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The digital challenge.

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Management Summary

With the big consulting agencies publishing incredible numbers about the tremendous potential of what is now becoming commonly called the "digital transformation", every company must ask itself: are we fit for the digital transformation? What is our status and are there any blockers on our way?

The core take away is not to resist the need to change but focus on the opportunities this opens for innovative and open minded companies and keep in mind that speed matters more than size and current standing. Due to the acceleration effects of digital technologies the change will be exponential. So it is the change factor per time (speed) that makes the difference and not the starting point. Also don't be afraid of the question: What might destroy the current business model the fastest way possible in the future? Be reminded about the Uber-effect and remember what happened to Nokia when they decided to look away and talk the changes down.

On the technological level and with information driven innovations in the cloud with hyperscalable backends, almost endless computing power and memory will alter business models, machine architectures and the value of partnerships. There is no escape from the maelstrom of the cloud and this whitepaper will highlight why this brings unique possibilities for the companies seizing the moment. So watch out for evolving standards and platforms and make them to your own standard before they will crush your current niche. Then use the easy accessibility of huge amounts of data for machine learning and to automate not only the mechanical and electronical control of a machine but also its capability to come to smart decisions and carry out autonomous smart or even super human actions.

A crucial prerequisite to exploit the huge potential of the digital transformation is: secure connectivity, secure connectivity, and secure connectivity. Go for it and go even one step further and try to achieve machines or machine components that can be flexibly rearranged without the need for new manual configuration or even worse new programming: boost reusability and efficiency by creating plug & produceable components and subsystems.

On the engineering level: start a model driven engineering process and target the digital twin. Your customers, specially the big ones, will make this to a prerequisite very soon. One reason could be either because of the enhanced engineering process with shorter realization times from idea to released product and cost reductions. Another might be because of transparency reasons, risk reductions or efficient maintenance and change management use cases.

Literally the digital transformation increases the digital share in the products and production systems. This is work done by your brainworkers like software and hardware engineers, data scientists and IT experts. If you want to win the transformation race win the race for these people, individually. So train and value your team – your people are more mission critical than any other success factor. This is always true but exceptionally important for your brainworkers. Also, be aware of Conway's law and build an organization that can build the systems and information systems of the future. Don't try to reach the goal of the digital transformation with a company culture and mindset of a hardware driven world. Start thinking like a start-up since as machinebuilder you are most likely a startup from a professional software perspective.

The digital transformation is too big and too fast to be covered by just one company. So do not try to do everything on your own. Don't waste time assembling and integrating single components or building up know-how in every single evolving new technology field. In order to reduce the overall complexity use system and solution providers or even better partners as third-party resources.

Enhance your risk assessment. The digital transformation will require management of a continuous and fast decision stream with a lot of uncertainty. The winners will be the companies that are able to handle this well. Maybe the best advice to cut a long story short is: Don't worry about wrong decisions – fail fast and as cheap as possible – otherwise you are simply too slow and too expensive for the digital transformation.

The digital transformation – nothing new but do we act accordingly?

Huge potential and completely new revenue streams

At the beginning of 2018 buzzwords like industry 4.0 or IIoT are nothing new anymore. They are already going to be transformed into actions and innovations and change the machine building business fundamentally:

- Every manager must ask himself: has my company already jumped on the bandwagon or are we still watching?
- What do we really know and what do we believe about the digital transformation? What is our maturity index [11]?
- Are we already going to be disrupted by any competitor without being aware?

The driver of the current digital transformation and the tightly connected huge economical potential is the everlasting national and international productivity race. It is not only getting faster for the participants - with the digitalization of industrial devices and services completely new revenue streams and market potentials like predictive maintenance as a service are emerging. The famous Industrial Internet white paper of GE [10] describes for example major trends, a technological vision and the resulting giant market potential. In numbers this means for example that factories have an IIoT or digital transformation opportunity as large as between 1.2 & 3.7 $ Trillion of impact [34], p. 6

The importance of this often called 4th industrial revolution can also be measured according to the huge national funding initiatives like Industrie 4.0 [8] in Germany, the Made in China 2025 [31] initiative in China, in the USA the IIC [32] or the comparable national initiative in Japan [33]. These national initiatives additionally support the companies on a national level (networking, financial) to push their competitiveness as fast as possible to the next level.

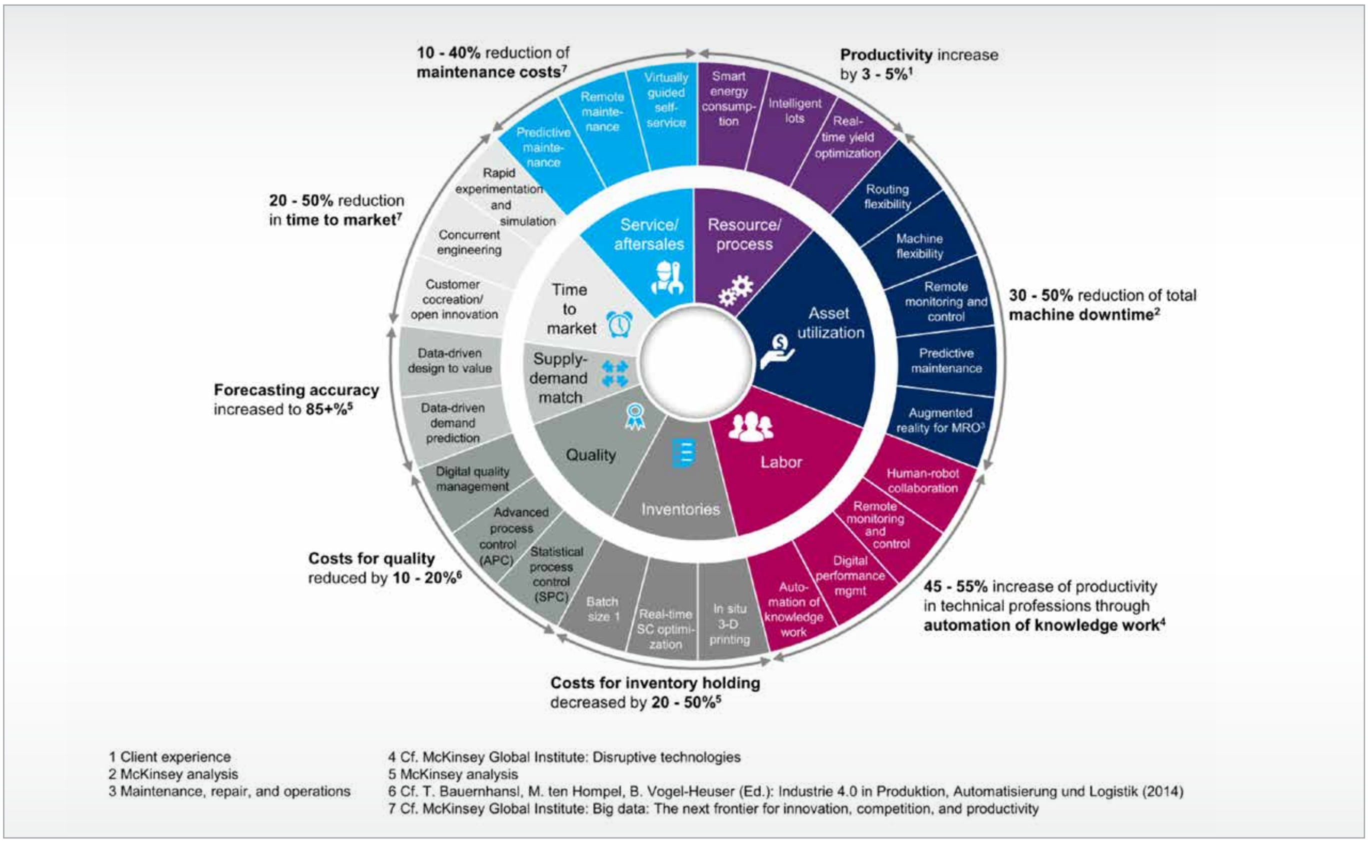

Figure 1: Industry 4.0 at McKinsey's model factories [35], p. 7

Speed is all that matters

One can say now – relax – technological change has always occurred in the machine building business so why should the digital transformation be so special? The digital transformation changes things so dramatically because it has the effect of bridging the gap between former separated technological domains. All of a sudden something becomes feasible which was just too costly not long ago or even not possible like gathering petabyte of data and analyzing it in a very short time at low cost on hyperscalable server farms. And following from that, a dramatical increase of the overall equipment efficiency and a significant reduction of downtime will be achieved.

We find that when IIoT systems communicate with each other, their value is multiplied [34], p.4. This makes interoperability essential but if it happens it skyrockets the benefits leaving every competitor far behind. As technology segments get closer and grow together through digitalization these cross functional innovations become more likely to occur: [5], p.11: "the nature of change has changed" – it becomes a must to expect the Uber-effect. Going on as before is not an option. Specific innovation initiatives need to be supported besides the running daily business. [17] emphasizes that and [4] describes that the operational excellence and the cash cows in the current business domain need to be supplemented with a systematic search for new business opportunities. No one is too big to fail anymore. Uber yourself before you get Kodak'ed [30] has become a known statement.

Therefore, it's not at all surprising that a growing number of technology companies especially the bigger ones already started the transformation process [9]. But some or – in other words – far too many machine builders are still hesitating. A McKinsey study from 2016 [20] gives a good overview of the current market activities. There is no time to lose.

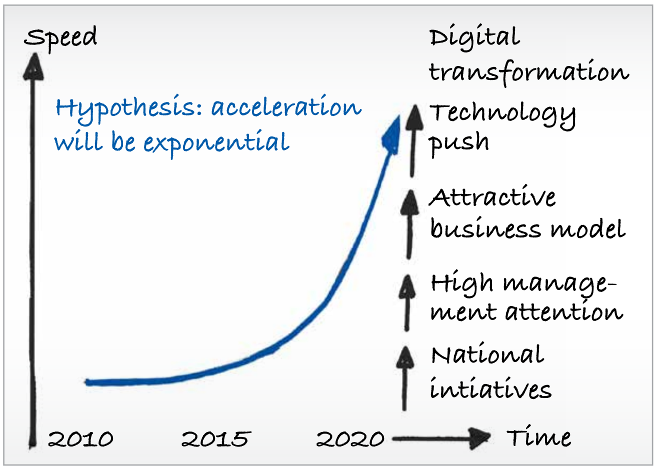

Figure 2: Digital transformation speeds up exponentially, a stepwise linear change will throw you back exponentially.

Scope of this paper

This paper will not further question if these changes are going on but will explain why they will alter the fundamental boundary conditions of every producing company and what consequences arise for machine builders. Although knowing that there is not the one and only strategy to master the situation this paper concludes with concrete advice for decision-makers of machine builders. New technologies create strong desires and new requirements – strategy review.

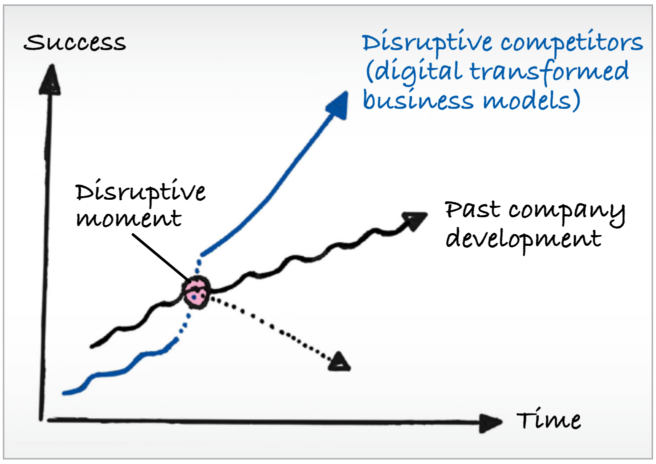

Figure 3: Disruptive business models become more likely to occur due to the rising risk of cross domain innovations – the Uber effect may happen in the machine building business as well. The changing speed of the digital transformation is not linear since disruptive digital innovations are not linear by definition.

Future digital transformed production systems

Flexibility to the maximum extend

We as consumers love individualized products and companies make great profits with our predilection. Web based car configurators, individualized beverages or sport shoes are already success stories. The flexibility of a production system for the batch size 1 is therefore comparable to the Holy Grail of production technology. The advancements of digital technology like cheap and high CPU performance or small and cheap memory mean the long-lasting technological dreams of extremely flexible and autonomous but cost efficient production systems are now very close to becoming true. This is not only true for consumer goods, also in industrial production industry batch size 1 is not a vision anymore. In domains like 2D and 3D digital printing the "batch size 1" approach is already cost effective enough to be competitive in parts compared with traditional production technologies. Numerous other areas or sectors are very likely

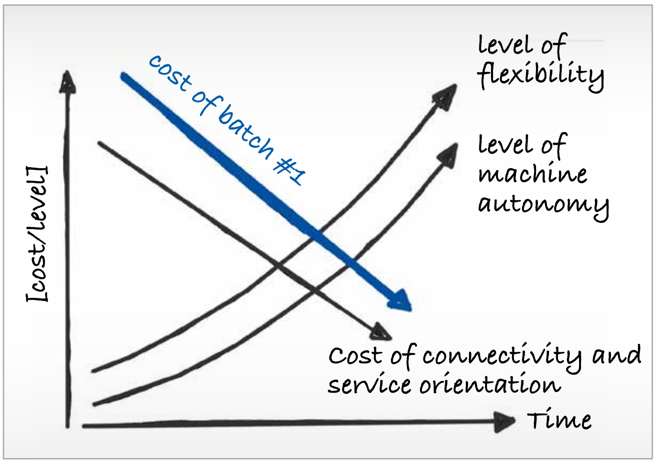

Figure 4: The digital transformation makes batch size 1 cost-efficient.

to follow within a short time as a result. Therefore, as claimed by Industrie 4.0 an order based production and true mass customization become viable production scenarios – not just at trade fair shows. With this trend in mind, new requirements become the decisive success factors for machines besides the excellence of process control.

Core requirements: connectivity and service orientation

The prerequisite for a batch size 1 or at least very flexible future production process is of course the full physical control over the production process itself. In the case of a successful machine builder this is most likely already given. But then, from a customer perspective, the focus to differentiate the machine performance moves on to new core requirements more focused on connectivity and service orientation like those listed in [6], p. 3:

- Autonomy, re-configurability and agility (Plug-and-work)
- Cross-linking/networking and local and global networks
- Interoperability in between diverse control systems and different cloud solutions
- Dynamically changeable runtime dependencies
- Management of diverse PLCs
- Introduction of the service paradigm in the production automation (production service)

The necessity for the machine to be part of a strong IT backbone – let's call it "cloud" for the moment – can be taken for granted. The machine itself becomes only one building block with standardized interfaces most likely being technologically implemented with protocols like OPC UA/TSN. Therefore, the value of this building block is not only defined through its functionality and maintainability but also by its adaptability and exchangeability. A rising level of system security, machine safety and a high level of usability despite of complex technology are also closely accompanying these core requirements.

Organizational footprint and new boundary conditions

The switched priorities impose new boundary conditions on machine builders and system integrators:
Software driven innovations and not hardware are the key to future success:

- The above mentioned core requirements cannot be solved with hardware alone. The solutions will be mostly implemented in software. Software will be the major enabler for reaching a higher level of machine flexibility, a higher degree of automation, better usability and a higher level of optimization and productivity. Once the shift from hardware to software is made the companies will focus even stronger on the machine software to define their market position and to differentiate from the competitors. Software has a self-accelerating effect on product life-cycles and innovation speed.
- Also McKinsey found that of the value opportunities created by the IIoT which are available to technology suppliers, the largest share will generally most

likely go to services and software and not to hardware. [34], p. 6

- Therefore, the ability to specify, design, implement, ship and maintain large software and IT systems is crucial for the machine builders in a digital transformed market. The traditional machine control application which is nowadays called “software” by machine builders will only be a tiny part of future systems.

You need to know what you already know:
In order to make machines and systems more flexible by being able to make smart decisions autonomously, they need a continuous flow of data and information. Even today, companies have a lot of data already but they don’t generate information from it – or they keep it in separate systems so that it’s impossible to derive decisions for the next control or management level out of it. Therefore, the IT (information technology) and OT (operation technology) need to grow together. This trend is already going on. [12] „Gartner predicts that by 2020, 50 percent of OT service providers will create key partnerships with IT-centric providers for IIoT offerings. “

- Information streams are going to be connected but are often separate today
- Organizations are going to be dynamically connected, which are nowadays only loosely coupled with tight and relatively static interfaces
- IT (management data on company level) and OT (software solutions on production and shop floor level) need to grow together
- It is going to be cost efficient to measure production parameters in real time, which was almost impossible to measure not long ago

Key hypothesis:

- Increase availability and uptime as well as productivity with an end-to-end data backbone which is capable of detecting current bottlenecks and can help to avoid future bottlenecks with simulation and intelligent data analysis
- Continuous KPI tracking and performance measurement is becoming a must

Handling the high technological complexity with strong partnerships:

- Software driven innovations and an all embracing dataflow in combination with flexible machining concepts increase the level of system complexity dramatically. Therefore, strong partnerships will be as important as a high competence level in software engineering and IT. These partners need to deliver entire subsystems for example consisting of entire automation concepts from sensors (e.g. cameras, process sensors like pressure, level or temperature sensors, position sensors like encoders and photoelectric distance sensors) and actuators (e.g. electrical motors [AC, DC, servo], pneumatic valve islands, hydraulic valves) including cloud connectivity solutions.

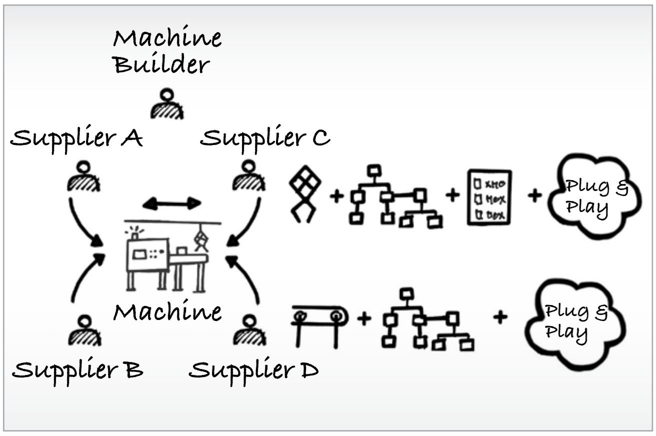

Figure 6: Strong partnerships will be an essential part of future success. The system partners will provide complete plug and playable subsystems. Nowadays machine building companies often act as system integrators with their own deep technical knowledge. In the future, this competency will be necessary and cost efficient only in very specific fields. Even cloud services as market places will be shared among partners.

- Partnerships are certainly not only restricted to the technical level. They will also involve the business level for example a shared cloud service as ecosystem for commercial

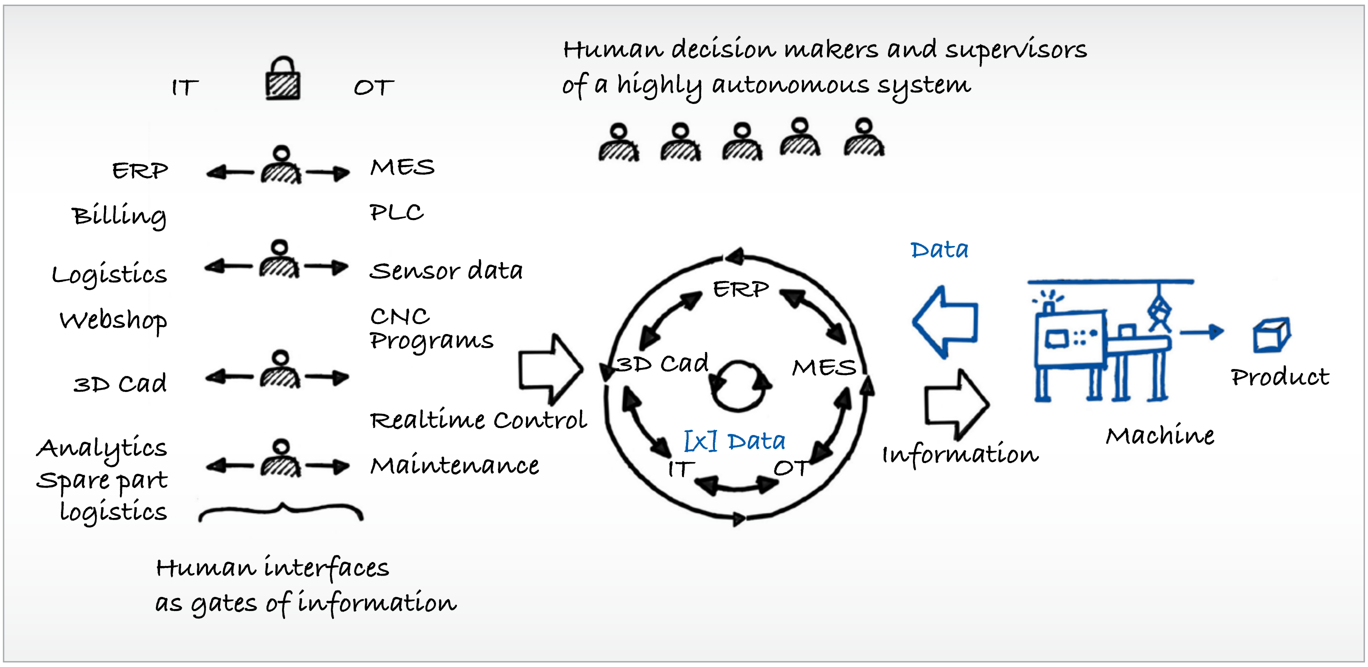

Figure 5: IT and OT need to grow together. The role of human gate keepers as information bottle necks need to be switched to supervisors of an automated information and decision stream from end-to-end data streams. A bidirectional flow of information and data including the product must be enabled.

software machine applications and further software data services in combination with hardware modules. All embracing cross domain interface standards comparable to HTTP/HTTPS in the IT world will become the technological foundation and business enabler. Due to the nature of generating and multiplying value by connecting different domains and technologies nobody can handle the digital transformation on their own.

Technological footprint

Accessibility of data and information as ultimate success factors: Cloud & IIoT

As we learned in the previous chapters: The ability of IIoT devices and systems to work together is critical for realizing the full value of IIoT applications; without interoperability, at least 40 percent of potential benefits cannot be realized. [34], p. 11. IIoT brings the connectivity, the cloud is predestined for data management of unlimited size and is the source of scalable and almost unlimited computing power for data analytics and continuous automated KPI computation. The ability to gather, store and handle huge amounts of structured and unstructured data is therefore somehow the origin of the digital transformation.

In the first instance it's tempting to set up one's own cloud solution and trying to establish the cloud platform alone. Unfortunately, at least another 450 companies already had that same idea [18]. It is hard to say how many platforms will survive but it is sure for industrial purposes – not many. The question which derives from that is: "Are you really willing to fight for your own platform or is it may be smarter to hitchhike on different cloud platform solutions providing the highest possible connectivity?" A rule of thumb can probably be: "The bigger your customers are, the bigger the cloud solution they will need" (or in other words the bigger the company they will expect behind the cloud solution). As soon as they choose one platform they will probably force all suppliers to connect to that very same solution.

A cloud platform is not just a huge data storage or software service platform but most often it is the interface to a whole market place like the Siemens Mindsphere, GE Predix or the latest announcement in the German machine building industry Adamos to name only a few. But currently it is still not clear if the market place approach in such a diverse field like industrial automation will be successful at all. There is a high risk that only customer specific solutions and not the general market place offerings will still be the major request. In the past machine builders often preferred proprietary software solutions because they thought this helps them to differentiate from their competitors. To cut it short: the race is still open and one should not commit oneself too early or too closely to one specific platform or business ecosystem. Besides the question if an own cloud platform needs to be set up it needs to be clarified how a cloud solution will alter the system architecture. A traditional machine centric data management perspective will be changed and opened up to a cloud centric data management perspective. The machine itself becomes a so called edge device [19]. The typical PLC mounted on a machine and commissioned with a static and specific software version will be replaced step-by-step by cloud services. This has an enormous potential with respect to scalability, updateability and maintainability by reducing the dependency on locally installed software/firmware. Computationally intensive calculations will be covered by a hyper scalable cloud. See Figure 7 how the different levels could potentially be defined.

Class	Service ability	Control locality
0	No service	All control programs are capsuled locally in the hardware system
1	Service only for non-critical and general functionalities	Some control programs, which include non-critical and general functionalities, are not located in the local hardware, but are spread over other systems (e.g. on the net)
2	Service for most functions available	Most control programs are spread on the net. Only time and safety critical control programs remain on the local hardware
3	All control programs as service	All control programs are spread on the net. Third entities can have access to all control algorithms in real time and also change them.

Figure 7: [6], p. 5 Evolution of a PLC in the cloud.

Tests with different architectures of cloud-based PLCs in a state of the art network showed that [6], p. 13 currently technical processes with timing requirements above 150ms can be successfully controlled via a cloud based PLC solution. This is of course, still far away from today's hard real-time requirements on the servo drive level where the timing is in the range of micro seconds.

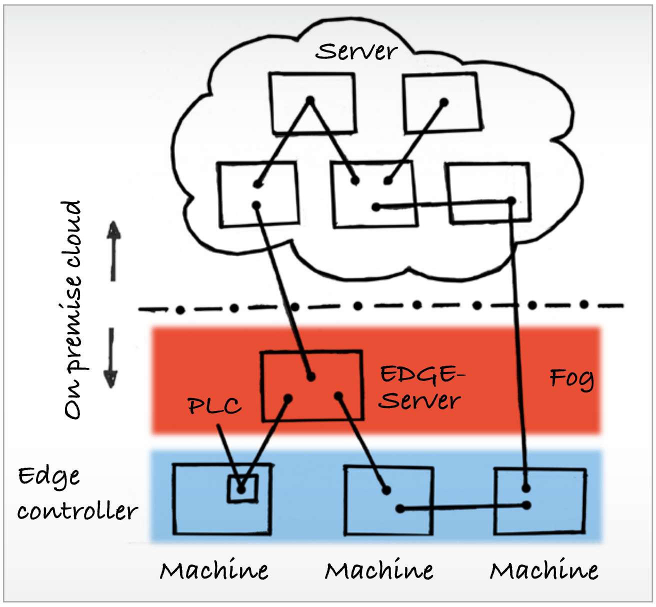

Figure 8: Possible architecture of a hybrid cloud and edge based production system. We need to expect a heterogenous level diverse mix of system control elements. Partially still directly on the machine, partially with servers in the shop floor intranet and partially with direct manipulation out of the cloud.

Close to the vision shown in Figure 8 there might be a new term emerging: the so called automation pillar [22], which could be a promising evolution of the automation pyramid (see Figure 9) even if this scenario does not yet include PLCs in the global cloud.

To get back to the performance issues of non locally executed control tasks – don't be deceived. The advantage in terms of flexibility of shifting as much functionality into the cloud

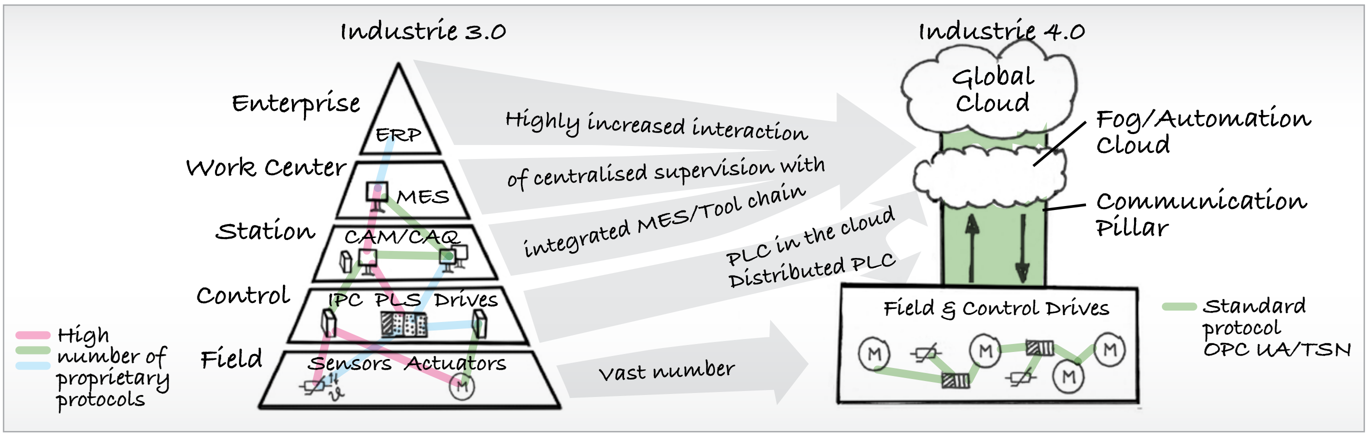

Figure 9: Potential future scenario for today's automation pyramid. Heterogeneous communication between the different system levels is replaced by standard communication that facilitates continuous, uniform connectivity. Based on: http://www.belden.com/blog/industrialethernet/what-is-tsn-a-look-at-its-role-in-future-ethernet-networks.cfm

as possible is tremendous. So, in the end the well known traditional system structure from bottom to top of Sensor/ Actuator Level, PLC Level, MES Level and ERP Level or also called "Automation Pyramid" will be dissolved. Currently it looks like it will be split up into an edge, fog and cloud layer. See [40] for the discussion of difference of the terms edge and fog. The machine builder's challenge will be finding a suitable system architecture that is able to be transformed from the today's possibilities to future technologies according to the progress the cloud based PLC approach is going to make. Possible steps could be like those shown in Figure 10 according to [6]. The four steps describe what kind of responsibility is gradually shifted in the cloud. The three major tasks a PLC needs to execute are defined as follows:

- CP basic: basic tasks to organize and run the logic control of the machine
- CP supervisory: software modules that are responsible for high level system management and user interface functionality
- CP critical: these modules are responsible for the critical real-time and safety tasks

The current standard is 100% local control which is responsible for everything from CP basic to CP supervisory and CP critical (Figure 10 a). A first step is to shift supervisory tasks into the cloud and to run only basic and critical tasks locally (Figure 10 b). The same kind of architecture can already be found in automation architectures that rely heavily on SCADA systems. If the server of the SCADA system is located on the premises it can be called "edge server". The local network of the edge server itself can then be called fog. Therefore, already today a SCADA system can run in the fog or in the cloud. The next step of shifting even more responsibility away from the local machine controller also involves all the basic machine logic (Figure 10 c). Only the execution of the critical tasks remains local. The last step in the evolution towards a cloud based control then finally even includes the critical tasks (Figure 10 d). The local functionality of the machine controller is then reduced to an IP-Connector.

Securing digital value: cybersecurity

Not a day goes by without the proclamation that security issues are the real blocker on the way to IIoT and Industrie 4.0. The usual story line includes then various shocking examples with the conclusion, that there is currently no way to be 100% secure even if the complete chain of trust is considered. And of course there is a real threat [37].

This story line helps companies selling security technology but does not help the machine builders or OEMs with making good decisions. So how to deal with this unquestionably hot topic? Initially it will be necessary to evaluate the potential risk not only in a way "what might happen" but also:

- How often will it happen? How disastrous can it become?
- Data corruption [Stuxnet, source https://en.m.wikipedia.org/wiki/Stuxnet], loss of data, loss of production, machine damage, threat of human lives, image loss, ...)

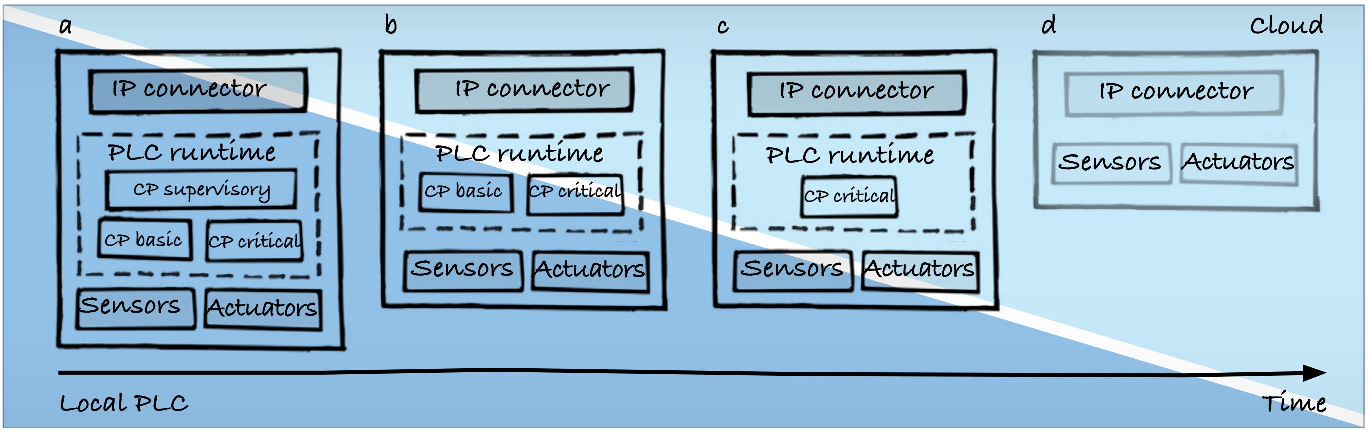

Figure 10: Evolution of a PLC in the context of a cloud based service provider [6], p. 3-4.

- What will it then cost?
- How much time will it take to recover and to be operational again?
- How much and in which way will it affect my customers?

Derived from that list a balanced budget can be estimated to secure the digital values that might be destroyed. The options for actions might then be:
- No connection to any network (it seems to be a naive solution but e.g. in case of securing critical master keys for the certificate generation even this might be a realistic option)
- Encryption of dynamic data streams with SSL, VPN
- Encryption of this static persistent data
- Encryption and protection of executable programs
- Protection of real physical entry points and protection of physical locations
- Protection of human entry points to the system (threats like social engineering, security awareness: email attachments, USB sticks...)

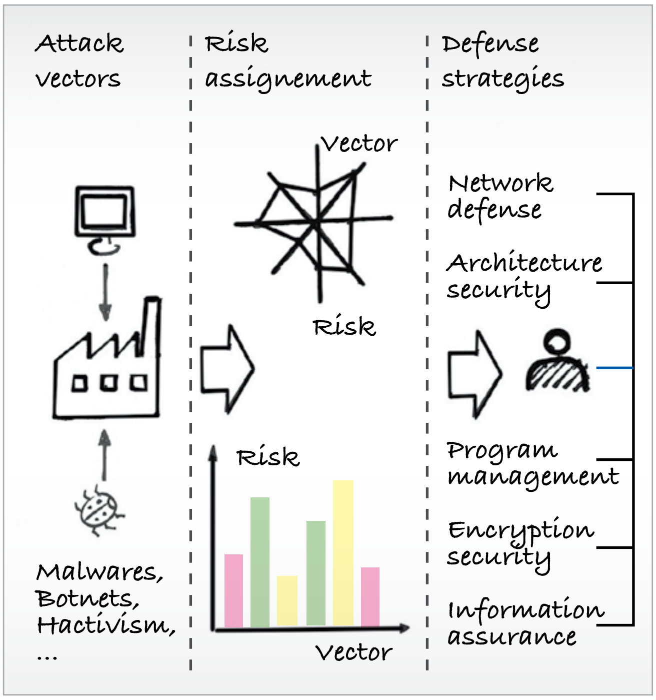

Figure 11: Security Factor matrix.

- Structural protection strategies like the partitioning of systems and subsystems with defined boundaries and firewalls. So that in case of an attack the damage cannot be epidemic. First line firewalls that secure companies as a whole are not sufficient anymore.
- Continuous anomaly detection of network traffic and data streams with deep package inspection engines (DPI) allow even protection against Zero Day Exploits, anomaly detection of login patterns and user behavior like sys-admin logins and data transfers, outside usual office hours to name some of the possibilities. Zero Day Exploits are attacks using unknown security vulnerabilities.
- The frequent simulation of attack scenarios in order to harden the system and to train the users, e.g. with a penetration test and vulnerability test platform like Achilles [25]

This list is certainly not complete and there is a complete industry for highly sophisticated defense strategies. To get a more complete picture see for example industrial standards like IEC 62443 [26] or see e.g. [36] as a full example of how to make a risk analysis and how to secure industrial assets which was conducted by the research project pICASSO. But in the end even cybersecurity is not a purely technical issue. The real challenge is to find an economically sensible security strategy that helps to secure values for an exactly defined risk level within a specific production scenario, executed by security sensitive and well-trained staff.

Creating faster value: model based development and digital twins

The life cycle of a digitally transformed production system starts with the engineering process. And if the cost efficient batch size 1 is the dream of any production technology experts so are digital twins for engineers. Maybe this is the reason why digital twins are so often named in one sentence with Industrie 4.0. The key issue of a digital twin is to be able to design, simulate, test and commission a machine or even a whole production system in a pure virtual environment as a pure virtual machine upfront and without any real world impediments. Even later in the product life cycle the goal is the simulation of a product update or a maintenance scenario upfront before the real system change.

The “killer-features” of a digital twin are mostly named as a great reduction in engineering time and a better optimized system right from the start with a significant reduction of cost and risk. The dream of a complete simulation is tightly connected with a complete data model and an unconstrained data flow; also a data model of every engineering tool of every engineering domain in the toolchain over the whole product lifecycle. This prerequisite is necessary for this engineering vision to become cost efficient. Today still too much manual modeling work is done multiple times. Often even the same aspect of the machine with different simulation tools. This causes the engineering process with digital twins being too time consuming and costly.

This modelling effort can only be justified for domains with an extremely high risk of damage in case of failure (avionic, military). Here, model driven engineering with a thorough simulation is not an option, it is a must. This is also true for domains with extreme short product life cycles, where time is the most precious resource. This pays off even with higher engineering costs due to a model driven product development process with digital twins and not optimal tool chains.

Outside these very specific industries there are only a few premium machine builders or system integrators that invest in relatively high level of digital twins. These companies manage to modularize their production systems in standardized building blocks, which can then be flexibly composed in the real physical world but also in the simulation as digital twin upfront.

It is very easy to claim a perfect toolchain. But in reality it is already very hard to connect at least one or two different engineering tools in a way that no data is lost in the engineering process. Up to now this connection is highly specific. The existing data exchange standards are by far not sufficient. The current level of the machine building industry is using a 3D-CAD design tool with simulation capabilities for physical stress. Add-ons for e.g. the entire 3D-electrical installation, wiring and tubing and additionally electrical CAD systems for the PLC programming are completing the toolchain. Sometimes extra simulation tools for some additional specific simulation tasks like controller settings or the sizing of gears, to name only a few, are also used. Usually none of these tools can exchange data in a meaningful and automated way out of the box to serve a complete toolchain for a digital twin. A lot of manual preparation of the datasets of the digital models needs to be done. And even then, it is mostly a one way data transfer with no way back. It is obvious: this does not fit the mission of a fast-paced, highly iterative development process of complex production systems of the Industrie 4.0 era.

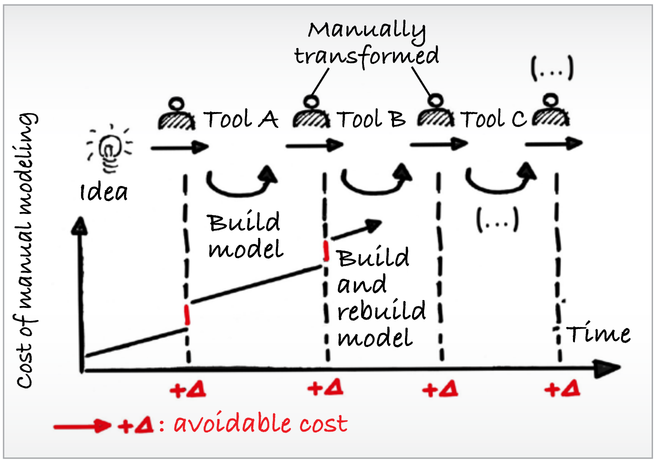

Figure 12: Avoidable modeling costs because of insufficient interfaces in between different engineering tools.

But there are advancements to overcome these long known data barriers:
On the system top level within the scope of the IIoT and Industrie 4.0 there are so called reference architectures evolving, check e.g. [1] for an overview and discussion. The practical application of the reference frameworks is still very limited since they are not defining specific data formats. They are focusing more on the basic structures of modern systems and modern machines. But these reference architectures are the foundation and serve as guidelines for other upcoming modeling standards and data formats.

On the level of engineering standard data formats there is a slightly accelerating trend towards all embracing top level standards like PROstep iViP, AutomationML or eCl@ss for attributes. This trend is certainly pushed by the discussion of the reference architectures. The common risk of all these standards is becoming too big and complex to be applicable. In the end they are not attractive enough to be fully supported and distributed by the engineering tool companies. This can be clearly seen e.g. by the STEP CAD exchange format. Although most of all the 3D CAD programs do support this standard, the model exchange with STEP always comes along with a tremendous loss of information of the 3D model. AutomationML tries to solve this issue by providing a structure (standardized by the IEC62714) as backbone and is furthermore incorporating already established standards like CAEX, Collada or the PLCopen [27] and is open for the integrating of further standards. But the use of AutomationML and the underlying standards is also still quite limited. Either they cannot represent the versions of the original modeling and design tools at all or like in the PLCopen the modeling level is so basic that it is simply too time consuming to work with this standard. However, the interest especially of the automotive industry to push the overall standards is high and it is worth keeping an eye on this trend.

Due to the lack of standardization the greatest advancements happen on the proprietary level of the engineering tools. Engineering tool providers try to enlarge the scope of their specific tools and step by step try to cover more of the engineering process. Although not based on any open standard this is nowadays in a lot of cases still the best way to handle engineering data. The drawback is a strong vendor lock in, that needs to be accepted in order to achieve an integrated data model. This means that cross tool data transfer between vendors is possible, but in almost all cases a loss of data needs to be considered. Therefore, even this possibility is strongly limited in practical application.

In the end the world of engineering is too varied to propose "the best" strategy. Possible steps to get over the data and model gaps could be as follows:
- Identification where in the current toolchain the biggest data/information loss occurs
- Identification of the biggest potential in closing a data gap in the toolchain
- Cost estimation and implementation
- Step by step bridging the data islands and closing of the gaps (see Figure 13)

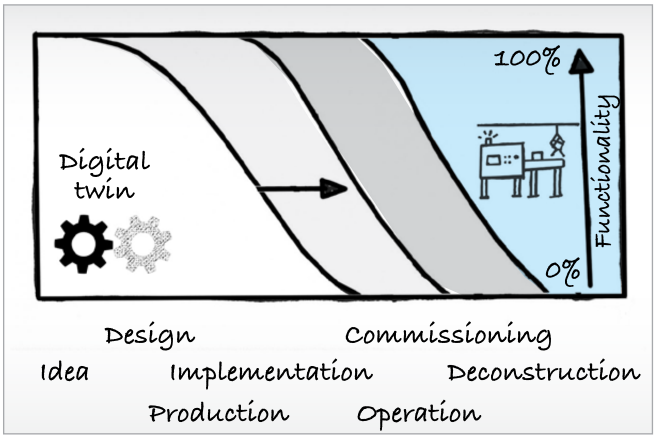

Figure 13: By closing the gaps step by step in between the engineering tools and therefore pushing the scope of a digital prototype further one can steadily increase the benefit of a digital model.

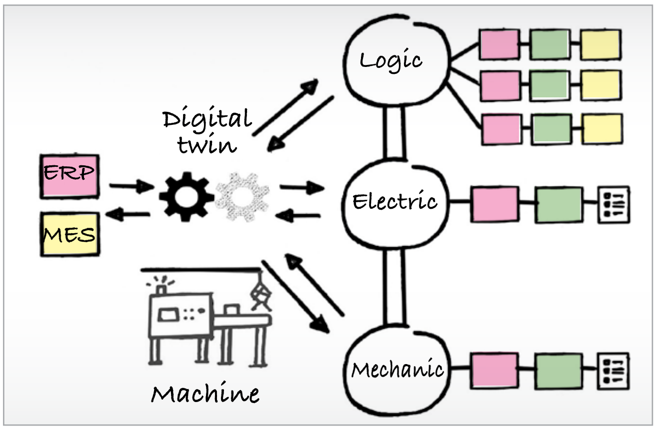

Figure 14: Different attributes of a digital prototype.

With this strategy the scope of the separate data models can be grown to get closer to the vision of a digital twin of the entire machine or production system. By using this approach, one needs to decide which of the two possible connection strategies fits the specific situation better (Figure 15):
- Peer-to-peer connections between as much tools as possible (network) or

- The definition of lead data format and adaption mapping of all the other formats to this (star topology)

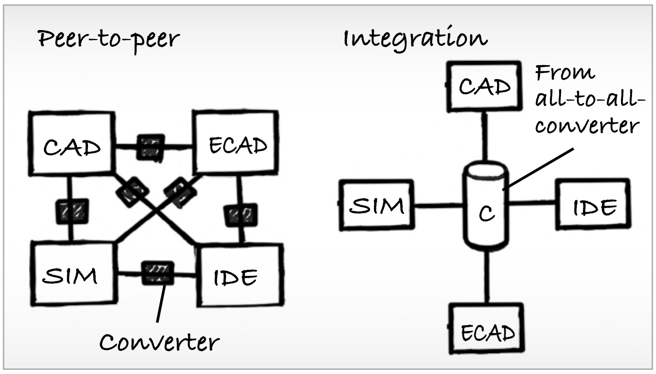

Figure 15: Different implementation strategies – peer-to-peer or one master exchange format/interface.

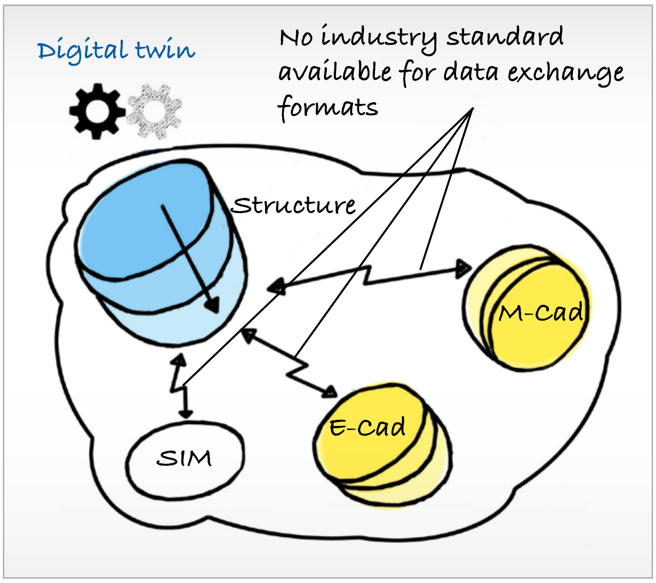

Figure 16: A promising strategy is to grow the scope of a digital prototype step by step. A key issue are the interfaces in between the different tools. If they do not reach a certain level of stability the whole scenario will never become cost efficient.

The first approach will probably lead to faster results since it is a lot easier to establish peer-to-peer connections. But if the number of tools which need to relate to each other is increasing the number of connections increase even faster. Therefore, it scales very badly. The other approach has the opposite challenge. Finding a common exchange format for all tools is very tough but once it is established it is comparatively easy to add new tools to the toolchain.

Agility as mission – connectivity as means: Plug & Produce

Use case 1: the resilient factory (source: Festo)
Resilience means durability, but also agility, adaptivity, redundancy, decentralization and the ability to learn. A resilient factory can produce a broad product spectrum with customer specific features and at the same time accommodate a high degree of seasonal fluctuation. Through the demand driven adaptation of the production lines, just in time production and, at the same time, optimal capacity utilization can be achieved.

Figure 17: The resilient factory is one of the strongest motivations for a Plug & Produce Scenario.

After discussing some core aspects of the digital transformation let's get back to the initial batch size 1 production scenario and the use case of a resilient factory (Figure 17) as a major motivation to increased machine flexibility. Topics like machine learning, cloud services and a fully digital engineering with digital twins help to get faster to smarter machines but the biggest decrease of engineering time and highest increase of agility will come through modularization and standardization of interfaces and the dynamic reuse of complete machine modules. This trend is inevitable since the faster machine builders with appropriate partners (Figure 6) will beat the slower ones.

The most important pre-requisite is that entire machine modules need to become plug and playable. Or in terms of a production line the core requirement is to reconfigure machine modules and to start production right after the change again: Plug & Produce is the definite goal. The consequence for the machine builder is to rethink interface concepts. Any proprietary concepts that require internal information of a specific machine module that is hidden and therefore not published over the interface will fail. The interfacing machine components will not be able to adapt dynamically. It is necessary that interfaces are not only defined via their data model but are also semantically defined. This makes upcoming standards like OPC UA so promising, which also provide semantic information and not only datatypes.

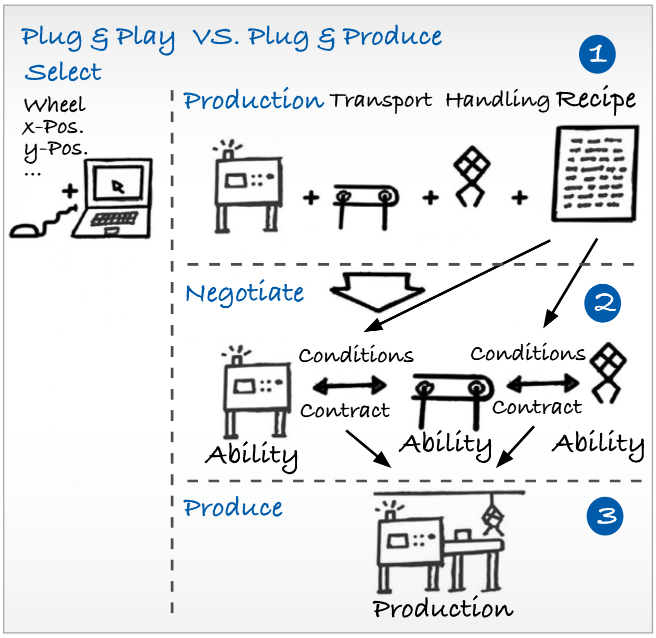

Figure 18: A boost in flexibility will happen as soon as part of a production system are able to manage Plug & Produce behavior.

To be able to manage a Plug & Produce scenario three steps are necessary:

- Step 1: the selection of the appropriate machine components of the production process in combination with the production recipe
- Step 2: contract definition in between the specified components of the production system where the abilities of the physical systems with respect to the conditions based on the recipe are negotiated
- Step 3: produce according to the negotiated contracts

Learn faster – machine learning and analytics

On the one hand it is unquestionable that artificial intelligence is currently one of the hottest topics of the IT world [41]. And with digitally transformed production systems we can easily and cost-efficiently gather a lot of data. The key is: data has only a very limited value by itself, it needs to be processed and transformed into actionable knowledge to unfold the potential. With this in mind, it is obvious that continuous data analytics and later artificial intelligent autonomous machines can enhance the production process and can make smart decisions in exceptional situations faster. The data driven approach can outperform any experienced human operator and autonomous machines will reach superhuman decision quality. Currently the most attractive business cases for the use of machine learning and data analytics are probably predictive maintenance and the continuous process optimization as a service.

One might think now that the question is what this technology can deliver today and what is still a matter of research. This might be true for the domain of the so called common artificial intelligence, which stands for an intelligence level comparable to human intelligence. But large parts of the domain of the mathematics of statistical learning have a solid theoretical foundation and are already well understood, like it is described in [14]. Other fancier parts like neural networks are still in rapid development and evolve almost every month to the next level. Huge breakthroughs like the success of the artificial intelligence Alpha GO zero [24] over human masters in the game Go show the fascinating fast advancements. This AI-Bot is now even able to achieve superhuman capabilities without the need of human pre-trained knowledge. But to keep it realistic, the application of statistical learning for machines is not a matter of the training capability of the latest neural network. It's a matter of the application and combination of quite well understood mathematical procedures like supporting vector machines or regression models just to name two out of many possible algorithms. The integration/organization of the engineering domain of statistical learning or machine learning respectively into the traditional engineering domains like mechanical and electrical engineering becomes by far the bigger hurdle, see [13] and Figure 19 to Figure 22.

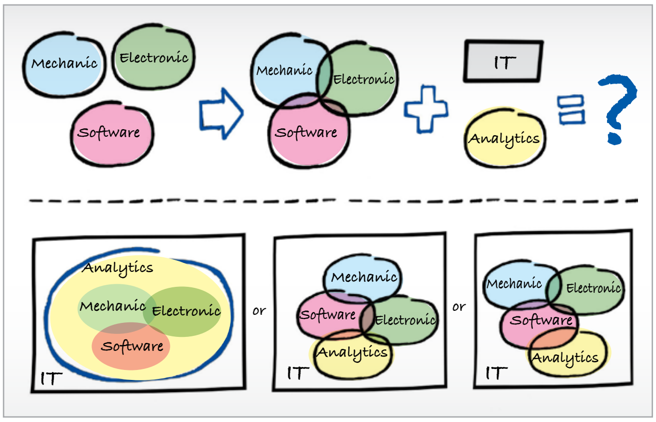

Figure 19: Mechatronic engineering as a collaborated engineering discipline is already very challenging. The integration of IT and analytics as new disciplines adds additional organizational complexity.

If you look for standards in the data mining process, see the currently most accepted standard workflow of analytics projects which is called CRISP-DM [21]. As in software projects the standard workflow of a machine learning/analytics project is highly iterative and proceeds in small iterations. The major steps to be carried through in a reoccurring way are shown in Figure 22. But be aware that data mining and analytics projects are not equal to software projects.

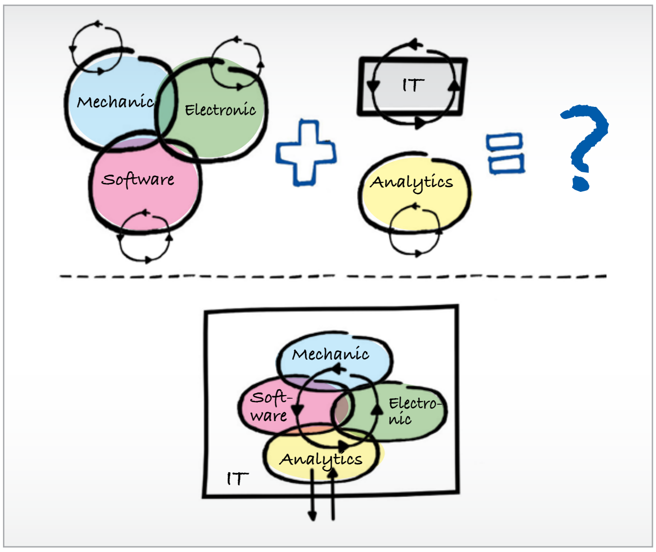

Figure 20: The work rhythm with milestones and a different planning strategy for the physical oriented engineering disciplines is conflicting with the very short iteration cycles of the IT and analytics world.

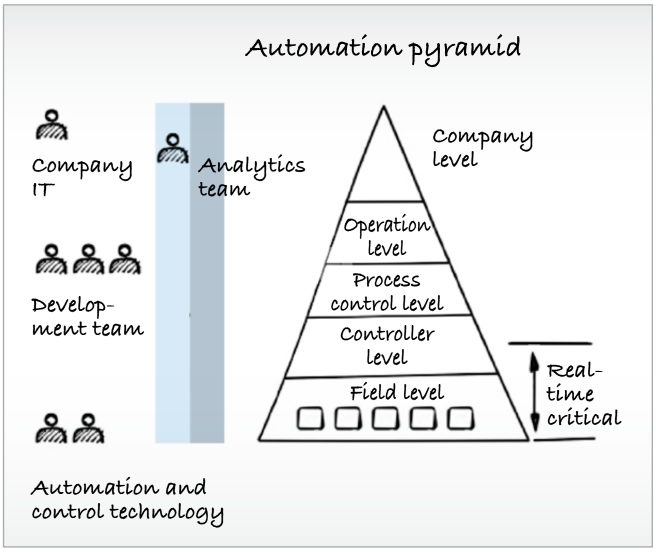

Figure 21: A successful analytics team that is behind a successful data driven product is cross linked all over the company and is not only an additional development team under the lead of the software development management.

These two domains are tightly connected but should not be mixed since they require a completely different education and face different challenges in the daily work.

Although data analysts are also programming, the focus of their work is not generating an overall software system. Their focus is the application of specific statistical algorithms and feeding back the results to an overall software system. This is a completely different perspective which requires different skills and workflows. Therefore, entering the domain of machine learning is like starting something completely new. It is not an additional subdiscipline of an existing domain. Therefore, it's only consequent to treat it from an organizational point of view as something completely new. You should not just try to add some additional engineers to your existing engineering department. Build up a new team and run it like a startup. The lean startup community has a rich set of tools and methods that can guide you through the first steps, see e.g. [15] as an initial starting point.

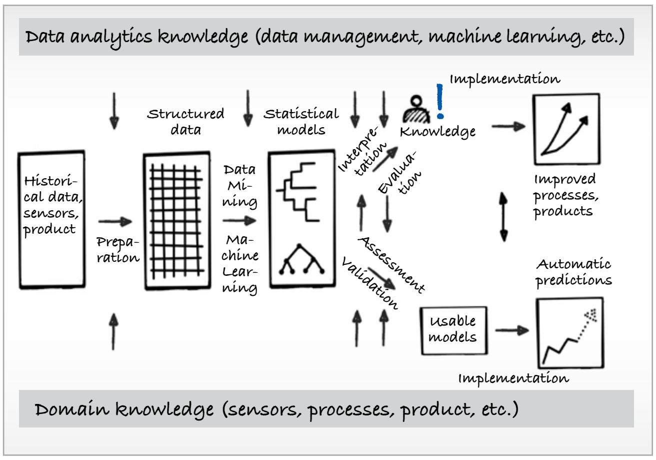

Figure 22: Standard workflow of a machine learning/analytics project.

Important: The foundation of any form of machine learning and data analytics is data. Therefore it is not a domain that can live on its own. It needs a data driven mindset and a cross-domain thinking within the company to generate value. This is very different to the traditional engineering domains of a machine builder the create value even if they work in separated silos. If this organizational challenge is underestimated data analytics projects will stay as marketing and management toys but will not become real contributions or even the core of solid future business models.

"Soft"-Blockers in the way of digital transformation

The digital transformation is clearly more than just a fast and continuously ongoing technological evolution. As explained here a major effect of the digital transformation is bridging different domains so that cross-domain innovations occur more easily. But in order to make this happen it also includes breaking down internal company barriers. It will be essential to create a seamless organization without the traditional silos for R&D, production, IT, administration, the sales organization and so on.

The hypothesis is that the technological competence will not be the critical enabling factor. It is the organizational competence of the companies that will make the difference!

First of all it will be the ability to optimize and exploit successful products in the current product pipeline and in parallel running an innovation process that explores the future core business. These are two completely different perspectives with different management strategies: reward systems for the employees, and preconditions for planning and risk management. The faster the company wants to proceed in the direction of Industrie 4.0 or the digital transformation the more it needs to shift the focus to the right side of Figure 23. Otherwise the risk of killing new ideas before they even get the chance to take off is extremely high, see for example [28] or [11], p. 7 "Modern technologies enable the build-up of a very broad data basis, but the optimal use of the whole potential this data offers depends just as much on the right organizational structure and company culture."

This is tightly connected with the invention of new business models. Traditional ways to calculate the return on investment will not fulfill the requirement for machine builder to make a financial risk assessment for digital transformed products. Selling and scaling hardware needs different calculation methods and financing methods in building up a cloud solution and or service based business model relying on predictive analytics.

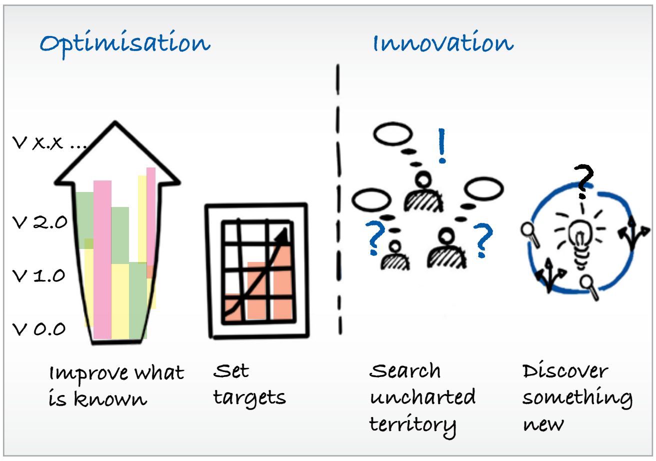

Figure 23: The capability to optimize and the capability to innovate is important but both worlds function in a different way and need to be treated differently [16].

The tricky question is: How to develop a strategy without having the usual deep insights and long-lasting experience. As an established company it is of course difficult to operate like a startup in an environment that is streamlined to optimize for success with well known boundaries. But the message is: "Uber yourself before you get Kodaked" [30].

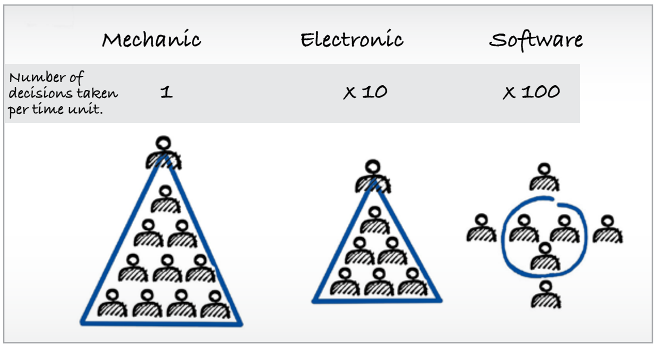

Figure 24: Hypothesis: Digitally transformed organizations operate in a different way than hardware or electronically oriented top-down organized development and execution teams [16].

Besides the balance of existing products (in combination with new and maybe even radical innovation and changes on the product and organizational level), the increased complexity of digital transformed production systems is an organizational challenge on its own. For example, software lifecycles are generally much faster than hardware lifecycles. This changes everything in a product pipeline with innovation of processes, development, production and maintenance. Hierarchical top down organizations that may work well in a slower hardware driven world will easily suffer from serious information and decision bottlenecks when making software driven innovations, see Figure 25. Small team sizes, optimized for personal responsibility and team self-reflection with well informed and well trained team members are the better answer for software development.

If a company is already aware of this, the next critical question needs to be solved: How can we find suitable developers for a product that is so difficult to define and for which I probably even do not know the best technologies to use in advance? Here again acting like a startup is the most promising strategy. See [15] as entry point for further information. To make things even a little bit more complicated: If then the new technology experts are on board, how do I manage them on a personal level? Brain workers like soft engineers, IT experts and data analysts need different management, control and motivation concepts. As their working progress is often hard to quantify in general and often costly in terms of time and heavy controlling processes, indirect and value based management concepts gain importance. So last but not least is the discussion about Conway's Law for example in [39] that claims: „Any organization that designs a system (defined more broadly here than just information systems) will inevitably produce a design whose structure is a copy of the organization's communication structure." It shows the tremendous importance of the organizational structure and is saying that a scalable modular system without taking the organizational consequences will not work. With the wrong organization one will always end up with a hard to maintain system monolith sooner or later.

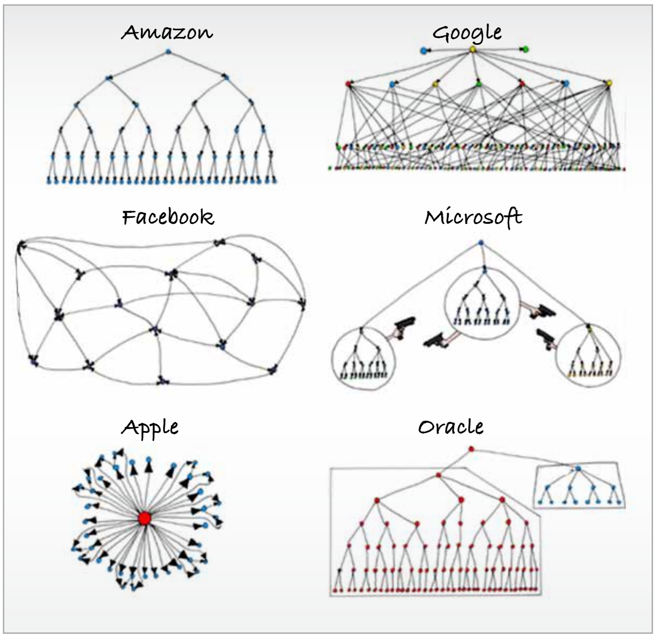

Figure 25: Organizational structures have a high impact on the products and systems the can create; picture source: http://bonkersworld.net/organizational-charts; M. Cornet.

It can be seen also in this context, that traditional workflows that separate the engineering domains will fall short and will only produce traditional products. As we know is already a collaborative mechatronic development process not easy to set up and to manage. With the essential integration of fields like IT and analytics under the new lead domain of software development, a radical change in the mindsets of the engineers will occur, see Figure 26.

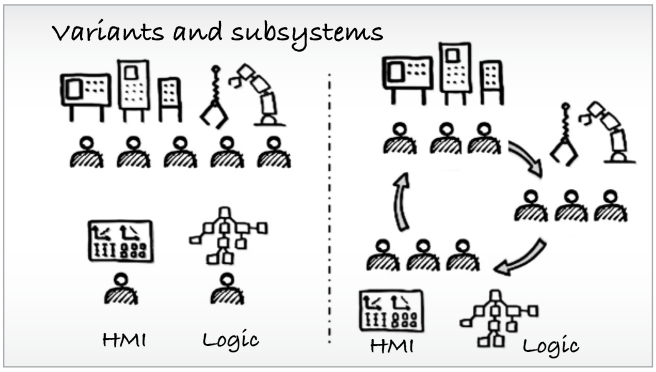

Figure 26: Cross-domain and team-based development processes are necessary. Development processes that separate people into specific „silos" are not efficient enough anymore.

Collaborative and agile development processes already known from the software development will increasingly replace traditional engineering models like the V-model [29].

Risk assessment for the digital transformation

Digital transformation is no easy topic for decision makers. On one hand there are huge potentials but on the other hand high risk with new and uncertain business models, high technical innovation speed in a market with traditional lifecycles longer than 10 years and on top the fear that faster competitors are probably already working on their chance to disrupt the market.

A pragmatic way to handle that risk is to calculate the expected opportunity loss and the expected value of information for an appropriate risk reduction. Making decisions under uncertainty is a research topic in itself but D. W. Hubbard nailed it down in his book "How to measure anything" [42] to an applicable decision making process under harsh management conditions.

According to Hubbard the terms uncertainty and risk are defined as follows:

- **Uncertainty:** The lack of complete certainty, that is, the existence of more than one possibility. The "true" outcome/state/result/value is not known.
- **Measurement of Uncertainty:** A set of probabilities assigned to a set of possibilities. For example: "There is a 60% chance this market will more than double in five years, a 30% chance it will grow at a slower rate, and a 10% chance the market will shrink in the same period."
- **Risk:** A state of uncertainty where some of the possibilities involve a loss, catastrophe, or other undesirable outcome.
- **Measurement of Risk:** A set of possibilities each with quantified probabilities and quantified losses. For example: "We believe there is a 40% chance the proposed business model will fail with a loss of 12 million Euro in platform and product development costs."

As we see the estimation or measuring of risk involves assigning probabilities. The Opportunity Loss (OL) for a particular alternative is just the cost if we choose that path and it turns out to be wrong. The expected opportunity loss is then the probability of being wrong multiplied by the cost of being wrong. To make a very simple example: suppose you can make additional 40 million Euro profit with a new digitally transformed product or functionality if the business model works, and you lose 5 million Euro (development, initial production, marketing campaign, ...) if it fails. And let's say your chance of failure is according to current state of information 40%:

- Opportunity loss if expenses for the development are approved: 5 M Euro (cost of the 1st series)
- Opportunity loss if development is rejected: 40 M Euro (gain foregone)
- Expected opportunity loss if approved: 5 M Euro × 40% = 2 M Euro
- Expected opportunity loss if rejected: 40 M Euro × 60% = 24 M Euro

Probably a chance of just 60% is still too low to decide for the investment. So how much can be spent to reduce the risk any further? This can be calculated by the expected value of information called EVI. It is the value of information which in this case is equal to the value of the reduction in risk. The value of perfect information (EVPI) would be the information that eliminates the risk to zero. In our example the value for consulting work that completely takes out the risk is simply worth 2 million Euro. In reality it is almost impossible to achieve that level of risk reduction. A good rule of thumb is therefore spending 2-10% of the EVPI. In this simple example it is still a good decision to invest 40-200 thousand Euro in any kind of action that leads to better information and lower risk such as prototyping, consulting, market analysis, usability and acceptance studies. This was just a very brief introduction in a very pragmatic and applicable way to come to better decisions under situations with high uncertainty. If you want to deep dive into the topic the mentioned book [42] is recommended as starting point.

Conclusion and take aways

Are you fit for the digital transformation? Test yourself and your organization if any blockers are on your way:

- Start questioning what might destroy your current business model in the future even if it looks like that it is a different market (remind the Uber-effect)
- Train and value your team – your people are more mission critical than any other success factors
- Watch out for evolving standards and platforms and adapt to them before they will eat up your current niche
- Start a model driven engineering process and work towards a digital twin. Your customers will make this to a prerequisite very soon
- Do not try to do everything on your own. Don't waste time assembling and integrating single components. In order to reduce the overall complexity use system and solution providers as third-party partners

Take away:

- If you did not start so far: start now there is no reason to wait any longer
- If you already started speed up because the other starters might be faster
- If you are already fast get even faster – change will be exponential
- Watch out for strong partnerships – cross domain innovations are often based on cross domain partnerships
- Invest sooner than later in finding the cloud strategy that fits you best
- Don't be deceived by security issues but take them seriously
- The digital twin is hard to achieve but it is worth working on actively in your engineering toolchain
- Besides the advancements in engineering "Plug & Produce"-able machine components will sky rocket flexibility and efficiency
- Be aware that software is eating the world and machine learning (AI) is eating software
- Even more critical than technological questions will be organizational questions. The winners of tomorrow will have a company culture and information structure that allows the whole organization to learn faster and cheaper
- Increase your ability to manage risk. The digital transformation encloses a huge potential but also a high risk that needs to be managed carefully but without hesitation.
- Do not worry about wrong decisions – fail fast and cheap – otherwise you are simply too slow
- The credo of a success full agile company is: "there is no loosing – either we win or we learn" [Dave Gerhardt, 2016]

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