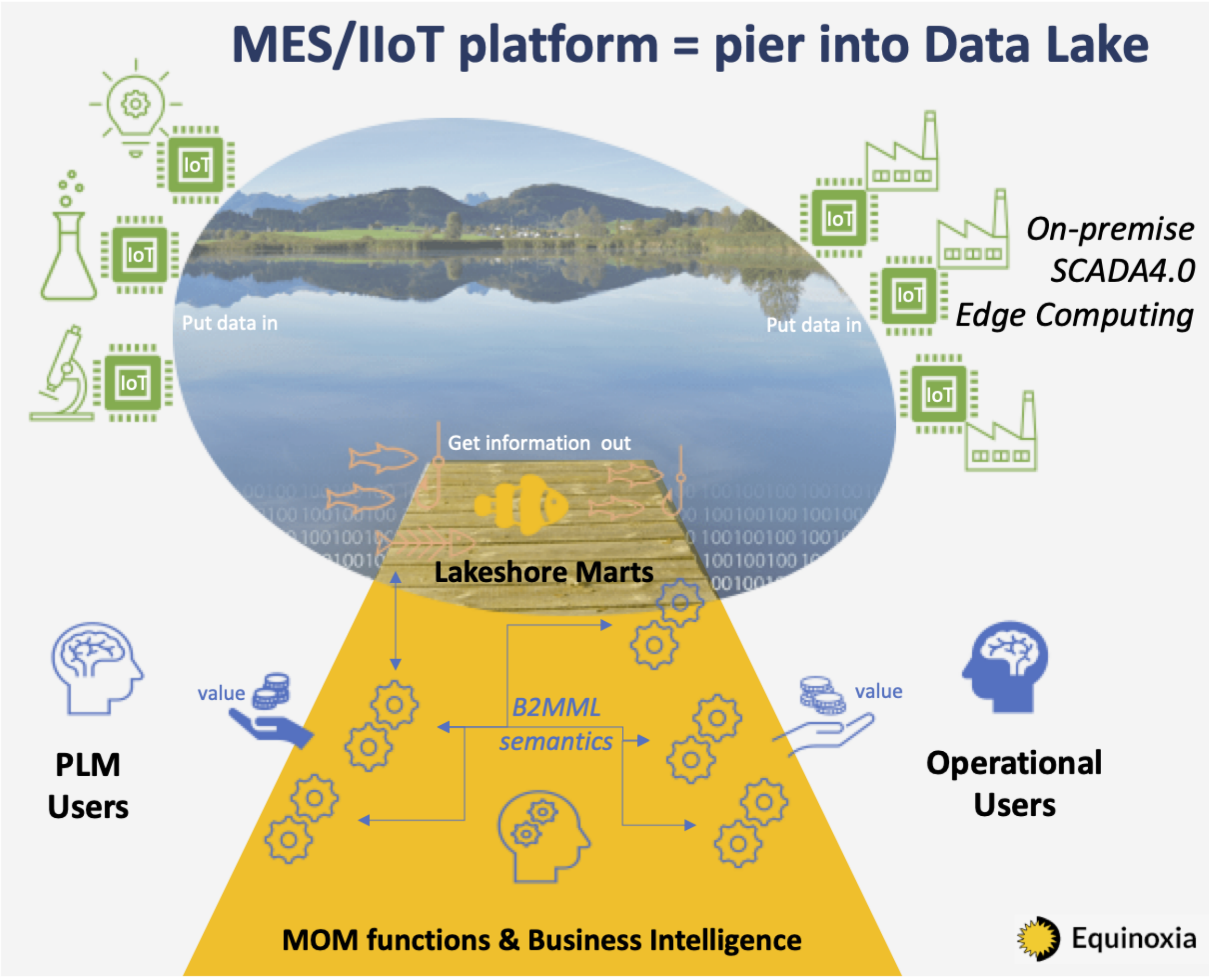

Figure 22: My proposal for a MAAS platform "MES/IIoT pier into the datalake"

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Appendices

A Literature Study on MES/IIoT market uncertainty

As explained in Chapter 2, a diverting primary literature research was executed, to analyse the Market Uncertainty. The detailed findings are as follows:

A.1 Definition and scope of 4IR remains ambiguous

Chiarello et al. [2018, p.1] found that „the total number of technologies covered is more than 1200, linked with more than 39,000 semantic relations." Reischauer [2018, p.28] also raised the notion of a communicative bubble concerning the label industry 4.0 and suggests to view industry 4.0 as „policy-driven innovation discourse in manufacturing industries that aims to institutionalise innovation systems that encompass business, academia and politics". In contrast, Pfeiffer [2017, p.113] mentions that „Industrie 4.0 got its discursive wings not primarily from the rise of new technical possibilities but rather from economic exigencies as identified by economic elites."

A.2 Capacity issues on investing in 4IR

Capacity issues are observed on the market. Lack of resources is observed by means of personnel and budgets for the 4IR transition. Specifically for Small and Medium Enterprises (SMEs) 4IR expense is referred to as incalculable [Maier and Student, 2015]. Large enterprises are likely to overrun SMEs, which is echoed by Agiplan [2015, p.50] „Available budgets for funding digital technologies in the majority of SMEs are considered perceptibly low." Due to the high amount of customisation required, for implementing 4IR solutions, the already scarce number of specialists even becomes scarcer due to lack of standards. This contradicts the initial 4IR Socio-political legitimation.

A.3 Make or Buy Hobsons Choice; it will always be tailormade

As an executive from a global business stated in IndustryWeek magazine „Technology is changing so fast, when a salesman from a 30-person IOT company tries to sell a $5 billion global company a specific tech solution, theres going to be some hesitation. I dont even know if that company will be around in two years." [Gold, 2018, par.6] The make-or-buy decision is, in fact, a *Hobsons choice*. It is always a make-decision, as it is impossible to choose *buy* because no standardised solution or framework or platform exist. It will always have to be fully customised, either in-sourced or out-sourced. What is required, is a COTS solution that is partly *infrastructure* and partly *configurable*. Key to the 4IR adoption delays is the make-or-buy decision. Manufacturing companies neither have the knowledge nor the resources in-house to build a solution. The same applies to solution vendors. Software solutions exist; such as Azure; however, these only sell toolboxes that must be so heavily customised that standardisation is at risk, even harmonisation is difficult. This is a known problem from 3IR. Related to this, three further practical 4IR problems were identified during the literature review. These originate from 3IR, detailed in the next section.

A.4 Cim-Salabim spelling magic words instead of integrating technology

Another reason for the slow 4IR adoption is a déjà-vu effect: At the 1985 Hannover Messe, Computer Integrated Manufacturing (CIM) was euphorically presented as expert-system for 21st-century manufacturing. Example software was SetCIM and CIM/21, which still serve as MES backbone of AspenTechs Manufacturing Suite. Brödner [2018, p.334] analyses Industry 4.0 spot-on: „But these are exactly the same requirements that should have been achieved by computer-integrated and knowledge-based production (CIM) as early as the 1980s. Today as then, the technology-centred view of production dominates the field, there is a wave of technology-centred exuberance and unsuitable attempts to overcome problems of the organisation of production processes technically. CIM was also concerned with networking as many computer-aided production components as possible and exchanging data between them. Such networked systems were subsequently implemented in many different ways. However, their functions were mostly used, contrary to what was originally thought, at the instigation of and interacting with human experts and their working ability. In contrast, attempts to implement extensive flexible automation using expert systems and other knowledge-based systems have failed miserably."

When Industrie 4.0 was introduced, many still remembered having invested large sums of money in CIM technology without directly noticeable productivity improvements. Back then, professor Scheer (nicknamed the German CIM-pope), mainly blamed short- term or unrealistic expectations and the selection of wrong advisors or partners in the introductory process [Scheer, 1991]. Jacobi [2013, p.82] also emphasises the high expectations associated with the introduction of CIM when he speaks of CIM-Salabim: „The too high expectations of being able to solve all problems in the company with a quick CIM introduction (CIM-Salabim) were not fulfilled." Another problem that has remained between 4IR and CIM/3IR is that System Integration is often owned by IT departments, with a risk of developing quick & customised micro-solutions in order to achieve short-term implementation goals, without business understanding or long-term considerations. The result is a moon-landscape with craters of hardware and software solutions. In theory, these could be connected, but incompatibility and data integrity issues significantly delay and often block the envisioned system integration process [Dolata, 1988].

The root cause is hidden deeper. CIM failed as only buzzwords were used in magazines and conference, whilst proper data-interfaces and centralised architectures of CIM applications were lacking. CIM remained monolithic, per site, with scarce connectivity to a few data sources. The integration aspect was missed-out. IIoT vendors may make the same mistake. One group offers IIoT-ready equipment automation using RAMI4.0 without actually offering MOM functionality. Another group offers IIoT data-mining applications, which are merely toolboxes without pre-defined MOM data-models and without pre-defined MOM interfaces. The assumption that NO-SQL interfaces on top of Data Lakes can add context real-time and can derive transactional batch information has been debunked. When implementing multiple sites, scattered data context may be a problem when Data Models are not standardised (at industry and/or company level). This is putting Data Integrity at risk. Also, Data Warehouses will be required as Data Lakes fail to meet acceptable performance for retrospective analysis of transactional data, e.g. IIoT may fail to serve as a Single Source of Truth [VDI3714-1, 2020].

Hirsch-Kreinsen [2016, p.20]] administers the coup-de-grâce: „If one adheres to these arguments, Industry 4.0 is less the driving agency of a new industrial revolution, than the expression of a path-dependent advancement of earlier technological concepts."

A.5 Reference architecture models are not fit-for-purpose

Remembering CIM-Salabim, the renowned *CIM-Pope* blogs that 4IR should not become a CIM-reload [Scheer, 2013, par.2]: „At first glance, these manufacturing systems [red: 4IR] looked no different than we had built them in the CIM (Computer Integrated Manufacturing) centre of my research institute at Saarland University over 20 years ago. At that time, the basic idea of integrating logistics, design and manufacturing was already there. There were no networking standards, no high-performance database systems and no internet so that the high expectations could not be met right away. Nevertheless, opportunities were also missed."

The development of a 4IR networking standard, e.g. reference model RAMI 4.0 seemed promising; it could prevent a CIM-reload [Scheer, 2013]. However, where advancement was expected on proven 3IR models, RAMI 4.0 is a warp back into time: The hierarchy axis falsely claims to reference IEC61512 & IEC62264, respectively ISA-88 and ISA-95. Not a single of the dozen reference models from ISA-88 and ISA-95 is incorporated into RAMI 4.0. Because of the consensus on 4IR being an incremental development upon 3IR, one would expect RAMI. 4.0 to incorporate proven models on System Integration and Manufacturing Operations Management. Nothing is less true.

RAMI 4.0 falls back to an IT-perspective and references just one ancient Control Hierarchy Model [Simpson et al., 1982]. Equipment Control is critical, see the left pillar below, but RAMI 4.0 should also include Process Management, the right pillar. We knew that already in 1982.

In fact, RAMI4.0 did not fully remove process (and recipe) management from the hierarchical models, it moved these to the communication layers Business and Functional, correctly implying that each hierarchy has its own process and recipe management ... but then left it ambiguous. At Business and Function level, nothing is defined, besides three high-level functions. Integration at the enterprise level and with the connected world will be troublesome. Every single plant has to consider existing standards for its machines [Frysak et al., 2018].

The lifecycle axis is even more old-fashioned reverting to a binary change/run approach, e.g. project/operations. 4IR concepts such as self-configuration are not addressed, nor layered configuration to reduce change impact. At minimum, a denominator between infrastructure control modules recipe master data order live data is expected. Frysak et al. [2018, p.37] wrote: „focusing on a single process on the Life Cycle axis makes it hard to describe other important related processes executed in parallel, like quality assurance processes or optimisation processes, revealing another pitfall. What also caused confusion is that a product, although marking the very end of the production process, and requiring a life cycle of its own, is also the lowest level of the Hierarchy Levels. Implying the product to be an integral part of the plant, the company and the production process was identified as another pitfall of RAM4.0."

On the Communication Layer, standards for communication are undefined, though a preference for OPC is specified. OPC is a messaging & transport service developed initially for flat time-based data series. It is excellent for alarms/events, time-series of data and it can include some low-level metadata. However, OPC is not strong on semantics. More complex datasets will have difficulties with OPC, such as Production Orders, Master Data, Recipes, BOMs, KPI blocks of data, reports, pictures/movies, etc. Interoperability requires interfaces to be standardised. A study by Gartner found that only 5% of the interface is a function of the middleware [Simoni, 2018]. The other 95% is a function of the application semantics. As stated by Frysak et al. [2018, p.36]; „key issue at this Layer is to define a single information model and its syntax and semantics that are valid and accepted throughout the enterprise and across enterprise boundaries."

It is unclear why RAMI4.0 dropped the current B2MML (XML) standard as defined in ISA-95 as this is a proven model and industry standard for this purpose. As RAMI 4.0 fails to standardise System Integration at semantics level, each WorkCentre needs their own definition, which may lead to poor data integrity within enterprises and may lead to significant challenges when interfacing the connected world.

The root cause is that RAMI 4.0 was labeled 'standard' with insufficient peer feedback. The standard may work for a singular ecosystem, where OPC to ERP and OPC to customer devices works fine; however, for broader applications and other use cases, RAMI 4.0 turns out to be underdeveloped. Peer networks need to be expanded beyond those whom the initial participants know well (Guilfoyle, 2020). ARC Advisory Group underwrites this technically Leeuw [2019, par.6]: „The structure of the AAS [RAMI 4.0 asset administration shell] must be standardized to enable exchanges. [...] To exchange information, the AAS instance can be mapped to OPC UA, MQTT, or other formats. The AAS type is likely to be expressed in the AutomationML standard." In other words; the RAMI 4.0 standard must be further standardised (...).

In general, it seems as if RAMI 4.0 is an isolated initiative. Lessons-learned from 3IR CIM-Salabim is not taken on board. The scope is limited to the AAS sub-model for SCADA4.0 see next section.

Another 4IR Reference Architecture Model exists in the US. The adoption is even worse as Yli-Ojanperä et al. [2019, p.1]] discovered: „only a minority of researchers were aware of the said reference architectures and that in general authors offered no discussion about the compatibility of their proposals with any internationally standardised reference architecture for Industry 4.0."

Would the situation be better around 4IR readiness methodologies? See section A.8

A.6 RAMI4.0 update of November 2020 ... is it comprehensive now?

German Standardization Roadmap Industrie 4.0 describes the information content and serialisation formats of an Asset Administration Shell DIN [2020, p.32]: „It specifies a technology-neutral UML model, an XML and JSON schema and mappings for OPC UA, AutomationML and the Resource Description Framework (RDF). It includes a definition of the AASX exchange format, which is used for the secure transmission of Asset Administration Shells. It considers security aspects and defines access rights for information stored in the Asset Administration Shell based on the Attributes Based Access Control (ABAC) concept."

The international standard IEC 62832 *Digital Factory* serves as a template for describing assets in the administration shell (see above). IEC 62832 is divided into three parts and defines a framework for using dictionary entries (e.g. classes and properties) to describe asset types and to describe specific assets. Thus, it offers an internationally binding basis for the use of properties, both for conventional engineering and smart manufacturing [Ye et al., 2020].

The special position of properties in I 4.0-systems is also evident from the numerous projects and activities for further developing the use and methodology of properties, from which future requirements and trends can be derived. In the project *Semantic Alliance for I 4.0 SemAnz40* funded by the German Federal Ministry for Economic Affairs and Energy (BMWi), it was shown how features could be used to form a suitable semantic basis for the exchange of information in the use cases of Industrie 4.0 [30]. Further activities are, for example, the VDMA guideline *Interoperability through standardised features* of the Working Group NA 060-30-04-05 *Product characteristics and libraries*, and the activities on NAMUR Open Architecture (Automation Networks and Services) and the ZVEI activity on Drive 4.0.

In Industrie 4.0, a companys cloud IT architectures should be based on standards and reference architecture models (e.g. RAMI 4.0, IDSA-RAM, IIRA). Depending on the IT architecture's respective requirements and the framework on which the company bases its business models, appropriate standards should be used in a targeted manner.

Striking examples are Fieldbus profiles (definition of parameters and behaviour of measuring and control devices with industrial communication connection), OPC UA Companion Specifications, but also abstract models such as EDDL (Electronic Device Description Language) and AutomationML, which provide a description tool for information models. From the point of view of semantics, domain knowledge has been transferred into information models, representing an essential contribution to interoperability.

A.7 Are the readiness models ready for 4IR?

Since the early days of 3IR, Information Systems and Innovation Management have been strategically assessed with capability maturity models (CMMI). For 3IR and 4IR, more than twenty variances of CMMi are in place; MESAs Manufacturing Operations Management Capability Maturity Model Singapore Smart Industry Readiness Index Industry 4.0 Readiness Index from Roland Berger SIMMI 4.0 (System Integration Maturity Model Industry 4.0) TU Dresden Heilbronn M2DDM (Maturity Model for Data Driven Manufacturing) from University Stuttgart Digitalization Degree of Manufacturing Industry from Friedrich-Alexander University Industry 4.0 Maturity Model from the Austrian Fraunhofer and Vienna University Reifegradmodell Industrie 4.0 developed at the Fachhochschule Oberösterreich Roadmap Industry 4.0 from University Caphenberg (Austria) Digital Maturity Model developed by the Swiss University of St. Gallen DREAMY (The Digital Readiness Assessment Maturity Model) from Confindustria Industry 4.0 Readiness Evaluation for Manufacturing Enterprises from Hungary Industrie 4.0 MM (Assessment model for Industry 4.0) from University Ankara Industry 4 readiness assessment tool developed at the University of Warwic (UK) Stage maturity model in SME towards Industry 4.0 Industry 4.0 Digital Operation Self-Assessment from Price Waterhouse Coopers APM Maturity Model (Asset Performance Management Maturity) from Capgemini The Connected Enterprise Maturity Model from Rockwell Automation Industrie 4.0 Maturity Model from Acatec Firma4.cz from the Ministry of Industry and Trade of the Czech Republic Pathfinder

4.0

Most models seem to be b(i)ased upon 3IR criteria. Key for 3IR used to be (and still is) the intended harmonisation between pillars in the corporation. Vertical and horizontal integration needs alignment on data and processes as a non-negotiable prerequisite for integration. Without alignment, data integrity is at risk, and more significant risk is failed adoption, e.g. business change. As Peter Drucker stated; „Culture eats strategy. For breakfast."

A.8 4IR is a cacophony of products; it lacks a systems perspective

4IR lacks (accepted) standards and platforms. RAMI 4.0 is not widely adopted and instead of building on top of existing standards ISA-88 and ISA-95 it reinterpreted the widely accepted industry standard by customising it to a late 1980 predecessor. Software solutions and communication protocols are in use for 3IR, such as various middleware solutions, and protocols such as B2MML, OPC, and similar standards in ERP and Supply Chain domains. Specifically, for 4IR cloud solutions are referred to, such as Microsoft Azure. However, adopted standards are still lacking. In reference to Business Eco-Systems, the current 3IR versus 4IR technologies may well be a Battle- of-Standards which is yet another argument that 4IR is de facto a settling-in of 3IR. This is a significant finding.

A.9 No abundance of resources to fuel 4IR

Some alternative views on 4IR and associated criteria were found during the literature review. Although scarcely back-up by academic resource these alternative views are worth mentioning. An observation of previous significant technological advancements is that actual progress of the technology is synchronised with an abundance of resources:

Economic boom goes hand-in-hand with technological advancement, is what some scholars believe [Grinin et al., 2016]. As they claim, during the economic recession, both the funding and the market is lacking for technological advancements. Whereas regular economic waves occur one a cycle of a decade, a *Kondratieff* double or super-wave leads to an economic boom every 40-50 years. As we are currently not in such an economic boom, scholars argue, prerequisites are therefore lacking for 4IR. Whereas the hypothesis is not academically sound, it is observed that enterprises merely allow short Return-On-Investment (5-years is common practice these days). Due to the current economic situation, long-term investments need strong business cases. The ambiguity around 4IR may cause limited investments. Further research on this hypothesis is required: does an industrial revolution go hand-in-hand with a boom in available economic-resources?

Unlimited energy resources were the driver of previous industrial revolutions. For the first industrial revolution; Wind, water and steam energy were relatively unlimited, compared to muscle power. The second industrial revolution got substantial leverage from electrical power, which provided relatively unlimited energy, compared to its predecessor. For 3IR, one could argue that electronics and automation offered an energy-boom on itself, as 3IR optimised energy production and consumption; respectively an increase and decrease. MESA claims a 30% efficiency-gain with 3IR horizontal and vertical integration. 4IR lacks this driver. In sharp contrast to the previous three industrial revolutions, 4IR does not have an energy-resource driver. Current climate politics are forcing renewable energy sources that are predicted to match 3IR energy needs barely. Following this reasoning without assessing its correctness climate change is blocking 4IR. Further research on this hypothesis is required.

B Factors for dominance - evaluated literature

In an earlier research [Vries, 2020], secondary sources were analysed and interviews were conducted with three experts. As baseline the 29 firm level factors offered by Van de Kaa et al. were taken, with 4 extra business ecosystem factors den Hartigh et al. [2013].

B.1 Possible Firm Level factors

Van de Kaa [Van de Kaa et al., 2011] *"focuses on the period beginning with the technological discontinuity and ending when one interface format has become dominant."* and has found 29 influencing factors for the Technology Battle. In his prescribed methodology, a sub-selection is recommended to be made prior to executing a Best Worst Method analysis. Each of Van der Kaa's factors is listed below, quoted literally from his work [Van de Kaa et al., 2011], including a frequency count on how often each factor was found described in the literature in 2011.

Each of the dominance factors is evaluated whether it is fit-for-purpose for the MES versus IIoT battle.

Characteristics of the format supporter

Van de Kaa et al. [2011] defines this as „The first group of factors relates to the strength of the interface format supporter (when formats are supported by multiple companies, we refer to the complete group of supporting companies). The stronger the format supporter, the better are the chances of the supported format becoming dominant."

1. **Financial strength** according to Van de Kaa et al. [2011] „is not only the current financial condition of the parent corporation, but also its future prospects. When introducing a format, financial resources can be used to compensate start-up losses including the cost of developing the format; a group of format supporters that has a higher financial strength than competitors can endure longer periods of low earnings due to low prices of products in which the interface format is implemented, as well as spend more on marketing of both the format itself and the products in which it is used and thus will have a higher chance of setting a dominant format. Sixteen studies mentioned this factor as positive."

   Evaluation - HIGH: (re)developing a MES as a COTS solution in the cloud is estimated to take 100 to 500 man-years development effort roughly equaling an investment of 10 to 50 million euro. These is a significant entry-barrier in the market.

2. **Brand reputation and credibility** according to Van de Kaa et al. [2011] „plays a significant role in the users' selection of a format. Past performance in setting dominant formats has a positive impact on the attitude to new proposals. Also, a group of format supporters with a good reputation will find it easier to attract other stakeholders to join the group resulting in an increase in the format's installed base. Thirty-nine studies suggested a positive relation between the factor and format dominance."

   Evaluation - HIGH: This is seen as a critical factor. New entrants that have a previous reputation are expected to have more credibility than brand-new players.

3. **Operational supremacy** according to Van de Kaa et al. [2011] is „when a group of format supporters is composed in such a way that it is able to exploit its resources better than competitors, it has an advantage over them which will positively influence its chances of reaching dominance with the format. This advantage is called operational supremacy. Operational supremacy can be reached, for instance, by the possession of a superior production capacity. A technological advantage of one or more members of a group of format supporters can increase the chances that their format will achieve dominance. Twenty-three studies mentioned this factor as having a positive effect."

   Evaluation - HIGH: in light of MOM this refers to being able to execute projects e.g. have sufficient knowledge and resources directly in house or indirectly available in its network.

4. **Learning orientation** is according to Van de Kaa et al. [2011] „the learning capabilities of the firm are described as the process by which knowledge about actionoutcome relationships and the effects of the environment on these relationships is developed. Failure to invest in learning can increase the likelihood of a format being locked out. With learning, we refer both to the know-how; the core capabilities, and the extent to which the firm can acquire new knowledge-absorptive capacity. The absorptive capacity refers to both technological know-how (the ability to generate technological breakthroughs) and market pioneering know-how (whether these technological breakthroughs can be commercialized). Learning from experience can increase the chances that dominance will be reached. For instance, in the television industry, firms that were also producing radios survived longer and had higher market share than those that did not: they were able to make use of their prior experiences in the radio industry. Therefore, the learning orientation of the group of format supporters plays a positive role. We found 47 theoretical studies suggesting a positive effect of which three quantitative empirical studies confirmed the suggested effect. However, one study shows that the prior experience of incumbents can also have a negative influence on market share as such experience restricted the incumbent in committing to a new format. This study demonstrates a situation in which firms invest too much in core capabilities and too little in absorptive capacity. Thus, a group of format supporters can, by investing in learning, increase the chances that its format reaches dominance, provided it invests in both core capabilities and absorptive capacity."

   Evaluation - HIGH: Existing players need learning to adapt to new technologies, in particular moving away from client/server architecture to cloud/IOT, moving from on-premise relational databases to Data Warehouses / Data Lakes, and to adopt data models and data processing with new technologies. Also, entrants need learning from existing data models.

Characteristics of the format

is according to Van de Kaa et al. [2011] „a format that is superior compared to other formats has a higher chance of becoming dominant. This superiority may include:"

5. **Technological superiority** „ Schumpeter defines technological superiority of a design as having features that allow this design to outperform other designs. On the other hand, David emphasizes that the most technically advanced format does not necessarily become the dominant one. Thirty-nine studies suggested a positive relationship between this factor and format dominance." [Van de Kaa et al., 2011]

   Evaluation - HIGH: the technologies are fit-for-purpose and are not superior to eachother. Nevertheless, the efforts for implementation and maintenance of the MES or IIoT are a significant factor. This is related to maturity and fit-for-purpose of the technology.

6. **Compatibility** is added by Van de Kaa et al. [2011] as „another characteristic of a format is the compatibility it enables. Compatibility concerns the fitting of interrelated entities to each other in order to enable them to function together. Horizontal compatibility concerns the fit between functionally equivalent objects (e.g., two Lego bricks or two telephones) When a format is backwards compatible the format is designed in such a way that the technology in which it is implemented is compatible with technologies in which the previous generation of the format has been implemented. For example, formats for analog color television have been specified in such a way that the color signal could be received by black and white television sets. By making a format backwards compatible the chances that it will achieve dominance increases as it can make use of the previous installed base of the format. Thirty studies suggested a positive relation between the factor and format dominance."

   Evaluation - DUPLICATE: Compatibility with cloud/IOT, and Data Lakes/Warehouses is fundamental, which are in fact Complementary Goods to eachother.

7. **Complementary goods** are according to Van de Kaa et al. [2011] „complementary goods are those other goods needed to successfully commercialize a certain format. Similarly, Farrell and Saloner recognize that the interchangeability of complementary goods creates demand-side economies of scale. Unsurprisingly, when an interface format is used in many complementary goods, this increases demand for the format. In 54 theoretical studies it was suggested that a positive effect exists between the number and variety of complementary goods in which the format is used and the chance that the format will achieve dominance. This was supported by three quantitative empirical studies."

   Evaluation - HIGH: Compatibility with cloud/IOT, and Data Lakes/Warehouses is fundamental. In fact, this is the sole reason of existence for IIoT solutions.

8. **Flexibility** refers to Van de Kaa et al. [2011] „the flexibility of a format refers to the incremental cost and time needed to adapt the format due to new developments such as changes in customer needs or technological improvements. Technology management literature indicates that flexibility facilitates the adaptation of a product to customer requirements, and thus has a positive influence on the installed base of products. Standardization literature addresses the topic of flexibility as well and implicitly assumes that a more flexible format adds to technological superiority and thus to dominance. We found ten theoretical studies suggesting this positive effect."

   Evaluation - DUPLICATE: of learning in this context.

Format support strategy

In this section, we survey the range of strategies companies can use to win a format battle.

9. **Pricing strategy** according to Van de Kaa et al. [2011] „refers to all actions taken to create market share through strategically pricing the products in which the format has been implemented. Sellers may be willing to temporarily price below cost in order to build an installed base and thus make the format more attractive. Such penetration pricing can also temporarily be used to block possible entrants. We found 33 studies suggesting that a low product price will contribute to format dominance, with which a further two quantitative empirical studies agreed."

   Evaluation - DUPLICATE: of switching costs. Product pricing is often less relevant than actual project and servicing costs.

10. **Appropriability strategy** following Van de Kaa et al. [2011] „refers to all actions that are undertaken by firms to protect a format from imitation by competitors. An open licensing policy will result in an increase in the installed base. We found 23 theoretical studies suggesting a positive effect; a more open appropriability strategy will increase the chances that a format will achieve dominance. For instance, Sun's open systems strategy led to the success of Java."

    Evaluation - LOW: both standards are available to the public, although ISA-95 is hidden behind a paywall, and the German DIN version of ISA-95 is multiple years behind.

11. **Timing of entry** is according to Van de Kaa et al. [2011] „the timing of entry is the point in time at which the first products in which the format is implemented enter the market. Early entry may be essential for achieving dominance although there is no consensus in the literature here. Early entry can contribute to dominance of the format by creating an installed base of products in which the format has been implemented. On the other hand, early entrants are hindered by a lack of market information and have to make a comparatively higher initial investment, thereby limiting their ability to support their interface format going forward [38], [95]. So, early entrants should have sufficiently deep pockets to exploit the advantage of an installed base. We found one study suggesting a positive effect and 32 studies suggesting a negative effect. Further, the quantitative empirical papers are not unequivocal. In five out of the six quantitative empirical studies, early entry is considered to

contribute positively to dominance. We believe that the relationship between timing of entry and format dominance is not linear. Christensen et al. and, in particular, Schilling argue that there is an inverted U-shaped relationship between timing of entry and dominance. Christensen et al. speak of a window of opportunity within which it is optimal to enter the market."

Evaluation - LOW: not relevant at this time anymore.

12. **Marketing communications** following Van de Kaa et al. [2011] „customer expectations play an important role in format battles and, therefore, marketing communications are important for gaining greater market share. In the early phase of a battle, pre-announcements of the format itself or announcements of company intention to implement the format in its products can be used to discourage users from adopting rivals' formats prior to the introduction of products in which one's own format has been implemented. For instance, in the DVD format war, the DIVX preannouncement may have slowed down the adoption of the DVD format. At later stages, marketing communications, like advertising or public relations, remain important. They can be used to form expectations that a format will become dominant [50]. These expectations can become a self-fulfilling prophecy in the sense that the format that is expected to become dominant will actually become the dominant format [96]. However, conflicting announcements can confuse potential customers and result in credibility problems. We found 40 studies suggesting a positive relationship."

    Evaluation - MEDIUM: Marketing communications play a role, in particular the fear of being a laggard and group pressure from MOM/MES/IIoT specialists.

13. **Pre-emption of scarce assets** refers to Van de Kaa et al. [2011] „ firms that are able to capture scarce assets at an early stage, thus denying them from other players, are able to create a competitive advantage, and can use this advantage to increase the chances of their format becoming dominant. An example of an asset is an important manufacturer of the product in which the format is used. The group of format supporters can exclude rivals by establishing a relationship with that manufacturer. We found ten studies that mentioned this factor as a positive factor."

    Evaluation - DUPLICATE: not physical assets are scarce but personnel is very scarce. Based on literature study a new factor will be introduced to cover this.

14. **Distribution strategy** according to Van de Kaa et al. [2011] „refers to the extent to which a firm pursues a strategy which increases the strength of its distribution system. A good distribution strategy for the products in which the format is implemented can make the difference in accelerating the acceptance of a technology. A good distribution strategy was mentioned in 24 studies as a factor that positively influences format dominance."

    Evaluation - DUPLICATE: covered by partnerships in the business ecosystem.

15. **Commitment** is described by Van de Kaa et al. [2011] „for an interface format to become dominant in the market, it is important that it obtains sufficient attention and support from each of the actors in the group of format supporters to survive the early stages, when the return on investment is usually low. When uncertainty is high and a high number of competing formats exist, companies tend to commit themselves to multiple formats at the same time. Then the group of format supporters can include companies that are not fully committed to one format. This divided commitment is likely to decrease a firm's market share position and may be negative for the group of format supporters of which the firm is a member. We found nine studies suggesting a positive relationship between commitment and format dominance."

    Evaluation - HIGH: Some MES vendors are marketing their solution to be in the cloud and IIoT ready, whilst nothing is less true and the company is not committed at all. This undermines the credibility of MES in general, and offers extra advantage for new entrants. Also vice versa, some IIoT vendors claim to be able to replace MES but can't even implement a simple OEE project.

Other stakeholders

The fourth group of factors relates to stakeholders other than the group of format supporters.

16. **Current installed base** is referred to as Van de Kaa et al. [2011] „many authors mention the installed base as a factor. Farrell and Saloner defined it as the number of users of a technology. Others focus on the technology itself and then the installed base is a measure of the number of units actually in use (as opposed to market share, which only reflects sales over a particular period). Since we focus on the implementation of interface formats in a technology, we define the current installed base as the number of units of technologies in which the format is implemented actually in use. When a market is affected by network externalities, the installed base has an effect on the adoption of the format. In 42 of the studies we analyzed, this factor was cited as having a positive effect."

    Evaluation - HIGH: Current MES installations can start a migration to IIoT/Cloud and Data Lake/Warehouse.

17. **Previous installed base** is according to Van de Kaa et al. [2011] „ formats that rely on a previous generation of technology have an installed base consisting of the units of that technology actually in use. The users of these units might upgrade to the new format. We found seven studies suggesting that a higher previous installed base will increase the chances that a format will achieve dominance."

    Evaluation - LOW: this applies to for instance General Electric, who could leverage its previous install base of PLC and MES package to promote their GE Digital IIoT solution. For this market the factor is merely a duplicate of the "Current Install Base".

18. **Big fish** according to Van de Kaa et al. [2011] „a big fish is a player (other than the group of format supporters) that can exercise a lot of influence by either promoting or financially supporting a format or by exercising buying power that is so great that this will tip the balance for the format to become dominant in the market [10]. An example of a big fish is IBM, who set the MS DOS format for personal computers. However, IBM's support is no guarantee for success despite their support for the Token Ring format, it failed to become the dominant format for Local Area Networks. We found 20 studies which suggested that the existence of a big fish will increase the chances of the format achieving dominance."

    Evaluation - HIGH: The big fish is Microsoft dominating the client/server and IoT/Cloud markets. Also Google Cloud and Amazon Web Service are big fish, who can significantly influence the technology battle.

19. **Regulator** according to Van de Kaa et al. [2011] „the regulator can prescribe certain formats (e.g., right/left side driving, railroad tracks) [10] in which case the result of a format battle is no longer a pure market outcome [81]. Thirty studies mentioned the regulator as a factor."

    Evaluation - LOW: although applicable for food, beverage and pharma market, no regulations on interfaces exists or is to be expected. Having said that, the FDA has been reluctant to accept data storage in the cloud. Also, for instance, Germany forbids storing of data outside of its country borders. These challenges can be overcome though and hardly influence the technology battle.

20. **Antitrust laws** according to Van de Kaa et al. [2011] „the judiciary can prohibit certain formats from becoming dominant through antitrust laws. An example of this is Microsoft's dominance with its Windows operating system. In 2004, the European Commission ordered Microsoft to make the source code of Windows interface specifications available to its competitors so that they could develop complementary software for Windows. Before this judiciary intervention, only Microsoft could write

software for Windows such as the Windows Media Player and offer that software with Windows. After this intervention the market share of both Windows and the complementary software written by Microsoft decreased since both could no longer make use of each other's installed base. The cost of switching from Windows to a competing operating system decreased considerably since it was not necessary anymore to switch complementary software. Another example can be found in the US instant photography market, where a federal court ordered Kodak to leave the market because it had violated the patents of Polaroid. This led to the failure of Kodak's format for instant photography [102]. This factor was mentioned in 15 studies, 13 of which suggested a negative relationship between judiciary intervention based on antitrust laws and format dominance."

Evaluation - LOW: both interface standards are open.

21. **Suppliers**: according to Van de Kaa et al. [2011] „other suppliers that adhere to a format are the companies that produce complementary goods or services in which the format is applied. Format supporters can, by influencing these suppliers, increase the chances that their format will achieve dominance. They can follow a system lock-in strategy where they attract as many suppliers of complementary goods to their network as possible. For example, in the early '90s, both IBM and Microsoft attempted to encourage firms to develop software for their respective operating systems as they competed to make OS2 or Windows the dominant format. In the battle for a video format, this factor also played an important role. JVC had access to a larger range of manufacturers of complementary goods than Sony and these manufacturers also offered a more diverse range of VHS devices. In 23 studies, this factor was mentioned, suggesting that the more a firm can attract other suppliers of complementary goods, the higher the chances are that the format will achieve dominance."

    Evaluation - MEDIUM: the standard OPC is currently often leveraged or announced to replace B2MML. Whereas this does provide market pressure, the need for a semantic interface is dominating. If however OPC would release a semantic interface, the battle may be decided.

22. **Effectiveness of the format development process** is described as Van de Kaa et al. [2011] „interface formats can be developed in different ways, for instance, by a single company, in a consortium of different companies, or in committees of an official standardization organization. Differences in, for instance, decision rules, process management and stakeholder involvement impact the effectiveness of the process, for example, in terms of its duration or the quality of the resulting specifications. This influences the potential of the format becoming dominant. In 11 studies, this factor was mentioned and each study suggested a positive relationship between the effectiveness of this process and the chances that the format achieves dominance."

    Evaluation - HIGH: The RAMI4.0 standard originates from Germany as part of its Industrie4.0 government funding program. Actual industry support in Germany is average, and outside Germany the industry support is low to nihil. If support for the standard would become EU funded and promoted, the battle outcome may shift. More importantly, if the RAMI4.0 workgroups would broaden their influence to Europe and abroad, the battle outcome may be decive.

23. **Network of stakeholders** refers to Van de Kaa et al. [2011] „several characteristics of the network of stakeholders supporting a format can have a positive influence on the chances that the format will achieve dominance. We emphasize the diversity of the network of stakeholders. A format that is supported by a diverse network (in which stakeholders represent each relevant product market in which the format can be used) will have a high chance of achieving dominance. This certainly was the case in the battle for a Digital Video Disc (DVD) format, where hardware manufacturers cooperated with movie studios to establish it1. Thirteen studies suggested that the diversity of the network will contribute to the chances that a format will achieve dominance."

Evalutions - DUPLICATE: of previous factor in this battle.

Market characteristics

Market characteristics cannot be influenced by the firm, they just exist, but impact the outcome of format battles.

24. **Bandwagon effect** is described by Van de Kaa et al. [2011] as „when some users have chosen to implement a certain solution to a matching problem, others tend to choose the same solution; often for reasons of availability of information. This so-called bandwagon effect positively affects the likelihood that dominance of one format will be reached in the market. This factor was mentioned in 32 studies."

    Evaluation - DUPLICATE: this is a chicken-or-the-egg with Network Externalities. Bandwagon effect is an increasing snowball because of information and learning from pioneers, making it low-risk to follow. Network Externalities is a positive sum game, claiming that additional followers will give additional advantage to the interface.

25. **Network externalities** according to Van de Kaa et al. [2011] „describe the effect that the utility an individual user derives from consumption of a good increases with the number of other agents consuming the good. A typical example is the fax machine the more machines the more possibilities for interconnection, provided that common interface formats are available to enable interconnection. Also, the utility of a format increases when the amount and variety of complementary goods that is available for that format increases. If an interface format possesses a higher installed base than its competitor and the network externalities are high, that format will have a higher chance of achieving dominance. Most studies (65) suggest a positive effect of network externalities on the likelihood that one format will achieve dominance. However, two studies suggest a negative effect and one study has empirically proven this negative effect. Here, it was argued that the existence of the network effects will induce more firms to introduce incompatible formats early on since each firm will want to take advantage of the lock-in effects which increase the number of formats that exist next to each other."

    Evaluation - HIGH: together with bandwagon effect. Being able to interface other systems with the same interface is crucial.

26. **Number of options available** according to Van de Kaa et al. [2011] is „The number of competing interface formats plays a significant role in the potential market share of a format. Four studies suggested that a larger number of competing formats in a market lower the chances for each of them to become dominant."

    Evaluation - LOW: not applicable.

27. **Uncertainty in the market** is described by Van de Kaa et al. [2011]; „ When uncertainty in the market gets too high, firms and customers are not willing to take the risks attached to choosing one particular format and postpone their decision. This decreases both the likelihood that dominance of one format will be reached and the speed at which this format will achieve dominance. This negative effect was suggested in nine studies."

    Evaluation - HIGH: The actual scope, ramifications and benefits from Industry4.0 remain unclear. Chiarello et al. 2018 found that *the total number of technologies covered is more than 1200, linked with more than 39,000 semantic relations*. The root cause is likely the policy making on 4IR. By lack of technical in-depth expertise, scholars focused on extrinsic effects and features of 4IR whilst the intrinsic 4IR system remained underexposed. Reischauer 2018 also raised the notion of a communicative bubble with respect to the label industry 4.0 and suggests to view industry 4.0 as *policy-driven innovation discourse in manufacturing industries that aims to institutionalize innovation systems that encompass business, academia and politics* while Pfeiffer 2017 mentions that *Industrie 4.0 got its discursive wings not primarily from the rise of new technical possibilities but rather from economic exigencies as identified by economic elites.*

28. **Rate of change** according to Van de Kaa et al. [2011] „refers to the speed of evolution within a specific industry both with respect to the technology and the market. A high speed has a negative effect on the emergence of a dominant format. The rate of change refers, for instance, to the speed at which new generations of the format are being introduced. When this speed is high it affects the desirability of committing to any format; the competing formats may be changed again before anyone has obtained dominance and this may make users reluctant to commit themselves. In five studies, it was suggested that a high rate of change negatively affects the likelihood that a format will achieve dominance.“

    Evaluation - DUPLICATE: although different from "Uncertainty" it drills down to the same idea.

29. **Switching costs** according to Van de Kaa et al. [2011] „are costs required to switch between competing formats. In many cases these cost include the procurement of new products (including complementary goods) in which the new format is implemented such as software for a PC with another operating system. If the format provides the interface between technology and man, the switching costs may include mental changes such as learning to use a new keyboard layout. When switching costs are high, it will take relatively longer before a new format becomes dominant. This negative effect was suggested in 20 studies.“

    Evaluation - DUPLICATE: this is closely related to uncertainty. The driver is not the switching costs, but the risk.

B.2 Possible Business Ecosystem Health factors

Whereas Van de Kaa et al. [2011] is very complete it was observed that Network Externalities is crucial for the complex environment of MOM suppliers, consulting firms, systems integrators, standardization institutes, SME's and corporations. In addition, the *Van de Kaa* methodologies seems to be biased to Firm Level factors assuming a technology battle between firms. In the reference list of Van der Kaa only one article was found on an industry standard battle. Therefore it was decided to do an additional literature research on the subject. One methodology was selected to expand the 29 factors, on Business EcoSystem health from Erik den Hartigh 2013. Four complimentary criteria are added in the field of Partner Health and Network Health:

Partner Health factors

according to den Hartigh et al. [2013]; Partner health is measured as an index of solvency (in period t and t-1), liquidity, total asset growth, working capital over total assets, retained earnings over total assets, EBIT over total assets and company revenue over total assets. These measures are deemed too detailed and we prefer to stick to Van de Kaa factor 1. "Financial Strength".

Network health measures

Network health of a partner is measured as an index of its number of partnerships (network relations), its visibility in the market and the variance of partner types it has relations with:

30 **Number of partnerships**: this says something about a companys connectedness. A higher connectedness means a higher health [Wasserman et al., 1994]. This was confirmed by industry experts.

Evaluation - DUPLICATE: see "covariance".

31 **Technology Market Share**: Visibility tells us something about the centrality of a company in the

market. Whereas den Hartigh et al. [2013] defined this as Google hit-rate, we prefer to measure it as Technology Market Share.

Evaluation - DUPLICATE: although not literally the same, this is quite covered by installed base.

32 **Product Market Share**: Besides Technology Market Share, also Product Market Share is important. A scattered market is more agile to respond to change, whilst an oligopoly is more robust.

Evaluation - DUPLICATE: although not literally the same, this is quite covered by installed base.

33 **Covariance with market** according to den Hartigh et al. [2013] „this indicates the variety of different partners a company has. Partners were by their characteristics classified into species. We first calculated the proportions of the species in the entire market as a reference point. We also calculated for each company the proportions of different species that it is related to. We then calculated the covariance between those the company proportions and the market proportions."

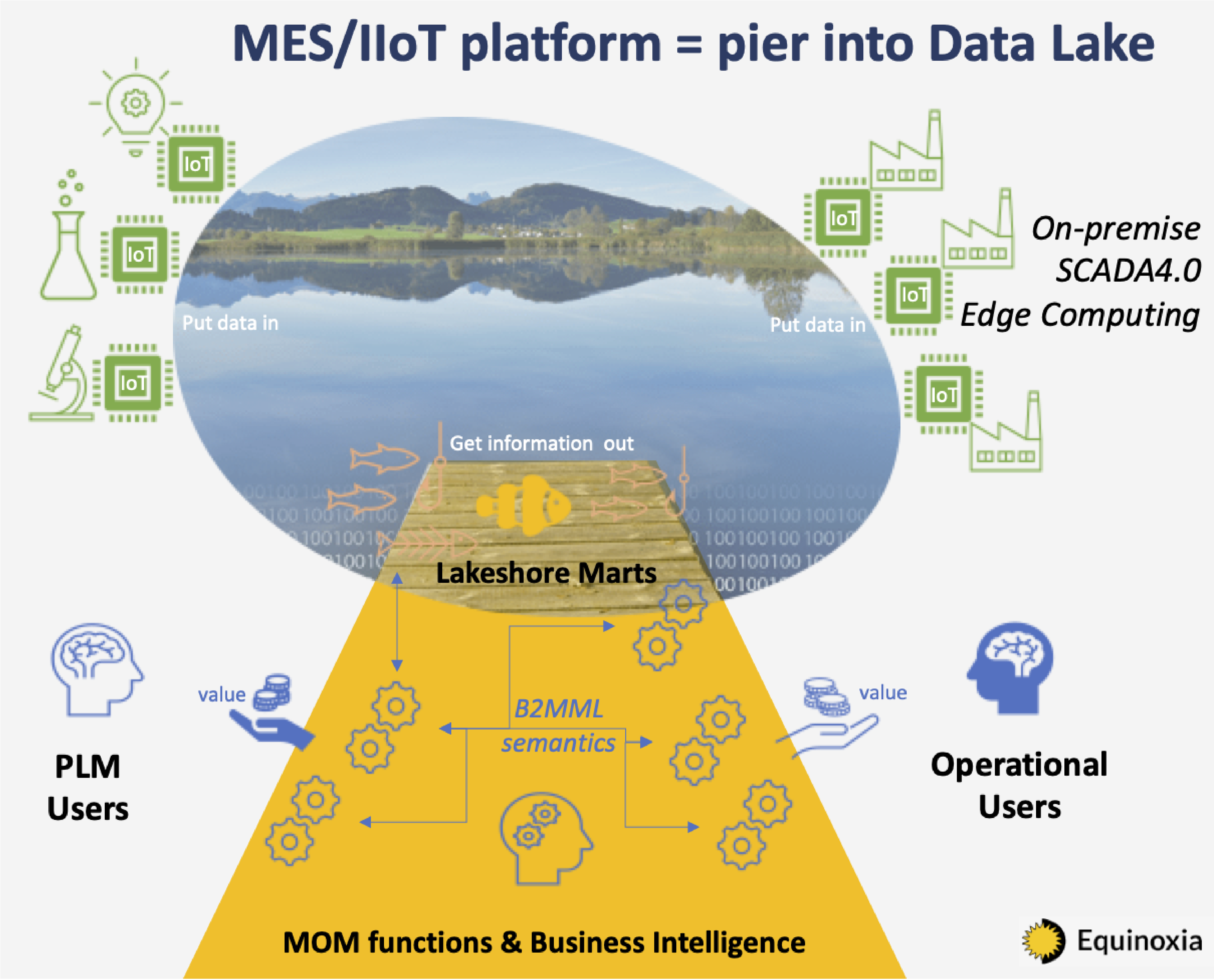
Evaluation - HIGH: Closely related to "suppliers" as written by Van der Kaa [Van de Kaa et al., 2011] and "Number of Partnerships". The cooperation with the market is crucial by means of willingness to partner and in having access to manpower from (local) system integrators, engineering firms, flexpools with contractors, recruiting agencies, university-graduates, etc.

Capacity issues are observed on the market. Lack of resources are observed by means of personnel and budgets for the 4IR transition. Specifically for Small and Medium Enterprises (SMEs) 4IR expense is referred to as incalculable [Maier and Student, 2015]. Large enterprises are likely to overrun SMEs, which is echoed by Agiplan [2015] „Available budgets for funding digital technologies in the majority of SMEs are considered "perceptibly low."

Or as an executive from a global business stated in IndustryWeek 2019: „Technology is changing so fast, when a salesman from a 30-person IOT company tries to sell a $5 billion global company a specific tech solution, theres going to be some hesitation. I dont even know if that company will be around in two years."

The back-cover shows the proposed Manufacturing-as-a-Service platform, as outcome of this study: **MES/IIot platform = pier into the Data Lake.**

The model is based upon the work of Klaus Thiel [2011] and Alexander Demmer from Excellent.Partners.


MES/IIoT platform = pier into Data Lake
IoT
On-premise
SCADA4.0
Edge Computing
Put data in
Put data in
Get information out
Lakeshore Marts
B2MML
semantics
value
value
PLM Users
Operational Users
MOM functions & Business Intelligence
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