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Contextualizing the outcome of a maturity assessment for Industry 4.0

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Abstract: The transformation of the manufacturing sector towards Industry 4.0 is setting the scene for a major industrial change. Currently, the need for assisting companies in this transformation is covered by a number of maturity models that assess their digital maturity and provide indications accordingly. However, in order to provide operational recommendations to diverse companies, there is a need for making the assessment company-specific. To cope with this challenge, this paper provides an illustration of a new digital maturity assessment approach - 360 Digital Maturity Assessment - which is based on the Problem Based Learning (PBL) model.

Keywords: Digital transformation, Maturity assessment, Problem Based Learning, Industry 4.0, Smart manufacturing

1. INTRODUCTION

Globally, the manufacturing industry is experiencing a tremendous change labelled as "The Fourth Industrial Revolution". This change, also known as Industry 4.0, is triggered by an exponential growth in new digital technologies such as cloud computing and internet of things. These provide an increasing number of new possibilities for the development of new products, processes and services. There are a lot of speculations about the potential related to the implementation of these new technologies (McKinsey and Company, 2015), ranging from the improvement in operational effectiveness to the increase of value provided through products and services (Schrauf et al., 2016) and entirely new business models. Not surprisingly, there is a great interest in Industry 4.0 driven by these expectations. A study performed among Danish companies shows that 76% of them expect digitalization to transform their business, offering significant business opportunities within the next three years, and 60% of them already have ongoing Industry 4.0-related initiatives (Ericsson, 2015).

Nevertheless, the digital transformation process involves multi-disciplinary activities and requires, therefore, a number of experts on diverse domains, which may not be present in all companies (small and medium enterprises, SMEs, in particular). This makes it difficult for many organizations to grasp the Industry 4.0 idea, still in is infancy, and to set up comprehensive strategies to address the digital transformation (Andulkar et al., 2018). Hence, there is a need for methodologies that can support companies in the operationalization of this transformation.

In order to answer this need, several digital maturity models have been published (see an overview in Schenk et al., 2015). They provide a framework to assess on a high level the digital maturity of the organizations along a well-defined evolution path. These maturity models are generally operationalized by the submission of a standard questionnaire to the organizations (see Appendix A, table 1). Answers are mapped in the defined maturity model and standard recommendations based on the assessed maturity level are provided to the organizations.

However, every organization is different: they have not only different characteristics related to their specific business but also diverse requirements and goals (Fig. 1). Hence, it is our belief that the process of defining a digital transformation roadmap has to be adapted to the specific context the company operates in. This conceptualization is the focus of the model development presented in this paper.

We will base our methodological approach on the Problem Based Learning (PBL) model: pedagogical fundament of Aalborg University recognised by UNESCO and which Aalborg University is continuously contributing to develop. The model has been introduced within the medical domain (Schmidt, 1983) to facilitate the learning process, answering the need for contrasting the approach of performing pre-defined diagnosis based on the first detected symptoms. According to it, every case is unique and has to be addressed based on the context, through an active interaction with the case environment (Savery et al., 1996). While case based approaches test the understanding of a problem through its verification among a number of cases, the PBL model bases the understanding of a problem on the specific contingency (Savery et al., 1996).

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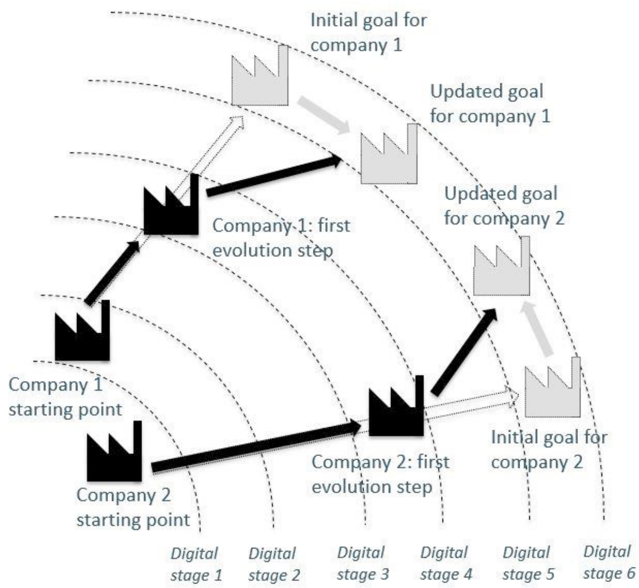

Fig. 1. Digital transformation direction of diverse organizations towards different and changing goals.

The contribution of this paper consists in bringing up the need for contextualization within the maturity assessment process in order to provide, as an outcome, company-specific guidelines, and propose an approach to cope with it. This leads to the following research question: i*s the PBL model suited as a methodological approach to contextualize the outcome of a digital maturity assessment?* To answer this, a new digital maturity assessment approach, the 360 Digital Maturity Assessment (360DMA) is proposed. It is composed by a novel maturity model used to structure collected information and by a methodology, based on the PBL model, to operationalize the assessment process. The paper provides an overview of the state of the art in terms of digital maturity models and defines the used one. Eventually it outlines the developed assessment methodology and describes a demonstration case to support the final discussion.

2. STATE OF THE ART

Both researchers and research institutions have published several digital maturity models (Lanza et al., 2016; Leyh et al., 2017; Lichtblau et al., 2015; Schuemacher et al., 2016), e.g. Fraunhofer IFF (Schenk et al., 2015) and Acatech (Schuh et al., 2017). Their common goal is to assess the digital maturity level of an organization and provide an indication of activities needed to increase this level. In order to do that, all of these models are based on the hypothesis that the digital transformation towards Industry 4.0 is an evolutionary journey (Kagermann et al., 2013) across a number of sequential digital stages, characterized by an increasing digital integration complexity. In other words, as a first key principle, they build on a cumulative capability perspective (Miller et al., 1994). As a second key principle, the digital transformation process is considered to involve a number of activities within multiple decision areas. Although different digital maturity models vary in terms of digital stages, number of dimensions that cover the different organization areas and implementation strategy (see Appendix A, table 1), they all present basically the same structure in terms of progression and arguments behind the different stages. Each maturity model provides a definition of the different digital stages and an indication of the considered dimensions. These elements create the framework used in order to map the current digital capabilities of the organization. These are assessed according to the definition of the different digital stages. The digital stage the organization is aiming for can then be identified. Through a gap analysis, the weaker dimensions are pinpointed as areas to be improved through the application of pre-defined activities selected depending on the digital stage.

3. THE MATURITY MODEL

The digital maturity model we are using is taking in consideration a number of existing digital maturity models (see Appendix A, table 1), ACATECH maturity model firstly (Schuh et al., 2017). In order to use a more familiar terminology and fitting scale for the Danish companies that are currently addressing – or starting to address - the digital transformation, a “zero digitalization” level has been introduced and the two “basic digitalization” levels presented by ACATECH have been unified. As an outcome, the maturity model used to assess the digitalization level of an organization is composed by six sequential digital maturity stages:

1. *None*: no digital awareness, idea or plan nor presence of digital data within the organization (e.g. everything is registered on paper or not registered)
2. *Basic*: digital processes are in place and operative as they generate digital data (e.g. machines on the production floor generate digital data related to their process) and there is a willingness towards the digital transformation from the management side
3. *Transparent*: data is collected and shared according to value streams needs (e.g. alert data from the equipment are collected and transmitted to the service department) and there is a digitalization plan from the management side in terms of development direction
4. *Aware*: data is analysed to capture valuable information in order to understand the business insights (e.g. proactive activities identification by crossing error data, product number, machine downtime, etc.) and there is a clear digitalization agenda (e.g. resources and activities are defined) shared at all hierarchical levels
5. *Autonomous*: decision making is performed autonomously based on automatically synchronized data from the organization and its direct customers and suppliers (e.g. logistics scheduling is automatically performed based on production state, customer orders and location, traffic condition etc.) and digital development is a well-established company practice at all hierarchical levels

6. *Integrated*: decision making is performed autonomously based on automatically synchronized data from the whole organization's network (e.g. suppliers' suppliers and customers' customers) and digital development is a well-established practice at all hierarchical levels within the whole organization's network

Each digital stage is considered to be the necessary enabler of the following, as its features need to be in place in order to pursue the digital transformation on a further level, e.g. to perform data analytics – aware stage - it is necessary to have data available – transparent stage - in the first place.

In order to map the digital capabilities of the organization, they are grouped into five areas, called *digital dimensions.* These have been obtained by clustering dimensions from the existing digital maturity models that have been analysed (see Appendix A, table 1). They consist of:

- *Governance*: indication of the current state of the company at an organizational level (e.g. strategy and plan, resource allocation, digital awareness, engagement on different hierarchical levels).
- *Technology*: presence of the elements that make possible to generate and process digital data (e.g. business intelligence tool, cloud computing platform, MES, ERP, augmented and virtual reality tools)
- *Connectivity*: availability of the infrastructural elements needed for data transmission inside and outside the organization (e.g. data sharing capabilities, IT security, standard data structuring or data transmission architectures)
- *Value creation*: ability to capture value from available data (e.g. pay-per-use or pay-per-save business model, take-back program, data usage for orders forecasting or product usage monitoring to enable predictive maintenance or guide the product design)
- *Competence*: presence of the mind-set and of the skills (internally or based on external partnerships) needed for performing the digital transformation and operate with digital solutions (e.g. digital competences, training culture, learning culture)

4. THE METHODOLOGY

The developed methodology is based on the PBL model and it is meant to act as a dialog tool between a company and the assessment party, whose aim is to provide a case-specific assessment outcome. The assessment paradigm therefore shifts from the currently used *expert model*, where a diagnosis is completely outsourced to external experts (Schein, 2009) to the *external helper model*, which bases the diagnostic process, facilitated by external experts, on the interaction with the assessed party (Schein, 1995, 2008). The involvement of the company in the assessment process not only enables a better learning of the case but also the acquisition of more valid data related to it (Lewin, 1997). The methodology is intended to be used iteratively in order to be able to adjust the transformation direction according to company goals changes and newly available digital technologies. The operationalization of the methodology requires, from the assessing party, the presence of field experts for the areas that have to be investigated, a mediator that directs the activities according to the methodology and a rapporteur that collects the information along the way. The assessment process consists of five sequential steps, built parallel to the PBL seven steps (Maurer et al., 2012) (Fig. 2).

At first, the c*reation of awareness* is addressed in order to present and clarify involved concepts and set the scene for the investigation. An overview of digitalization and of what is included in the industry 4.0 agenda in terms of technologies (e.g. cloud computing), implications (e.g. IT security) and use cases (e.g. predictive maintenance or autonomous guided vehicles) is provided. This activity can be done in several ways such as study visits, workshops with external experts and demonstrations in imaginary Industry 4.0 factories (e.g. Madsen et al., 2017).

The next task, representing for PBL the formulation of a research question, consists in the *definition of scope* from the company side: the unit of analysis considered in the investigation of the digital maturity is identified (e.g. one production line, one department, etc.). The scoping of the investigation goes through a short presentation by the organization about their understanding, status, strategic focus and perspectives in relation to the digital transformation.

Data collection is then performed, consisting in collecting information related to the organization and, specifically, to the defined unit of analysis. This operational step covers the three PBL steps related to idea collection, idea structuring and question identification. These tasks are here represented by the analysis of organization's information material, by the submission to relevant stakeholders (e.g. managers of functional areas involved in the digital transformation) of a "self-assessment" questionnaire and by the eventual preparation and execution of an expert interview workshop. This involves the relevant stakeholders and it is focused on low-graded and mismatching questionnaire answers. The workshop is divided in a number of sessions that covers the different areas that have to be addressed (e.g. IT, logistics, etc.) together with the related field experts from the company.

The *evaluation and solution selection* is aiming to answer to the formulated learning objectives by mapping the collected information within the defined digital maturity model. The current maturity stage of the organization (of the defined unit of analysis) is therefore assessed both at an overall level and in relation to each digital dimension. This is done by relating the collected information to the definition of the digital maturity stages that have been stated in the maturity model. The visibility of the maturity level of each digital dimension makes possible to identify the areas where digital enablers are lacking and therefore defines a direction for the improvement activities.

PBL		360DMA	
Step 1	Clarification of concepts	Step 1	Creation of awareness
Step 2	Formulation of the problem statement	Step 2	Definition of scope
Step 3	Idea collection	Step 3	Data collection
Step 4	Idea structuring		
Step 5	Identification of single tasks		
Step 6	Self-study	Step 4	Evaluation and solution selection
Step 7	Post-discussion	Step 5	Debriefing

Fig. 2. 360DMA methodology operational sequence parallel to PBL seven steps.

These activities are then selected according both to the measured digital maturity stage and to the strategic focus, goals and perspectives of the company, identified in step 2 (i.e. *definition of scope*).

Eventually, a *debriefing* covers the PBL post-discussion step: the assessment outcome is presented plotted on a spider graph (Fig. 5). A number of pilot projects in order to address the identified needs and achieve the next digital maturity stage are proposed.

5. DEMONSTRATION CASE

The 360DMA has been tested and initially validated by the authors within a large Danish manufacturing company. The aim was, other than the outcome for the assessed company, to validate the approach. In accordance to the presented methodology (Fig. 2), the assessment process started with the creation of awareness related to the industry 4.0 agenda. The authors, covering the field expert, mediator and rapporteur roles, provided an overview of new technologies, use cases and research projects to company stakeholders directly involved in the digital transformation of the organization. From their side, they presented the company business, key performance indicators and goals. The company vision has been identified as pointing towards the improvement of operations efficiency in the Danish production facility to increase the turnover of 10% yearly by reducing the impact of labour on product cost. The specific goals in order to move towards this vision concern production data visualization and analytics and the introduction of autonomous internal logistics. These elements helped defining the scope of the investigation by focusing on the Danish production facility and, specifically, on production data and internal logistics. A multiple answer questionnaire composed by 24 questions has been adapted accordingly and provided to the relevant company stakeholders (including the COO/executive vice president – project sponsor - the project manager for the digitalization agenda and four project team members: a corporate senior manager, an operations controller and the corporate senior director from the IT department and the supply chain director). Through the analysis of questionnaire answers, critical points have been identified as an undefined digitalization strategy (in regards to both resources and plan), unclear data accessibility and usage, a non-standardised IT infrastructure, low training practices, unclear digital capabilities, no benchmarking in relation to competitors, low digital devices in production and remote work possibilities. The data collection workshop has been planned involving the same company stakeholders and with a focus on these critical points, addressed in four sessions to cover the unit of analysis: customer ordering and production setup and execution, procurement and internal logistics, product development, IT. By discussing them, the non-standardised IT architecture and the unclear data accessibility and usage have been identified as particularly critical points in relation to the company goals. Once all the information related to the multiple critical points have been collected, the assessment process was finalized by mapping them within the maturity model according to the definitions of the different maturity stages. The organization has been assessed as aiming for the transparent stage. The gap that has to be addressed in order to achieve it concerns the connectivity area (Fig. 3). The limitations for the digital transformation are represented by the company tendency of developing tailor-made branches of the IT infrastructure anytime they are needed and by a lack of data structure. Due to them, the capability of collecting and sharing data according to value stream needs, i.e. transparent stage, is limited. According to that, one recommendation was to consider the introduction of a standard in regards to the IT infrastructure in order to facilitate the integration of new elements. Moreover, it has been suggested to standardise the way data are structured in order to enable data analytics and, eventually, sharing and visualization.

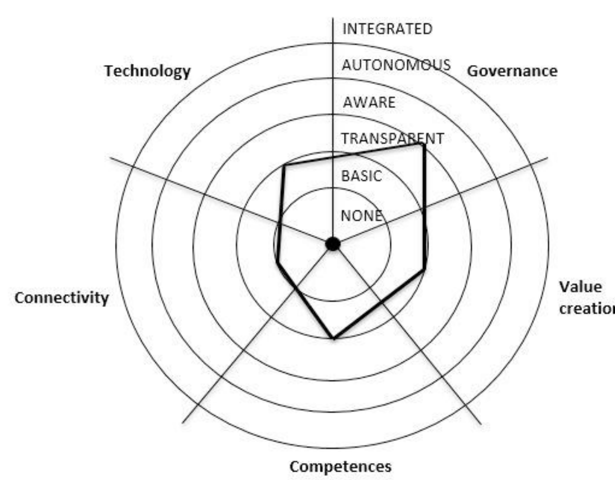

Fig. 3. Digital stage in relation to the five digital dimensions (demonstration case example).

6. DISCUSSION

The demonstration case shows how all the recommendations that have been provided as an outcome of the assessment process are not only based on the maturity stage but also directly related to the initial goals stated by the company. The process that led to their identification started from the initial company presentation and continued through a sequence of dialog elements – the questionnaire first, the expert interview later – that narrowed the investigation down to the digital transformation limitations concerning the specific context. However, to generalize the contextualization capabilities of the 360DMA multiple assessments have to be performed in organizations with the same degree of digital maturity but different characteristics and goals. A different outcome in terms of recommended activities should be observed. Besides, its capability to adapt to company goals changes has to be verified by performing multiple iterations of the assessment in the same organization. Different recommendations should back up different goals, even if the company and the digital maturity stage are the same.

7. CONCLUSION

The contribution of this paper consists in bringing up the importance of a contingency approach within the digital assessment framework and in proposing an approach to cope with that. The integration of the PBL model with the digital maturity assessment process is responding to a need for assisting diverse companies in their digital transformation according to their specific context. The developed methodology, tested through a demonstration case, acts as a dialog tool with the assessed company, investigating its specific context. Recommendations are provided accordingly and consist of company-specific activities. This makes possible to assist organizations in their digital transformation at an operational level. Further research efforts can be allocated on the development of toolboxes to operationally intervene to address the improvement of each one of the defined digital dimensions (e.g. identify where to introduce digital solutions to improve connectivity) and to quantify the related potential.

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Appendix A

Table 1. Industry 4.0 maturity models

Model name/ reference	Maturity stages	Dimensions	Comments
SIMMI 4.0 Leyh et al (2016)	Five stages: 1. Basic digitization level 2. Cross-departmental digitization 3. Horizontal and vertical digitization: 4. Full digitization 5. Optimized full digitization	Four dimensions: 1. Vertical integration 2. Horizontal integration: 3. Digital product development 4. Cross-sectional technology criteria	- Focus on the IT-landscape - General activities enabling stage transitions are presented
Schuemacher et al. (2016)	Likert-scale reaching from 1- “not distinct” - to 5 - “very distinct” -.	Nine company dimensions, further detailed into 62 maturity items: 1. Strategy 2. Leadership 3. Customers 4. Products 5. Operations 6. Culture 7. People 8. Governance 9. Technology	- General questionnaire
ACATECH Schuh et al (2017)	Six stages: 1. Computerization 2. Connectivity 3. Visibility 4. Transparency 5. Predictive capability 6. Adaptability	Four dimensions (Industry 4.0 capabilities), each one defined by two principles: 1. Resources 2. Information systems 3. Organisational structure 4. Culture	- Capabilities are examined for each area of the company - Questionnaire combined with visits
IMPULS Lichtblau et at (2015)	Six stages: 0. Outsider 1. Beginner 2. Intermediate 3. Experienced 4. Expert 5. Top performer	Six dimensions which are further detailed into 18 fields: 1. Strategy and organization 2. Smart factory 3. Smart operations 4. Smart products 5. Data-driven services 6. Employees	- On-line self assessment - Actions for stage transition are presented