"Metro Map" Illustrating the Digitalisation in Industry

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Abstract. This paper presents an illustrated model to explain digitalisation in industry in a holistic, non-technological way. It reflects the dimensions of the product lifecycle and the supply chain. More specifically, it discusses the interaction between customer, product, production, and suppliers along a product's life and how digitalisation supports these interactions. Particular attention is given to the transition from type to its product instances. Especially in the case of complex products, mastering this transition plays a key role in understanding digitalisation requirements. Reclining the concept of type and instance, different element of the digital twin, as digital master and the different shadows, are classified. Developed initially to structure a course in an engineering master's program, the model has evolved to be used in different courses and currently supports consulting and applied research projects to orchestrate digitalisation initiatives in the industry.

Keywords: Education · Digitalisation · Industry 4.0 · Holistic view · Metro map

1 Introduction

Digitalisation in industry is moving forward at a fast and continuous pace. Underlying technologies of connectivity, interoperability, Industrial Internet of Things (IIoT), could computing, artificial intelligence (AI), machine learning (ML), or mixed and virtual reality (AR/VR) are advancing rapidly. At the same time, digitalisation has also changed the way we look at our processes and organisations. To give a few examples, agility and cross-disciplinary have become important concepts in product development [1], the collaboration between customer and producer was brought to a new level [2], and the approach of the smart factory is rapidly changing our perception of processes and data [3].

The educational sector needs to follow these developments and is challenged with a high degree of complexity [4]. On top of the traditional fundamentals of engineering, today's students need to grasp the essence of digitalisation and learn to create value proposition in real-world cases. To do so, not every technology must be understood in detail in the first place. Rather, a concept of the different approaches, interfaces und and

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use cases in the context of the product lifecycle and along the product's supply chain is required. Still, it remains a huge challenge to squeeze all these aspects into a single course. Thus, we need simplification without losing context.

In analogy to a metro map, perfection is not the aim, but orientation, connection, timing, and transfer. The goal of the presented work is to illustrate the simplified complexity of digitalisation. Yet ensuring that the students understand relations, dependencies, mechanisms, and the different dimensions of business processes and applied technologies. Whatever type of engineer they become, from mechanical to software engineers, they will contribute to the digitalisation with their holistic views and considering the other specialist fields. This is the inevitable base in the present and the future of interdisciplinary engineering co-operations.

Today, industrial digitalisation plays a major role in most engineering degree programs. Interesting enough, an overreaching model to explain the different approaches of digitalisation along the products lifecycle in its context could not be identified by the authors. Instead, academic work on specific concepts, such as "Smart Factories" or didactic approaches such as gamification is well described in the context of engineering education. In addition, previous experience and work from the authors in the context of PLM education, closed-loop PLM, and smart factory testbeds incorporate the presented model [3–5].

2 Educational Model "Digitalisation in Industry"

A good didactical design of a module/course addresses the content in different ways to the participants. In principle, knowledge is divided into factual and structural knowledge [6]. In general, factual knowledge is on a deep taxonomy level of 1 or 2, while structural knowledge leads to higher levels. The latter is divided into declarative (what), procedural (how) and conditional (when) knowledge [7]. The metro map supports teaching accordingly by allowing locating the theory elements in the big picture and thus addressing the semantic memory (concepts, network of concepts) of course participants. The associated exercises, in turn, support knowledge acquisition via the procedural memory system. To complete the course, guest lectures from the industry are also included in the lessons, which are explaining real-life use cases and thus address episodic memory. The metro map always forms the basis and thus becomes a "table of contents" for the whole module/course and eases the recall of knowledge accordingly.

2.1 Introducing the Model

The model of digitalisation in industry has been illustrated in similarity to the metro map as e.g. known from the "standard tube map" from the London Underground [8], the map from the Tunnelbana from Stockholm [9] or the S- and U-Bahn map from Berlin [10]. Not only the concept indicating different metro lines has been adapted, but also the interchange stations, the internal interchanges, and the different zones.

Metro Lines. Four different metro lines are incorporated plus an additional direct connection.

- The line "Digitalised Product" (DP) represents the classic development methodology [11].
- The line "Digitalised Manufacturing" (DM) marks the manufacturing of the product.
- The line "Operating Product" (OP) represents the customer journey from initial requirement to maintenance.
- The line "Manufacturing Equipment" (ME) represents supplier involvement, e.g., of manufacturing equipment.
- The line "Requirement Engineering" (RE) is illustrated by a feedback loop form operation data (line OP) to the requirement engineering in the digitalised product (DP).

Zones. The digital twin model (DT) is composed of the physical product in real space, the virtual product in virtual space, and the connections of data and information exchange [12, 13]. In the model of digitalisation in industry the DT has been matched to the product lifecycle covering the digital master and the digital shadow of the product in production and operation [14, 15]. In other terms, this represents the product's stages "as designed" (instance), "as built", and "as maintained". Properly applied, the digital twin's value proposition leads in a wide range of areas to related benefits [16].

Supply Chain Management (SCM). The supply chain is indicated on the right side of the illustrated model. It consists of the supplier, the manufacturer, and the customer. As it has recently been differentiated between supplier relationship management (SRM) and customer relationship management (CRM) the present approach is combining both in the holistic approach of supply chain management (SCM) [17]. Eventually, both alternatives can be brought into connection with the model.

Internal Interchange Stations. Master data and configurations are two internal interchange stations. They are shared by the two lines digitalised product (DP) and digitalised manufacturing (DM) and do not cross borders of companies (customer, manufacturer, and supplier). It is undisputed that product design and production must rely and operate on identical data having one single point of truth.

Interchange Stations. In contrast to the internal interchange station, the interchange stations are bridging the border between manufacturer, customer, and/or supplier. This requires related interfaces and in the case of an applied electronic data interchange (EDI), managed file transfer (MFT), and/or enterprise filesharing services (EFS) management [17] of access rights and data format. A typical enabler for these kinds of communication between partners within a supply chain are the enterprise resource planning (ERP) systems. Following internal interchange stations have been implemented into the model of digitalisation in industry.

2.2 Illustration of Use Cases

Smart Factory. The Smart Factory is a concept to support the envisioned goal of digitalisation in manufacturing [18]. But for achieving a fully connected manufacturing system, mainly operating without human force by generating, transferring, receiving, and processing necessary data to conduct all required tasks for producing all kinds of goods, the related products must be designed accordingly.

Mechatronic products are getting predominant as they offer the opportunity for related data allocation in production and operation and being part of the (industrial) internet of things ((I)IoT). In consequence, the manufacturing does not end by delivering a physical entity but continues in collecting data, creating insights, and offering services. Therefore, taking the model of digitalisation in industry the students are instructed, to focus on the metro lined "Digitalised Product" (DP) and "Digitalised Manufacturing" (DM).

Digital Twin's Shadow – Data-Driven Services. Services of the future will be based on data analytics offering e.g. condition-based maintenance. The aim is, to illustrate that data-driven services are offered throughout the whole product development and manufacturing process. Depending on the point of view it is vertical or in a kind tilted. Furthermore, the illustration gives the opportunity to discuss the issue that operation data of production means are required to enable services of the product in operation. An example could be traceability preventing consequential damage to the manufacturer's customer. If e.g. an insufficient surface quality can be linked to an abnormality of a milling machine during a certain period, this data needs to be matched accordingly: Which parts have been produced while the abnormality occurred? In which products are they? And which applications require the specific surface quality (related applications)?

Product Lifecycle: While many authors agree on three principle phases in the product lifecycle (beginning of life, mid of life, end of life) [19], we choose to focus on the two stages of a product's life accruing to RMAI: the lifecycle of product type and the lifecycle of the product instances [5, 20]. The underlying concept of type and instance can well be explained by the discussion of their representation as digital master or digital shadows receptively. So, it becomes obvious that we need a properly released type as the baseline to created instances without the high price of manual work. Even more in the case of product variance, the systematic creation of instances based on the customer's configuration becomes essential to build data-driven services that relies on the product instance. While the result of the configuration remains a filtered view on the digital master, it serves as a template to create an instance. At this very moment, the lifecycle of the instance in its physical and digital appearance starts to live. The purple metro line illustrates how we can learn from product instances to improve our product types. This concept is also known as closed-loop PLM [21] (Fig. 1).

Requirement Engineering Based on Load Profiles. Using load profiles of applied products for a next-generation or just an upgrade is essential for defending and probably extending existing market shares. The present technical specification can be taken and optimise the product and the manufacturing accordingly. The efficiency gets increased ("Doing the things right.") and leads to a better margin or a reduced price aiming for a higher quantity in sales and therefore scaling effects (economy of scale). The model of digitalisation in industry and especially this metro line "Requirement Engineering" illustrates to the students the value of fundamental data analysis avoiding over or under-engineering a product.

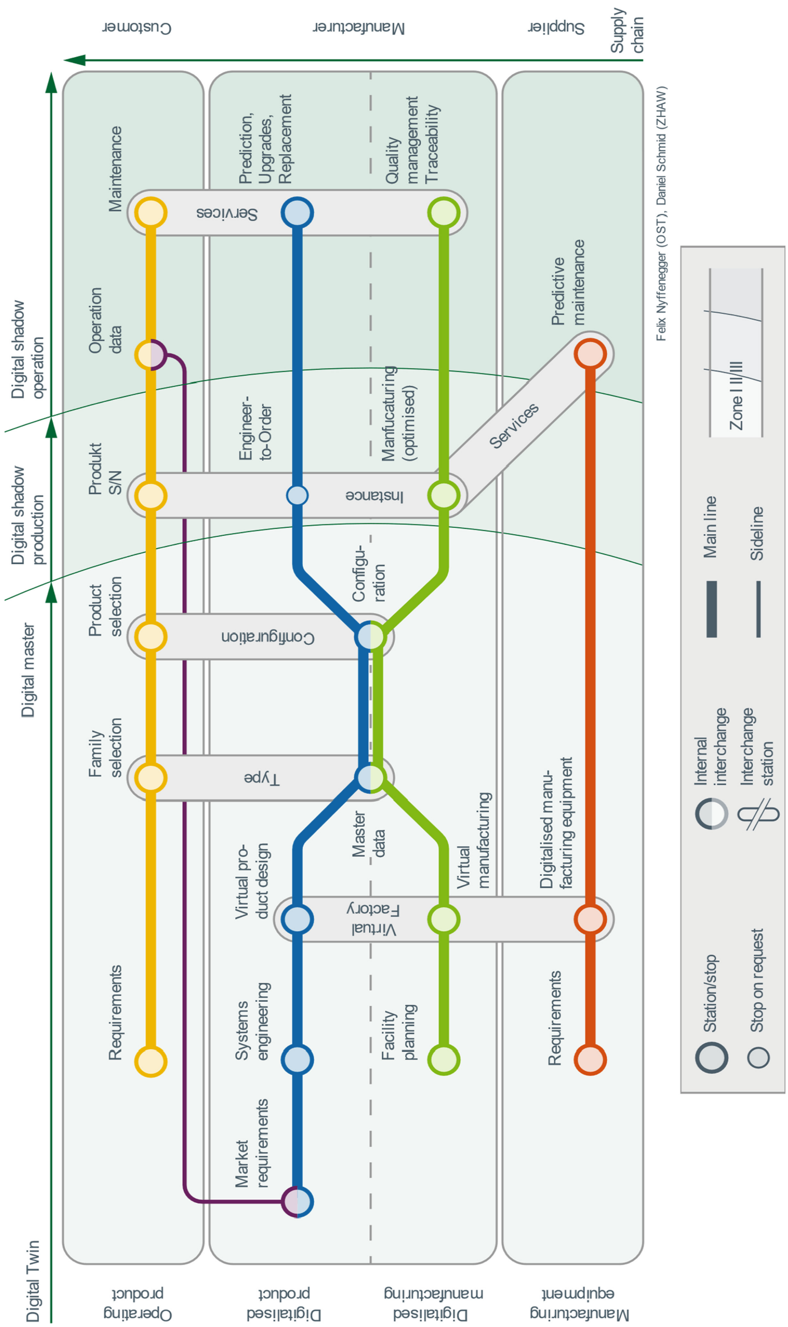

Fig. 1. Illustration of the digitalisation in industry in the style of metro map

3 Application of the Model in Education

The presented model was co-created while elaborating a didactical concept for a new module "Digitalisation in Industry" for the master's program of Swiss Universities of Applied Sciences (Master of Science in Engineering, MSE). In this section, some insights are given into applications of the model as a framework for the module.

3.1 "Digitalisation in Industry" (Master of Science in Engineering)

As mentioned, the module (course) is part of a master's degree program that is open to different types of engineering. The students might have different backgrounds, from mechanical to software to food engineering. The education goal of the course can be summarised as follows:

1. Enabling the students to contribute to digital transformation in the industry. They learn about digital transformation's fundamental concepts and technical and organisational requirements. They will be able to ask the right questions in a conceptual discussion.
2. The students obtain an overview of the processes, data structures and information flows based on different product strategies inside a company.
3. They are qualified to evaluate different approaches to a company's product strategy, architecture, production processes, and the deployed IT solutions. Relying on this, they can identify and apply optimization strategies.
4. They are familiar with state-of-the-art concepts of digitization to classify efficiency and transparency in production processes (industry 4.0).
5. They are familiar with the basic concepts of digitized products (Internet of Things) and how these are linked to the processes and data streams of the original company to increase the range of product-related services or business models.
6. They can rationally decide between "digital" and "non-digital" solution concepts.

Given this aim and target audience, it becomes obvious that not the technical details but a holistic understanding of all elements are required: technical, organisational, and business-related. We expect students to meet the taxonomy level 3 to 4 according to the classification of Bloom [22]. The following learning units were chosen to complete the required holistic view:

- End-to-end process from market requirements to recycling
- Digital twin concepts: Digital master (type) and digital shadows (instance)
- Dealing with product complexity and variants
- Challenges related to developing mechatronic products and IoT connectivity
- Sales to delivery and smart sales approaches
- Efficiency in production applying "Industry 4.0"
- Data-driven services for predictive and condition-based maintenance
- Adaption to business models (e.g., pay per use and subscriptions)
- IT tools along the process chain (CAD, PLM, ERP, MES, IoT Backbones)d

Figure 2 illustrates how these topics are reflected on the metro map. Each learning unit is structured into theoretical and practical parts (exercises). While the topics change pretty rapidly over the course, the exercises always rely on the same two elaboration examples:

An industrial pressure sensor is used as a first example showing the complexity of integrated and cross-disciplinary IoT products. It can be used in two representations. The first one links the complexity of the real product's issues in detail. The other is a highly abstracted conceptual model of the sensor based on 5 Lego bricks to discuss the link between mechatronic disciplines and customer-driven variants. The second example is an invented scenario of a company producing sorting machines and its customer that runs a local package delivery service. This example gives the full context of a supply chain between component suppliers, OEM, and industrial customers. A Lego-based machine represents the simplified product yet gives an accurate level of product structure complexity.

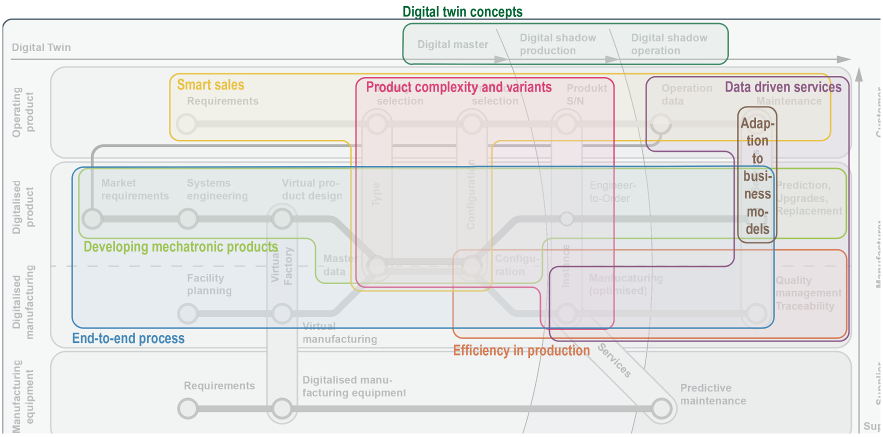

Fig. 2. Learning units in the context of the model (metro map)

Having enough understanding of these topics, elaborated by the examples, the students will be able to ask the right questions in a conceptual discussion. This last step in the didactical concept is consolidated by a final exercise where the students must elaborate and implement a concept for an IoT driven service. The given problem is a real-world problem of a local airport. The implementation, however, will be realised by the usage of prepared low-code tools. It will convey a feeling of implementation complexity without losing too much time. Of course, the groups must defend their concepts to improve their reasoning.

3.2 An Overview of Further Application

Besides the example of the application discussed above, the metro map was used in various courses to support orientation (Table 1).

Table 1. Further application of the metro map

Degree	*Title*: Educational target	Main topics	Tax. level
BSc	***Smart Factory***: The students are getting an overview of product development, manufacturing technologies, and Industry 4.0. It shall lead to the understanding that development and production need to co-operate accordingly, utilising the full potential of the smart factory	- Development process - Manufacturing technologies from turning and milling to additive manufacturing - Modern development tools and how creating the master data - Concept of the digital twin - Cost management	2–3
BSc	***Smart Products and Production 1&2***: The students get a sound understanding of complex developments, product configuration, and state of the art tools as such CAx. Furthermore, they can select and apply suitable manufacturing technology and use data from development, manufacturing, and product operation to create data-driven product functions and services	- Variant and cost management - Non-linear kinematic systems - Manufacturing technologies - Quality management and usage of related data - Basics about sensor technologies and applications - Digital twin and introduction into "Industry 4.0"	2–4
BSc	***Product Data Engineering***: This course aims at the hands-on experience of mechatronic product development, including IoT aspects. The students must develop a remote-controlled IoT toy that shows interaction with its remote friends. On the way of development, the students work in groups	- Mechatronic development tool chain - Systems Engineering/SysML - IoT Stack/Communication - Understanding of the views on a product from different disciplines - Instantiation of products	4–5
BSc	***Applied Digitalisation in Industry***: Embedded into a smart factory setup for unihockey ball production (injection modelling, configuration, assembly) the students learn about the value and implementation of different use cases in industry 4.0	- Use Cases of Industry 4.0 - Discrete event simulation for production planning - Introduction into IoT communication in an industrial environment - Introduction to AI/ML for prediction of factory events	3

(*continued*)

Table 1. (*continued*)

Degree	*Title*: Educational target	Main topics	Tax. level
CAS	***Production Management***: This certificate of advanced studies addresses the management level of the industry, particularly in the manufacturing sector. They will learn about the latest movements, concepts, and technologies in production management	- Digitalisation in industry - Lean manufacturing principles - Integrated data management in an industrial context - Complexity management - Use cases of industry 4.0	4

4 Conclusion

As stated in the introduction, the presented work is not the result of actual research, but rather the outcome of a creative process. However, it proved to be helpful in organising and planning courses in the field of digitalisation in industry. Particularly, it helped to create a common understanding among the different involved lecturers and experts from the industry. Feedback from the annual student's survey 21/22 of the module mentioned in 3.1 particularly shows high appreciation for the structure of the course and the alignment among the lecturers.

Based on project reports and exams by the students, we can state that our illustration provides good support in the argumentation of technical concepts. However, our students struggle to create clear value propositions for their suggested approaches and use cases regarding digitalisation in industry. It might be a general lack in the education of engineering programs. Yet, the holistic context helps to discover and discuss such gaps. In addition, we are investigating enriching the our model with an extra layer to explain the value proposition of different use cases.

Due to positive feedback, we also started to use this model for strategic planning of digitalisation initiatives in consulting and applied research projects. Hence, it helps to argue links between different digitalisation initiatives and supports a proper road map setup. Eventually, the positive feedback from the management level moved us to publish our approach.

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