Aalborg Universitet

AALBORG UNIVERSITY DENMARK

A self-assessment framework for supporting continuous improvement through IoT integration

Nygaard, Jonas; Colli, Michele; Wæhrens, Brian Vejrum

Published in:
Procedia Manufacturing

DOI (link to publication from Publisher):
10.1016/j.promfg.2020.02.079

Publication date:
2020

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Nygaard, J., Colli, M., & Wæhrens, B. V. (2020). A self-assessment framework for supporting continuous improvement through IoT integration. *Procedia Manufacturing*, *42*, 344-350.
https://doi.org/10.1016/j.promfg.2020.02.079

Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 42 (2020) 344–350

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

International Conference on Industry 4.0 and Smart Manufacturing (ISM 2019)

A self-assessment framework for supporting continuous improvement through IoT integration

Jonas Nygaard[a*], Michele Colli[a], Brian Vejrum Wæhrens[a]

[a]*Aalborg University, Dept. of Materials & Production, Faculty of Engineering & Science, Aalborg Øst, 9220 Denmark*

* Corresponding author. Tel.: +45 6196 7179 ; *E-mail address:* jonasn@mp.aau.dk

Abstract

The emergence of Industry 4.0 provides the promise of reaching a new plateau of productivity by supplying new means of process excellence, and as such, it brings many opportunities as well as challenges to practitioners. However, the knowledge of the process related to adopting digital technologies in organizations is scarce and so is the knowledge related to managing and measuring progress. Several maturity models and adaptations of other well-known frameworks are used to strategically address the digital transformation, but there is a need for more operational and context-specific guidance towards the integration of digital technologies, such as IoT. The purpose of this paper is to propose, following a design science approach, a self-assessment framework, which seeks to guide organizations in improving the performance of their existing processes through the integration of IoT. The framework aims at enabling individual organizations to assess their processes continuously from an information flow perspective (i.e. location, processing capabilities and use) identifying improvement potential to be leveraged by integrating such technology.

Keywords: Digital transformation; Industry 4.0 (I4.0); Self-assessment; Continuous improvement; Internet of things; Maturity assessment; Value stream mapping; Model development

1. Introduction

The emergence of the fourth industrial revolution (industry 4.0) is expected to pave the way for the manufacturing industry in terms of exceeding current operational effectiveness, providing new value propositions of products and services, and enabling new business models [1]. The interest in Industry 4.0, from practitioners, is continuously growing in anticipation of realizing these promised opportunities. One could argue that the concept of industry 4.0 has peaked on the hype curve (i.e. the concept has reached the peak of inflated expectations), and is now being addressed with some skepticism. Still, the willingness to experiment with the technologies and the adaptation is on the rise. While expectations towards results are high, actual results are still difficult to capture [2]. A survey conducted of the Danish industrial companies revealed that 73% organizations expect that IoT will offer significant opportunities within the next three years (compared to 40% globally), but only 60% of the participating organizations are already actively pursuing IoT initiatives (compared to 79% globally) [3].

There is an increased awareness that the digital transformation is multi-disciplinary, i.e. it not only addressees technologies but also competences, business models, governance structures, etc. [1,4]. Furthermore, organizations are different in terms of the way they operate, proprietary capabilities, strategic goals, and their presence in the market. The processual complexity following from considering the multi-disciplinary nature of the digital transformation together with the individual specificities of organizations means that high-level generic frameworks fail in providing context-

2351-9789 © 2020 The Authors. Published by Elsevier B.V.

10.1016/j.promfg.2020.02.079

specific guidance to the individual organization in how to operationalize the transformation [5]. Especially small- and medium-sized organizations (SME's) are struggling. They lack the experts required to cover all relevant disciplines, nor do they have resources available to apply these standard and time-consuming frameworks [6], and hereby they struggle to adopt the systemic requirements related to the industry 4.0 transformation where the objective is not only to adopt individual technologies, but rather to establish holistic production solutions.

The outset for this paper is the belief that the process of improving process excellence for organizations, through the use of IoT integration, must be supported by well-known and simple frameworks that consider the individuality of each organization to provide context-specific suggestions for process improvement. This is supported by the concept of zone proximity development developed by Vygotsky (1978) which argues that development is supported by boundary objects (i.e. frameworks), guiding the learner in defining what is required to move from the current zone of development to the next one [7]. Furthermore, the use of a self-assessment framework (the boundary object) for supporting continuous improvement is argued by Caffyn [8]. This facilitates a constructive dialog among the involved organizational entities, the establishing of a common understanding of the current state of capabilities (in this case digital capabilities) and of a common ground from which actions and development plans originate [8].

The presentation of the model development of this conceptual framework is the focus of this paper. This will provide the foundation for future work concerning its test and implementation.

The contribution of the paper lies in proposing an approach, which answers the need for operational guidance practitioners – SMEs in particular – may have in regards to the integration of digital technologies (such as IoT). Based on this, the following research question is defined: “How can companies identify continuous improvement potential related to the integration of IoT?”

To answer this, the authors developed a self-assessment framework, which companies can use internally – hence eliminating the need for external resources - for supporting the continuous monitoring and navigation of their process through the introduction of IoT. The framework focuses on the information flows within and across existing processes, aiming at increasing transparency and supporting decision-making processes. We argue that the purpose of IoT is to promote data transparency across processes (i.e. integration) to allow for a higher degree of digital data processing and connecting it to business processes and capabilities. The framework is constructed as a five-step process utilizing a tool from the well-known Lean toolbox – i.e. the Value Stream Mapping (VSM) [9] – for mapping the existing operations, as well as a novel digital maturity model – i.e. 360DMA [1] – for relating them to the new digital capabilities. The tools have been chosen as the organizations know them very well, and therefore we argue that it is easier for the individual organization to adopt the proposed framework. Therefore, to clarify, the contribution is not the tools utilized within the framework but how these tools are utilized in synergy to enable practitioners in, independently, assessing their use to IoT enabling technologies and identifying room for improvement in existing processes. The proposal of this novel self-assessment framework focuses on promoting increasing value creation by increasing connectivity through the deployment of novel technologies. The framework is addressing digital development on a tactical level through the investigation of operational processes, in contrast to digital maturity models which addresses digital development on a strategic level.

In the following, the paper presents the literature forming the basis for constructing the framework. Secondly, the methodology for the model development is presented, followed by a presentation of the self-assessment framework. Lastly, the potential and future work with the framework are discussed.

2. Literature review

2.1. Value Stream Mapping in the digital era

Since the definition of Lean production and lean tools such as Value Stream Mapping (VSM), for the identification of waste in production activities, it has been extended to consider logistics, product development, and other indirect business areas. [9]. The broad adoption of VSM at practitioners is argued, by Meudt et al., to be due to the holistic perspective utilized in the tool [10]. The emergence of digitalization has had a similar impact on the use of this iconic tool as a new generation of VSMs is promoted, which considers the increased demand for close interaction with external partners, stronger links between processes, etc. [10]. Meudt et al. propose VSM4.0 which intensifies the focus on information flow and incorporates a focus on information waste and integration between the physical material flow and digital information flow [11]. The process of VSM4.0 maintains the well-known steps of the classic VSM tool; defining added value, analyzing the current state, and defining the future state. However, the final step, concerning the future state, is altered to consider the digital element of the tool; the focus on the integration of material and information flow is materialized in the form of a reference model depicting the procedure for creating information integration [11].

2.2. Assessing maturity in the digital era

There is a consensus concerning the structuring of digital transformation through maturity models (e.g. models reviewed by Mittal et al. [6]). The concept and use of maturity have been deployed in the industry since the 1930s, as a method for describing and assisting the development of individuals and organizations [12]. While the concept was originally used in quality management it has later been deployed in a variety of evolutionary industrial contexts, all with the function of providing structured development paths through the use of maturity stages [13,14]. Accordingly, the purpose of maturity models is to provide, in a simplified form [15], the expected and desired development path within the individual theme [16]. Maturity models have faced criticism as being over-simplistic [17] and to not consider the diversity of contexts as only one maturity path is defined [18]. Mittal et al. conducted a review of the available maturity assessment revolving digitalization [6]. During this review, it was found that nine of 15 presented well-defined assessment approaches and/or an indication of the prescriptive outcome. Only two of these nine models considered the specific context through either company visits either interview which supports the criticism of these models for being over-simplistic. However, as the fourth industrial revolution, i.e. the digital transformation, is an evolutional development path [19], maturity models are fitting methods, despite the criticism, for describing this progression. One model, in particular, is addressing the need for being contextually accurate [1]. This proposes a six-stage maturity progression path addressing five organizational dimensions: value creation, technology, connectivity, governance, and competences [1]. Governance and competences are related to how the transformation is managed (e.g. agile approach) and what are the available skills and learning culture supporting it. Connectivity represents the magnitude of internal and external integration, while the technology progression concerns the increase of data processing capabilities. These go from the capability of generating digital data describing a behavior (basic stage) and, afterwards, of making them available according to value stream needs (transparent stage), to the capability of analyzing it (aware stage) and automatically processing the obtained information (autonomous and integrated stage) (Fig. 1.). Value creation is related to how the transformation is capitalized [1].

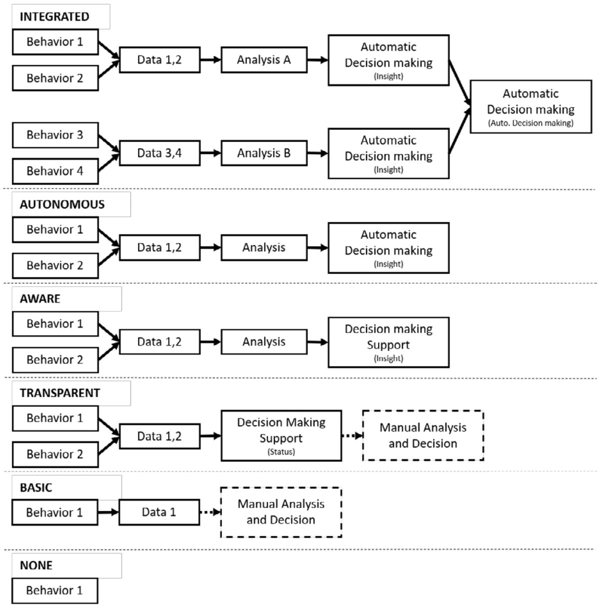

Fig. 1. Data Processing Capabilities.

2.3. Self-assessment frameworks

Self-assessment frameworks are well-known from the continuous improvement toolbox as a means for addressing such transformations. While these frameworks have been applied within various focal areas, their presence is primarily within the area of quality and continuous improvement (TQM). A study revealed that managers found these frameworks beneficial in understanding the concepts and importance of TQM, while 37% of surveyed managers (with considerable experience of self-assessment) argued that self-assessment frameworks are impacting business results positively [8]. Self-assessments have taken many different shapes, with varying success. Questionnaires for one may result in the respondents reflecting on the organization's practices but that does not make it a self-assessment [8]. Other frameworks have utilized external frameworks and models as reference models for organizations to compare themselves against [20,21], some of which prompts the respondent to score themes and detailed items on a scale (e.g. Likert scale) [22]. These self-assessment frameworks range in their coverage and level of detail. While some cover many aspects of an organization some are more specific, e.g. focus on how human resource practices conflict with total quality management [23]. Maturity has also been proposed for structuring self-assessments. Within the field of quality management, Crosby developed a maturity grid that considers five maturity stages related to six measurement categories for the quality operations of an organization [13].

3. Methods

This paper proposes a self-assessment framework, which must be useful in a practitioner's context, making design science a fitting methodology. Hevner et al. and Wendler proposed a design science research framework, describing how artifacts (i.e. the self-assessment framework) can be designed and tested [24,25]. In accordance to design science research framework [24] the work originating from the business needs from practitioners, the target user of this research, i.e. the desire for support in improving process excellence through the use of IoT integration. To understand the current state of the literature on the subject, a review is conducted which helps to build the foundation upon which the answer for the business needs is built. Furthermore, the review ensures the academic relevance of the proposed framework by focusing on the current state and the gaps currently present. In this case, the focus of the literature review is to identify current frameworks, structures, and processes for self-assessment in the context of digital transformation, and more specifically IoT integration, as well as the potential gaps. The investigation of the current literature is followed by the model development of the artifact. This consists of a self-assessment framework to empower practitioners in assessing their potentials of building process excellence through IoT integration. We focus on the Abduction process for the model development throughout this paper. We use the VSM method [10], with an extended focus on the information flow, to map the current state of the organization. The 360DMA [1] is utilized to link the current state of the information flow to digital capabilities and to provide the foundation for identifying a mismatch between current value creation and value creation potential due to the potentially sub-optimal use of the available IoT technologies. It is not sufficient to develop a structure for a framework, as testing is needed to evaluate the framework and its benefits [25]. Therefore further work is needed, focusing on testing the framework in the hands of practitioners. This future work revolves deductive reasoning, focusing on the contextualizing capabilities of the framework, i.e. its ability to provide context-specific improvement suggestions.

4. Model development

The proposed self-assessment framework is based on the VSM4.0 [10] in terms of its operational steps and on the 360DMA maturity model [1] in terms of the reference model used for identifying the improvement potential of the assessed organization based on the technologies (and of their digital capabilities) deployed for managing the information flow (i.e. is the potential of the deployed technology fully utilized?) (Fig. 2.).

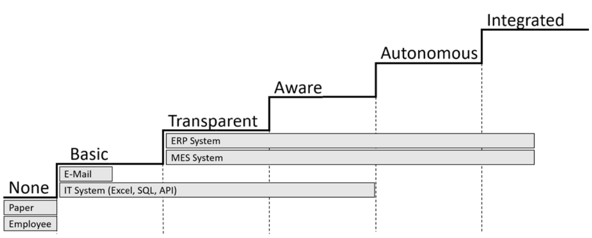

Fig. 2. Example of integration of OT (operations technology and IT (MES/ERP) plotted in relation to their digital capabilities (360 DMA maturity model used as reference)).

The proposed self-assessment framework consists of five sequential steps (Table 1.). These concern the identification of critical processes in order to be able to scope the self-assessment, the mapping of the activities the selected critical business process consists of, the identification of the technologies used to process the information flow across such activities, the evaluation of such technologies in regards to their digital capabilities (using the 360DMA maturity model as a reference model), and the evaluation of the mismatches between the maturity stage of the deployed technologies and their actual use for processing the information flow and creating value for the related process' activities.

Table 1. Steps of self-assessment approach.

Step #	ACTIVITY	REFERENCE
1	Scope identification (critical process)	Experience
2	Activity mapping	VSM4.0 [10]
3	Information flow mapping	VSM4.0 [10]
4	Technology mapping	360DMA [1]
5	Value creation mismatch	360DMA [1]

Initially, the scope of the self-assessment is identified by focusing on the most critical business processes (e.g. order processing, supply management, order fulfillment) and identifying the related performance objective. What is critical to a given organization depends very much on the individual context and its strategic capabilities. These interviews can be conducted either as one-to-one discussions or in larger groups consisting of representatives of various positions within the organization. The questions address the context and concerns elements such as the value proposition of the organization, the manufacturing strategy utilized, the critical performance objectives to the organization and its customers. The aim is to guide the effort of the self-assessment towards processes in the organization that are truly relevant for the success of the individual organization. The collection of data concerning critical processes is supported by interviews utilizing open-ended questions and their evaluation in terms of criticality – and, therefore, the identification of the scope of the self-assessment – relies on the knowledge of the involved stakeholders.

The second step concerns the mapping of the activities the selected process consists of. This activity is performed to gain an in-depth understanding of the current nature of the critical process. This mapping is done, according to the VSM4.0 practices [10], by breaking the overall process down into more detailed process steps. The investigation of the process's activities provides information such as activities' cycle time, number of employees involved in each activity, changeover time, etc. While some of the measures, such as the number of personnel, are not immediately required for the completion of this self-assessment, they may prove beneficial for evaluating the potential change in performance, from the continuous use of the framework. Hence, their inclusion is indirectly important for the entirety of the self-assessment.

Subsequently, the information flow involved in the performance of the addressed activities (e.g. supporting related decision-making processes) is mapped, following the structure proposed by Meudt et al. in their VSM4.0 [10]. The data source (i.e. where data is generated), sink (i.e. where data is used) and storage space are mapped for each flow of information across the process.

In the following step, the deployed technologies utilized for processing such flows of information, whether being in physical (i.e. paper, employee) or digital form (i.e. communication systems, operational IT, ERP, MES), are identified and mapped – using the 360DMA maturity model as a reference model – in relation to their data processing capabilities (i.e. technology dimension, see Fig. 1.) and integration level (i.e. connectivity dimension). The technologies are mapped both according to their actual use for processing information and to their potential capabilities (Fig. 2.). Data concerning the actual use of such technologies as well as their potential is collected through interviews with relevant stakeholders in the organization, involved in the use of the addressed technologies.

Eventually, the value creation mismatch is evaluated as the discrepancy between the potential and actual use of such technologies (for data processing and integration). This identifies if storage and processing technology are deployed in the organization sub-optimally (i.e. these do not deliver to their full potential). For this gap analysis, two outcomes are possible. If there is a value creation mismatch, the organization is not fully utilizing its current data storage and processing capabilities (i.e. deployed technologies for processing the information flow). This suggests the presence of a gap in the competences (e.g. lack of internal skills or learning culture) and/or the governance (e.g. lack of management support) dimensions, causing the sub-optimal use of the deployed technologies and limiting process improvement. If there is no value creation mismatch, the organization is facing a gap in technology and/or connectivity. This suggests the need for deploying more advanced technologies for support process improvement (e.g. the organization is currently utilizing MS Excel to automatically conduct analyses while a more advanced tool could be supported to perform automatic decision making).

It is the intention that the self-assessment is conducted regularly for each of the critical processes within the organization. Naturally, the efforts put into conducting the self-assessment are expected to be higher during the initial iterations, partly due to the unfamiliarity of the framework and partly due to lack of existing data to be utilized immediately. Furthermore, the frequency of which the self-assessment is conducted is expected to be strongly related to the rate of change, internal and external, as with no change the outcome of the self-assessment is expected to be the same. However, due to the subtle nature of change, it is suggested that the self-assessment is performed sooner than later.

5. Discussion

As called for by Röglinger et al. and Mittal et al., this research guides practitioners through the use of methods that consider context-specific processes and needs and hence supports a more situational transformation towards the digital organization [6,26]. Furthermore, this research addresses the digital transformation at a tactical and operational level in an attempt to make it more tangible for practitioners. Especially, the proposed self-assessment framework is addressing the need for providing SMEs with approaches which support their digital transformation and, in particular, the improvement of their operational performance through the integration of new technologies, without the need for relying on external resources and expertise [1,6]. To do so, the proposed framework is designed around a VSM approach, well-known and extensively used by a wide spectrum of companies, including SMEs. By relying on existing tools the applicability of the proposed self-assessment framework relies on the practitioner's familiarity with the utilized tools – i.e. for practitioners with no to limited knowledge of VSM efforts in acquiring knowledge of said tool is required, limiting the immediate applicability of the proposed framework. What differentiates this framework from the classic VSM used by companies is the focus on the information flow (already discussed by Meudt et al. [10]) and the inclusion of a digital maturity model (i.e. the 360DMA) as a reference model for the assessment of the technologies deployed to process the information flow and the identification of potential improvement possibilities concerning it. Such characteristics aim to translate the use of an effective self-assessment tool such as the VSM into the novel digital transformation language, extending what is proposed byMeudt et al. (i.e. VSM4.0) by identifying – as an output of the assessment – the gap in terms of technology capabilities use [10]. This is meant to facilitate the internal discussion and identification of potential improvement of existing processes, either involving the deployment of new technologies, either the facilitation of more effective use of the already deployed ones.

However, the lack of structured data limits the replicability of the proposed framework. Utilizing well-known tools such as VSM does not guarantee replicability as more organizations tend to modify these tools to their specific context, which potentially contaminates the tool itself as well as the outcome of the self-assessment. The emphasis on well-known methods in this framework seeks to do what self-assessments are meant to be: "very thought-provoking…" [8]. Through the process of conducting the self-assessment, the practitioners will engage in an internal dialog of how they are currently conducting their processes, as well as how their data storage and processing technology is utilized. However, like all self-assessment frameworks, this is merely a framework. Once the assessment is conducted the ability to act on the results is what creates value in the organization (i.e. the element of continuous improvement).

As the framework is yet to be tested and validated it is difficult to assess how it may impact and help practitioners in their digital journey. To test and validate the self-assessment framework multiple cases must be investigated. It is expected that the self-assessment framework can be utilized regardless of the context it is tested within, and that the steps are applicable accordingly.

A limitation is that a potential outcome of conducting the assessment is pointing towards missing capabilities within competences and governance without any immediate indication of what in particular is insufficient or how to overcome the insufficiency. The quality of the outcome and the proposed improvements are partly dependent on the users' ability to conduct the required data collection and analysis with no to very little guidance from experts. Furthermore, this assessment framework lacks operational indicators concerning how to operationalize the identified future potentials. This limitation was also identified in the maturity model presented by Colli et al. [5].

The proposed self-assessment framework addresses the brownfield context only, i.e. the use of digital technologies to support already existing processes. This is essential as many companies are facing the challenge of integrating new technologies in a traditional environment. The new computerized technologies, albeit the opportunities they promise, usually have critical shortcomings and a high degree of uncertainty that keep them from completely replacing the way companies are traditionally approaching processes. Thus, it is not simply a matter of replacing the traditional with the new but of combining the two cleverly to unlock performance. Organizations should experiment frequently, but not overload their organization. Besides being front-loaded, experimentation should be done through many simple experiments along the way, not through formalized handover tests at the end of the project to confirm decisions already made. However, the typical organization that moves to the frequent-experimentation mode can overload itself, thus slowing down decision making and defeating the value of the experimentation. Therefore, anticipate and exploit early information through ''front-loaded'' innovation processes. The idea here is that it is more efficient to get your learning behind you early in a project by experimenting heavily initially to discover what works and what does not. While this brownfield context is relevant for many practitioners, opportunities concerning operations in a greenfield context are present.

6. Conclusion

The contribution of this paper lies in addressing the digital transformation as a context-specific process with an outset in the distinctive task environment of the individual organization. The proposed self-assessment framework contributes with a sequential process of utilizing well-known tools – i.e. the contributing element is the sequence of steps, not the tools utilized in the individual step – for the practitioner to continuously assess their use of digital technologies to promote data transparency in existing processes – i.e. promoting IoT integration. This is supporting the improvement of digital maturity of an organization, [1,4,5,6] by following the logic of proximal zone of development [7]; arguing that progression in (digital) maturity is enabled by a boundary object (the framework) to guide the development from one zone of development to the next. Specifically, the use of a self-assessment framework is supporting continuous improvement due to its enabling of a constructive dialog across the assessed organization as well as of a consensus concerning its current state. This is providing solid basis for the definition of actions and project plans, such as the integration of IoT capabilities. Following the terminology of Vygotsky (1978) [7], through the use of the boundary object (the framework) it is expected that the assessed organization will be able to develop IoT capabilities which would not have been possible to learn without any assistance – i.e. bringing the organization from the zone of current development to the zone of proximal development. Conducting the self-assessment can be done by the individual organization without the need for page-after-page questionnaires and expert participants to analyze the structured data from said questionnaires. The proposed framework, which is yet to be tested, is a self-assessment framework developed for empowering practitioners to gain a more tactical and operational view of their current processes and the potential sub-optimal use of current technologies. The framework draws on well-known methods for assessing current operations. Furthermore, it is supported by reference models from digital maturity models for structuring the assessment and the discussion regarding future potential capabilities of technology.

The future work is two-fold. Initially, the testing of the proposed self-assessment framework is required leading to the validation of the framework. The validation lies in the ability of the model to contextualize into different scenarios. This is assessed through the testing of the model in different cases, from which the outcome and contextual factors are mapped for the tests. The testing is preferably performed through the use of multiple cases, each of which utilizes the self-assessment framework according to the proposed steps and subsequently comparing the outcomes according to their individually current use of technology and the suggestions from the framework. According to Sánchez et al., contextualizing capabilities of a proposed framework can be considered validated when, during the tests of said framework in real contexts, different factors of the context determines the outcome of the self-assessment [27]. Secondly, this self-assessment framework only addresses the brownfield contexts, i.e. the technological potentials in existing operations. Hence, we must also address the greenfield contexts, i.e. the technological potentials in new/future processes. In addition to that, there is a need for further research efforts towards the definition of how to operationally design IoT-based solutions addressing the identified continuous improvement needs.

7. References

[1] Colli M, Berger U, Bockholt M, Madsen O, Møller C, Wæhrens B. A maturity assessment approach for conceiving context-specific roadmaps in the Industry 4.0 era. Annual Reviews in Control 2019.
[2] Gartner. Gartner Hype Cycle. https://www.gartner.com/en/research/methodologies/gartner-hype-cycle. 2019. Accessed September 2019.
[3] Ericsson. A study of the adoption of "Internet of Things"among Danish companies. digital.di.dk/SiteCollectionDocuments/Analyser/IoT_Report_onlineversion.pdf. 2015. Accessed 12 July 2018 .
[4] Schuh G, Anderl R, Gausemeier J, ten Hompel M, & Wahlster W. Industrie 4.0 maturity index managing the digital transformation of companies. Acatech Study April 2017.
[5] Colli M, Madsen O, Berger U, Møller C, Wæhrens BV, Bockholt M. Contextualizing the outcome of a maturity assessment for Industry 4.0. Ifac-pa- personline 2018;5111:.
[6] Mittal S, Khan MA, Romero D, Wuest T. A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs). Journal of Manufacturing Systems 2018;49;194–214.
[7] Harland, T.Vygotsky's Zone of Proximal Development and Problem-based Learning: linking a theoretical concept with practice through action research. Teachting in Higher Education 2003;8-2.
[8] Caffyn, S. Development of a continuous improvement self-assessment tool. International Journal of Operations & Production Management 1999;19-11.
[9] Rother M, Shook J. Learning to see. Lean enterprise Intitute, Fourth Edition; 1999.
[10] Meudt T, Metternich J, Eberhard A. Value stream mapping 4.0: Holistic examination of value stream and information logistics in production. CIRP Annals - Manufacturing Technology 2017.
[11] Hartmann L, Meudt T, Seifermann S, Metternich J. Value stream method 4.0: holistic method to analyse and design value streams in the digital era. 6th CIRP Global Web Conference 2018.
[12] Shewhart, WA. Economic control of quality of manufactured product . ASQ Quality Press; 1931.
[13] Crosby PB, Free QI. The art of making quality certain : 17. New York: New American Library; 1979.
[14] Nolan, RL. Managing crises of data processing. Harvard Business Review 1979;3-4.
[15] Klimko, G. Knowledge management and maturity models: Building common understanding. In Proceedings of the 2nd European conference on knowledge management 2001.
[16] Becker, J, Knackstedt, R, Pöppelbuß, J. Developing maturity modelsfor IT management. Business & Information Systems Engineering 2009;1-3.
[17] De Bruin, T, Freeze, R, Kaulkarni, U, Rosemann, M. Understanding the main phases of developing a maturity assessment model. ACIS 2005 proceedings 2005.
[18] Teo, TS, King, WR. Integration between business planning and information systems planning: An evolutionary-contingency perspective. Journal of Management Information Systems 1997;14-1.
[19] Kagermann, H, Wahlster, W, Helbig, J. Recommendations for implementing the strategic initiative industrie 4.0. Acatech April 2013.
[20] Evans, JR. Something old, something new: a process view of the Baldrige criteria. International Journal of Quality Science 1996;1-1.
[21] Ghobadian, A, Woo, HS. Characteristics, benefits and shortcomings of four major quality awards. International Journal of Quality and Reliability Management 1996;13-2.
[22] Souza, SA. The Oliver Wight ABCD Checklist for Operational Excellence. 4th ed. New York: John Wiley and Sons; 1993
[23] Dale, B, Godfrey, G, Wilkinson, A, Marchington, M. Aligning people with processes. Measuring Business Excellence 1998;2.
[24] Hevner, AR, March, ST, Park, J, Ram, S. Design science in information systems research. Management Information Systems 2004;28-1.
[25] Wendler, R. The maturity of maturity model research: A systematic mapping study. Information and Software Technology 2012;54-12.
[26] Röglinger, M, Pöppelbuß, J, Becker, J. Maturity models in business process management. Business Process Management Journal 2012;18-2.
[27] Sánchez-Pi, N, Carbó, J, Molina, JM. A knowledge-based system approach for a context-aware system. Knowledge-Based Systems 2012;27.