Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnline CONFERENCE PAPER ARCHIVE

IFAC PapersOnLine 52-13 (2019) 1609–1614

Facilitating Digital Transformation by Multi-Aspect Ontologies: Approach and Application Steps

Kurt Sandkuhl[1,2], Nikolay Shilov[3]
Alexander Smirnov[2]

[1]*Rostock University, Rostock, Germany.*
[2]*ITMO University, St.Petersburg, Russia*
[3]*SPIIRAS, St.Petersburg, Russia*
e-mail: kurt.sandkuhl@uni-rostock.de, nick@iias.spb.su, smir@iias.spb.su

Abstract: Today, companies feel a need to invest in digital transformation due to customer demand and market pressure, but at the same time also experience many challenges in planning and implementing digital transformation processes. The aim of the paper is to facilitate this process in the following areas: identification of factors on digital transformation projects to be observed, multi-aspect digital transformation ontology formalizing the elements and interrelationships of these factors with an illustrative example and application steps.

Keywords: Digital transformation, digitalization, ontology, multi-aspect ontology.

1. INTRODUCTION

Digitization and digital transformation are topics frequently discussed in research, industry and society with the expectation to have substantial effects on markets, companies and their operations. Digitalization can be understood, in simplified terms, as a generic term for efforts to convert information, processes, products or services into a form that can be processed or supported by information technology (Zimmermann et al., 2016). In the scientific literature there are different approaches to subdivide digitisation historically into phases which, depending on the point of view of the observer, are more technologically oriented (Berman & Bell, 2011), consider the socio-economic change triggered by digitisation (Hirsch-Kreinsen & ten Hompel, 2017) or examine specific industries (Heinemann, Gehrckens, & Wolters, 2016) – to name just a few examples. The current phase of digitisation is often referred to as the "third" (Rifkin, 2013) or "fourth industrial revolution" (acatech, 2013). The focus here is on the disruptive social and economic consequences which, due to the potential of digital technologies to substantially change markets, lead to new technological application potentials and the resulting changes in economic structures, qualification requirements for employees and working life in general (Hirsch-Kreinsen & ten Hompel, 2017).

In the practice of many manufacturing enterprises, digitisation often still is associated with historically the “earlier” phases of digitisation and activities such as the optimisation of internal business processes, sales channels or products; the automation of internal workflows, improvement of business processes, data exchange with customers and suppliers; and the use of possibilities of electronic business transactions, customer communication via social media, etc. (Zimmermann et al., 2016). Each of these topics is considered well researched in its own right, which is why these digitization topics are not the primary object of the paper. Rather, the focus is on the transformation of enterprises with changing business models or markets, i.e. when emerging changing customer needs, competitive situations, potentials for new service offerings or new partner structures affect both the range of services and service creation processes of a company as well as the organizational structures and requirements for employees and leadership substantially change. This is often triggered or accompanied by substantial changes in the markets and is accompanied technologically by the systematic collection and use of data.

Fig. 1 illustrates the area of digital transformation and the focus of the paper (upper left quadrant). The two axes show on the one hand the operational processes of a company (value creation and service provision) and on the other hand the services or products offered by the company (service offer-

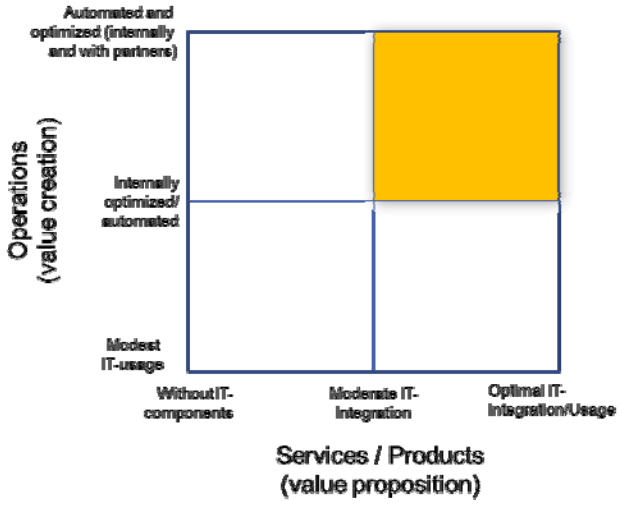

Fig. 1. Digital transformation (based on Berman & Bell, 2011).

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2019.11.430

ings). The focus is on the transition from conventional to innovative business models.

A number of case studies and surveys in industry indicate that companies feel a need to invest in digital transformation due to customer demand and market pressure, but at the same time also experience many challenges in planning and implementing digital transformation processes. An examples for such surveys is a study among 12000 German companies (Warning & Weber, 2017) where 41% of all enterprises see a "strong push" towards digitization. Furthermore, (Depaoli & Za, 2019) and (Nambisan, Lyytinen, Majchrzak, & Song, 2017) conclude based on empirical material that there is a clear need for better support of enterprises in digital transformation.

In the context of the above situation, this paper proposes a more formalized instrument for supporting manufacturing companies in digital transformation. This instrument is envisioned as an ontology-based representation of the knowledge required to decide and plan transformation steps and a procedural recommendation how to use this knowledge. More concrete, the paper proposes a multi-aspect ontology capturing the core success factors of digital transformation and interlinking these factors to support cross-aspect analysis. This multi-aspect digital transformation ontology can be tailored to individual enterprises and used for investigating digital transformation options and their effects on the organization.

The main contributions of the paper are (a) identification of factors on digital transformation projects to be observed in companies, (b) multi-aspect digital transformation ontology formalizing the elements and interrelationships of these factors, and (c) steps of applying the multi-aspect ontology for digital transformation.

The paper is structured as follows: Section 2 describes a literature analysis for identifying factors influencing digital transformation of companies. Section 3 introduces the concept of multi-aspect ontologies and its foundations. Section 4 illustrates the multi-aspect digital transformation ontology. Section 5 discusses the steps for applying the ontology in companies. The results are summarised in the Conclusion section.

2. FACTORS INFLUENCING SUCCESS OF DIGITAL TRANSFORMATION PROJECTS

Digital transformation is a complex task including many different facets and aspects. An ontology meant to support enterprises in digital transformation processes has to reflect these different aspects in order to be able to represent required knowledge or to identify shortcomings in an organization. As a starting point for constructing an ontology, performed a literature analysis was performed addressing the following research question (RQ): *What factors have been identified affecting the success of digital transformation?*

The literature analysis was based on a search in Scopus and in Google Scholar on the keyword pairs of "digital transformation" and "success factor". Variations of these keywords, such as "digital transformation success" or "digital transformation antecedent" were also tried. The search was performed in title, abstract and keywords. For the hits returned by the search engines, decisions were made on their relevance by reading the abstract.

The most relevant publications identified by the literature study include a project from University of St. Gallen aiming at evaluating the maturity of digitalization in companies (Back & Berghaus, 2016). The project investigates various dimensions that were originally developed for the systematic transformation of companies from the industrial age to the information age (Winter, 2003). Almost all dimensions can also be found in the literature on factors influencing digital transformation, such as (Azhari, Faraby, Rossmann, Steimel, & Wichmann, 2014; Dömötör, 2011; Heinemann et al., 2016). These factors are a defined strategy for digital transformation, an appropriate management and involvement of employees, products or services according to the changing needs of customers, employees with the right competencies and task and role models, a digitization-friendly corporate culture, suitable internal work processes ("operations"), digital governance structures for controlling transformation and suitable technologies for the products/services or operations.

A synthesis of the definition of these factors from the above literature sources resulting in the following interpretations of the factors, which were used as a basis for the multi-aspect ontology (see section 3):

- Strategy: A strategy is intended to create awareness of the digital transformation, thus expressing a precise target picture. The objective of the strategy can be interpreted in different directions. For example, the goal can be improved customer focus, increased efficiency, internal processes or new business models. The digital strategy should be integrated and communicated in all parts of an enterprise.
- Leadership: Managers should bring digitalization into the enterprise and enable employees to participate. In this way, all corporate divisions are to be involved in the implementation of the digital strategy.
- Products: Communication with customers is essential; in addition, non-customer-oriented areas such as IT must seek dialogue with customers. This point is important in order to gain an advantage over the competition.
- People: Mandatory task and role models should exist for the digital competencies of employees in all areas of the company. In addition, further training opportunities should be provided.
- Culture: In a major change process, the company's culture must always be taken into account. Due to the fact that digitization does not only take place in individual departments, but across such borders, processes must be considered. Accordingly, the organizational structure must be designed for digital processes, which can ensure transparency and dynamism. At the same time, communication and cooperation within the company, but also with external staff and customers, must be promoted.
- Operations: Due to the new digital orientation, further elements of the business have to be adapted. The digital

communication in the enterprise leads to more agility in the organization. External stakeholders can be better integrated through this type of communication.

- Governance: The digital transformation activities must be visible and controllable for the company. Digital governance structures should help with a number of tasks: mobilising resources, acquiring digital skills and reducing system redundancies. Frameworks and guidelines are often used to this end. Furthermore, the process of digitisation should be assessable, which is why the digital strategy must be measurable through economic targets.
- Technology: In the field of technology use, an essential task linked to digitization is cross-channel interaction. Many customers use different communication channels. The provider of services should have an overview of all transactions (e.g., purchases) and services for the customer. Furthermore, there enterprise should treat every channel as equally important, since negative customer experiences with a certain channel falls back on the company.

3. MULTI-ASPECT ONTOLOGIES

Ontologies have proved themselves as one of the most efficient ways to solve the problem of semantic interoperability support. Still there is a need for common ontologies of problem areas with supporting multiple modifications in a quick and simple way, as well as semantic queries in a given context (Saripalle & Demurjian, 2018).

Different workflows often rely on different mechanisms caused by their nature. For example, classification and feature definition tasks can be solved by using some general ontology model, and more specific problems, such as configuration models, might require different notations (e.g., constraint satisfactions) for more efficient problem solving. Such a variety of notations and formalisms significantly complicates the process of creating flexible information ecosystems.

The difficulty of supporting conciliated ontologies that capture different views on the same problem, as well as developing an ontology model for representation and processing of information produced in the decision support processes, lies in the necessity to operate not only with different terminologies but also with different formalisms used to describe different domains; the terminologies and formalisms in turn depend on the tools used to effectively solve the domains' problems.

It is generally accepted that models of specific problem areas (for example, configuration models of complex systems) can be obtained by inheriting or extending a common ontology. However, in systems with a dynamic structure, such as an enterprise, this solution does not allow to achieve the required flexibility, since the expansion of the general ontology with the appearance of new information objects requires ontology matching. It should be noted that the automatic ontology matching methods are still not sufficiently reliable (except narrow domains), and manual ontology matching significantly reduces the efficiency.

In (Lim, Liu, & Lee, 2011) a solution is proposed based on semantically annotated multi-faceted ontology for product family modelling to automatically suggest semantically-related annotations based on the design and manufacturing repository on the example of laptop computers. Such a solution may be effective in one particular problem area, but it doesn't scale well.

Multilevel platforms are being developed that are characterized by interactions and interdependences between several areas (Boudreau & Hagiu, 2008; Deng et al., 2018). For example, to describe the proposed resources on the e-commerce platform, various attempts have been made to ensure syntactic and semantic compatibility for B2B systems and services. Among them is the international standard for the classification of products and services eCl@ss and its transformation into the ontology eClassOWL (Hepp, 2005); the light ontology of GoodRelations originally used to describe the offers of goods and services in the Internet (Hepp, 2008) but currently covering many B2B elements, including web resources, offers, prices, conditions, etc. However, many important elements, such as business-object, people, culture, etc. are not considered in this work.

The most progress in this direction is achieved by M. Hemam who in co-authorship with Z. Boufaïda proposed in 2011 a language for description of multi-viewpoint ontologies - MVP-OWL (Hemam & Boufaïda, 2011) extended in 2018 with probabilities (Hemam, 2018). However, the authors of the language do not take into account possibility of intersection of ontology fragments relating to different viewpoints, also the methodology of the ontology development is not presented.

In this regard, application of the apparatus of multi-aspect ontologies aligning different views on the same problem and applying them both for providing semantic interoperability of, and for solving applied tasks in some specific application areas seem to be a promising solution.

4. ILLUSTRATIVE EXAMPLE OF MULTI-ASPECT DIGITAL TRANSFORMATION ONTOLOGY

A straightforward approach to developing an ontology for digital transformation would consider the common ontology split into parts related to particular core success factors of digital transformation. However, this approach would only work if the factors were separate and did not touch the same elements. As a result, the whole picture of digital transformation success factors looks as shown in Fig. 2, where the factors overlap. In this case, the apparatus of multi-aspect ontology is beneficial.

The developed ontology uses different formalisms for representing different areas corresponding to the success factors. Below, some of these are described.

The Strategy part was built based on the Enterprise Ontology (Artificial Intelligence Applications Institute, 2017) using OWL (W3C, 2018). It includes the following high level elements: Purpose, Pattern, Objective, Vision, Mission, Goal,

Achievement, Strategy, Planning, Process, Action, Decision, Assumption, Influence Factor, Success Factor, Risk.

Same approach was used for defining the part related to the Culture success factor. It is based on the formal definition of culture proposed in (Birukou, Blanzieri, Giorgini, & Giunchiglia, 2013) and includes the following high level elements: Norm, Value, Shared Meaning, Pattern, Behaviour, Process, Decision, Action, Interaction.

The technology related part was built based on VDI 2860 (Verein Deutscher Ingenieure, 2018) guideline. It describes processes, workpieces, flows, functions, parameters, adjustments, and rules that define complex function relations. The ontology language OWL 2 is used for function composition ontology development. The ontology is described by *ALCR(D)* description logic (Staab & Studer, 2009), because it is decidable and has PSpace-complete hardness of concept satisfiability (problems that can be solved by a Turing machine using a polynomial amount of space) and ABox (assertion ontology component) consistency (Baader, Milicic, Lutz, Sattler, & Wolter, 2005) in the case when TBox (terminological ontology component or vocabulary) is acyclic. In addition, SWRL-rules are specified for function composition deriving.

A schematic illustration of the fragment of resulting multi-aspect digital transformation ontology is shown in Fig. 3.

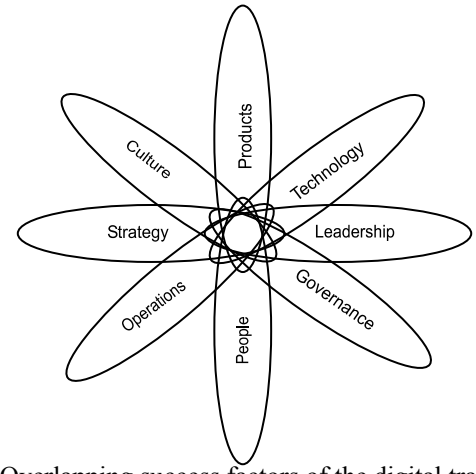

Fig. 2. Overlapping success factors of the digital transformation ontology.

5. APPLYING THE MULTI-ASPECT DIGITAL TRANSFORMATION ONTOLOGY

Application of the digital transformation ontology in an enterprise requires in the first step tailoring the content for the actual enterprise under consideration, i.e. refinement of the knowledge captured in the ontology until the required level of detail is reached (specialization), extension of domain-specific parts beyond operations and products, and population of instances for the enterprise. This step can be performed in

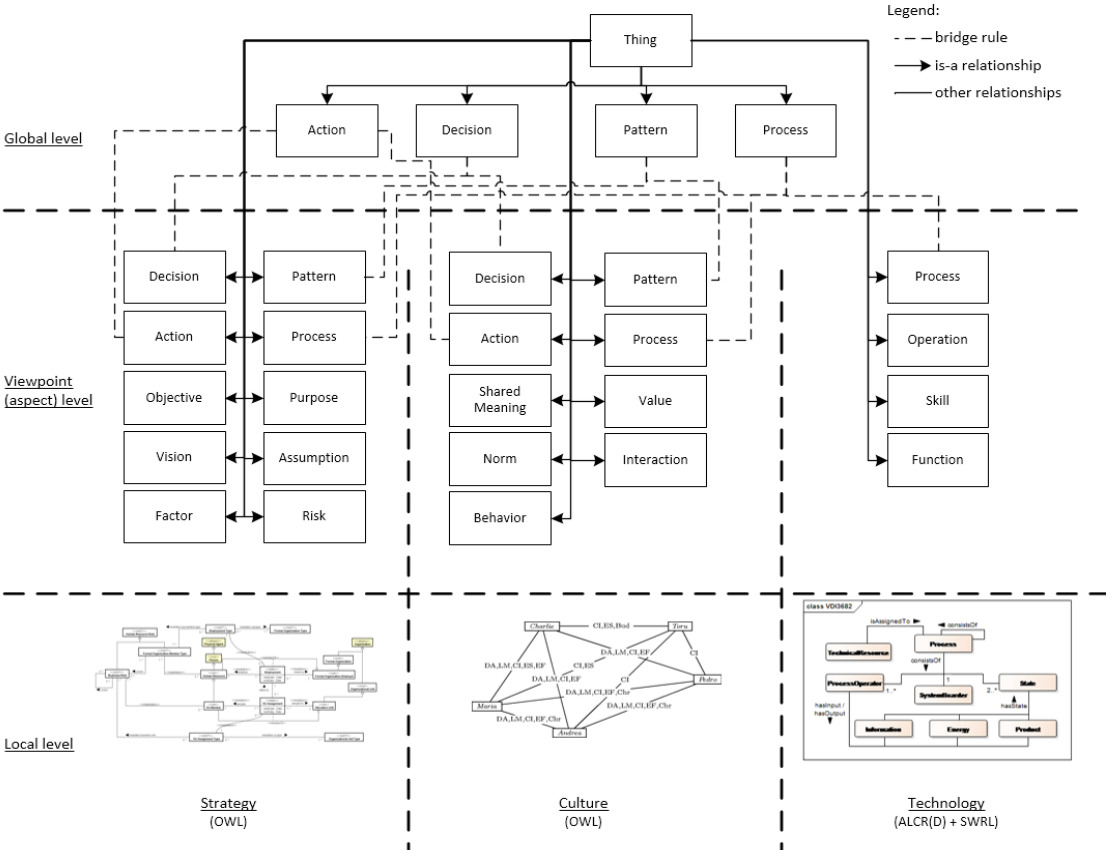

Fig. 3. Illustration of a fragment of multi-aspect digital transformation ontology.

several different ways:

- Development from scratch: in enterprises without any existing knowledge models, process descriptions, product structure information or other documentation explicating the current situation, a knowledge modelling process has to be initiated. Elicitation techniques known from enterprise modelling (Sandkuhl, Stirna, Persson, & Wißotzki, 2014), such as interviews with subject matter experts or participatory modelling workshops (Stirna & Persson, 2018), can be used to identify relevant knowledge required for the digital transformation ontology. In comparison to existing approaches for enterprise ontology development, cf. TOVE (Gruninger & Fox, 1995), the aspects represented in the digital transformation ontology (i.e., the success factors) have to be the guiding perspectives instead of focusing on processes, organisation structures, systems and products.
- Reuse of existing ontologies: in particular in application domains with established reference models (such as SCOR in the logistics area), the reuse of these models should be investigated, which will lead to the integration of relevant "slices" of the existing model into the digital transformation ontology. Integration does not only mean specialization of aspects on the digital transformation ontology by reusing content but also interlinking other aspects of the digital transformation ontology with the reused content.
- Transformation from enterprise models: in case of existing enterprise models capturing the current situation of an enterprise, integration of relevant parts of such models should be considered. Transformation of the representation from enterprise modelling language to ontology language is one of the required activities. Furthermore, specialization of aspects and interlinking is required as already discussed above for the reuse of ontologies.

After finishing the above first step, the digital transformation ontology is ready for application in the enterprise. Querying the ontology can be used for:

- the different aspects captured in the digital transformation ontology and their interlinkage do not only explicate the success factors of digital transformation, but also their dependencies. Already when tailoring the digital transformation ontology for an enterprise, awareness of these dependencies will increase in many enterprise and not sufficiently interlinked aspect will become clear and can be used for improvement processes.
- when preparing organizational changes required for digital transformation, the multi-aspect ontology can be applied to assess the effect of the planned changes in the organisation. Starting from the aspect(s) to be modified, the digital transformation ontology will allow for identification of elements in other aspects affected by the modification. The change of established products to new product/service bundles, for example, will probably lead to modifications in operations related to the established products, in competence requirements of the staff, and in the governance of the organization.
- For the required changes in technology and IT-systems, different alternative ways to perform these changes can be evaluated based on the digital transformation ontology. The digital transformation ontology contains all relevant information to identify which aspects and concepts are affected by changes in other aspects. This allows for comparing the change "footprint" for different alternatives.

6. CONCLUSIONS

The paper considers the process of digital transformation and seeks for ways to facilitate it. Consideration of eight success factors of digital transformation projects and application of multi-aspect ontology apparatus to provide for interoperability between these, with different success factors being ontology aspects, is proposed.

ACKNOWLEDGEMENTS

The paper was partially supported by projects funded by grants ## 18-07-01201, 18-07-01203, 18-07-01272 of the Russian Foundation for Basic Research, State Research no. 0073-2019-0005, and by the Government of Russian Federation, Grant 08-08.

REFERENCES

acatech. (2013). Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0. Deutschlands Zukunft als Produktionsstandort sichern. Abschlussbericht des Arbeitskreises Industrie 4.0.

Artificial Intelligence Applications Institute. (2017). The Enterprise Ontology. Retrieved from http://www.aiai.ed.ac.uk/project/enterprise/enterprise/ontology.html

Azhari, P., Faraby, N., Rossmann, A., Steimel, B., & Wichmann, K. S. (2014). *Digital Transformation Report*. Retrieved from http://www.wiwo.de/downloads/10773004/1/dta_report_neu. pdf

Baader, F., Milicic, M., Lutz, C., Sattler, U., & Wolter, F. (2005). *Integrating Description Logics and Action Formalisms for Reasoning about Web Services*. Dresden. Retrieved from https://iccl.inf.tu-dresden.de/web/LATPub683/en

Back, A., & Berghaus, S. (2016). *Digital Maturity& Transformation Studie. Über das Digital Maturity Model*.

Berman, S. J., & Bell, R. (2011). *Digital transformation: Creating new business models where digital meets physical*. *IBM Institute for Business Value*.

Birukou, A., Blanzieri, E., Giorgini, P., & Giunchiglia, F. (2013). A Formal Definition of Culture. In *Models for Intercultural Collaboration and Negotiation* (pp. 1–26). Springer. https://doi.org/10.1007/978-94-007-5574-1_1

Boudreau, K. J., & Hagiu, A. (2008). Platform Rules: Multi-Sided Platforms as Regulators. *SSRN Electronic Journal*, 29. https://doi.org/10.2139/ssrn.1269966

Deng, Q., Gonul, S., Kabak, Y., Gessa, N., Glachs, D., Gigante, F., … Klaus-Dieter, T. (2018). An Ontology Framework for Multisided Platform Interoperability. In *9th International Conference on Interoperability for Enterprise Systems and Applications (I-ESA 2018)*. Berlin, Germany.

Depaoli, P., & Za, S. (2019). Designing e-Business for SMEs: Drawing on Pragmatism. In A. Lazazzara, R. C. D. Nacamull, Ic. Rossignoli, & S. Za (Eds.), *Organizing for Digital Innovation* (pp. 237–246). Springer. https://doi.org/10.1007/978-3-319-90500-6_18

Dömötör, R. (2011). *Erfolgsfaktoren der Innovativität von kleinen und mittleren Unternehmen*. Wiesbaden: Gabler. https://doi.org/10.1007/978-3-8349-6552-3

Gruninger, M., & Fox, M. S. (1995). Methodology for the Design and Evaluation of Ontologies. In *Proceedings of IJCAI'95, Workshop on Basic Ontological Issues in Knowledge Sharing*.

Heinemann, G., Gehrckens, H. M., & Wolters, U. J. (Eds.). (2016). *Digitale Transformation oder digitale Disruption im Handel*. Wiesbaden: Springer Fachmedien Wiesbaden. https://doi.org/10.1007/978-3-658-13504-1

Hemam, M. (2018). An Extension of the Ontology Web Language with Multi-Viewpoints and Probabilistic Reasoning. *International Journal of Advanced Intelligence Paradigms*, *10*(1), 1. https://doi.org/10.1504/IJAIP.2018.10003857

Hemam, M., & Boufaïda, Z. (2011). MVP-OWL: a multi-viewpoints ontology language for the Semantic Web. *International Journal of Reasoning-Based Intelligent Systems*, *3*(3/4), 147. https://doi.org/10.1504/IJRIS.2011.043539

Hepp, M. (2005). eClassOWL: A Fully-Fledged Products and Services Ontology in OWL. In *Poster Proceedings of The 4th International Semantic Web Conference ISWC 2005* (p. 2). Galway.

Hepp, M. (2008). GoodRelations: An Ontology for Describing Products and Services Offers on the Web. In *Knowledge Engineering: Practice and Patterns* (pp. 329–346). Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-87696-0_29

Hirsch-Kreinsen, H., & ten Hompel, M. (2017). Digitalisierung industrieller Arbeit: Entwicklungsperspektiven und Gestaltungsansätze. In *Handbuch Industrie 4.0 Bd.3* (pp. 357–376). Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-53251-5_21

Lim, S. C. J., Liu, Y., & Lee, W. B. (2011). A methodology for building a semantically annotated multi-faceted ontology for product family modelling. *Advanced Engineering Informatics*, *25*(2), 147–161. https://doi.org/10.1016/j.aei.2010.07.005

Nambisan, S., Lyytinen, K., Majchrzak, A., & Song, M. (2017). Digital Innovation Management: Reinventing Innovation Management Research in a Digital World. *MIS Quarterly*, *41*(1), 223–238. https://doi.org/10.25300/MISQ/2017/41:1.03

Rifkin, J. (2013). *The Third Industrial Revolution: How Lateral Power Is Transforming Energy, the Economy, and the World*. St. Martin's Griffin. Retrieved from https://www.amazon.com/Third-Industrial-Revolution-Lateral-Transforming/dp/0230341977

Sandkuhl, K., Stirna, J., Persson, A., & Wißotzki, M. (2014). *Enterprise Modeling*. Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-43725-4

Saripalle, R. K., & Demurjian, S. A. (2018). Attaining Semantic Enterprise Interoperability Through Ontology Architectural Patterns. In *Computer Systems and Software Engineering* (pp. 705–740). IGI Global. https://doi.org/10.4018/978-1-5225-3923-0.ch029

Staab, S., & Studer, R. (Eds.). (2009). *Handbook on Ontologies*. Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-92673-3

Stirna, J., & Persson, A. (2018). *Enterprise Modeling*. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-94857-7

Verein Deutscher Ingenieure. (2018). VDI 2860. Retrieved December 14, 2018, from https://www.vdi.de/richtlinie/vdi_2860-montage_und_handhabungstechnik_handhabungsfunktionen_handhabungseinrichtungen_begriffe_definitionen/

W3C. (2018). Web Ontology Language (OWL). Retrieved December 14, 2018, from https://www.w3.org/OWL/

Warning, A., & Weber, E. (2017). Wirtschaft 4.0. Digitalisierung verändert die betriebliche Personalpolitik. *IAB Kurzbericht*, (12), 1–8. Retrieved from http://doku.iab.de/kurzber/2017/kb1217.pdf

Winter, R. (2003). Modelle, Techniken und Werkzeuge im Business Engineering. In H. Österle & R. Winter (Eds.), *Business Engineering* (pp. 87–118). Springer. https://doi.org/10.1007/978-3-642-19003-2_5

Zimmermann, A., Schmidt, R., Sandkuhl, K., El-Sheikh, E., Jugel, D., Schweda, C., … Lantow, B. (2016). Leveraging Analytics for Digital Transformation of Enterprise Services and Architectures. In *Emerging Trends in the Evolution of Service-Oriented and Enterprise Architectures* (pp. 91–112). Springer. https://doi.org/10.1007/978-3-319-40564-3_6