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Industry 4.0 readiness in manufacturing companies: challenges and enablers towards increased digitalization.

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Abstract

Digitalization is changing the business environment and companies face challenges to make progress. A first step to support companies is to verify their digital readiness, capabilities, and developing clear plans for improvement. This paper aims to evaluate the digital readiness of seven companies through the application of a self-check tool, followed by a deeper investigation through a case study, to identify reasons, challenges/barriers and enablers towards digitalization. A workshop was conducted to evaluate the use of a self-check tool and collect other analysis. Results include the readiness level and comparison between companies, actions and practices towards increased digitalization.

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1. Introduction

A Smart Factory, representing the implementation of Industry 4.0 fundamentals, uses technologies in a way that business and engineering processes are integrated making production operate in a flexible, sustainable cost and resource efficient way [1, 2, 3, 4].

According to Geissbauer et al. [5, p.27] a roadmap for digital transformation starts by evaluating company's own digital level of maturity "(...) to understand what strengths you can already build on, and which systems/processes you may need to integrate into future solutions". When companies are able to respond to circumstances or environment in an appropriate way, they can achieve a higher maturity, which implies a potential for growth in capabilities and processes used to develop products or services [6, 7, 8].

The Swedish goal is to turn the country into the world's leading nation regarding sustainable manufacturing, innovation, digital transformation, and competitiveness. However, the country is actually losing competitive advantage when compared to other countries. There are not many well-functioning implementations in operation so far [1, 3].

In a previous study, Antonsson [9] investigated eleven large companies from different industries in Sweden, seeking to identify the maturity level in the manufacturing function towards transition to Industry 4.0. The results indicated a low digital maturity level in those industries, lack of a strategy for Industry 4.0 implementation, and prioritization of the topic in not more than 60% of the companies. The author suggested that further investigation is needed regarding the enablers and paths for implementation.

Therefore, the research questions arise: (1) What are the challenges, barriers and enablers that companies are facing

towards digitalization? (2) Is the use of digital maturity assessment an useful way to evaluate the current-state of the digital readiness and to provide a path for improvement? The purpose of this paper is to present the results of a preliminary investigation of the digital readiness from a set of seven manufacturing industries of different sizes, identifying challenges, enablers, and best practices in the journey towards increased digitalization. Results from the readiness assessment are compared with the ones provided by ‘IMPULS Report’, from German industries [10]. Complementing, a case study is conducted at one of the assessed companies.

This research is part of a broader project called ‘SMART PM’, focused on how to prepare the organization for the digital shift, and how to move up in terms of digitalization matureness by cost efficient automation of performance management.

2. Conceptual background

Due to the large number of publications about Industry 4.0 and different definitions, the first part of this section aims to present conceptual terminology that guided the research and the second part presents characteristics of more digital mature companies and challenges and barriers identified in previous studies and global surveys.

2.1. Terminology

As listed by Kane et al. [4] one of the challenges of the fourth industrial revolution is to identify a common language, that makes it possible to find a common ground or at least a starting point for the discussions. This paper does not aim at presenting an extended Industry 4.0 terminology review. The intention is just to present some relevant concepts identified during the research.

The terms digitization, digitalization, and digital transformation are been largely used in the Industry 4.0 context. For the aims of this research, digitization represents the transformation of the information process from an analog to a digital format; digitalization is connected with the use of the technologies and data to improve and transform the business processes; and digital transformation is a broader term encompassing changes in the business models, activities, processes, and competences to enable to have all benefits of the full deployment of the new technologies, i.e. “(...) *questioning existing ways of managing and structuring it, but also challenging everyone in the organization*” [4, p.4, 12]

Industry 4.0 or the *fourth industrial revolution* represents embedded and connected systems erasing the boundaries between the real and the virtual factory, represented by the Cyber-Physical-System (CPS) and the Internet of Things. Big data is large datasets, continuously updated, that cannot be analyzed by conventional methods, i.e., data analytics processes need to be deployed to analyze the big data, creating useful insights that support the decisions, enabling data-driven processes. All processes are supported by information and communication technology, represented by

all devices and systems that can enable the data to be digitized, processed, stored, and transmitted [3, 10].

According to Westerman et al. [13] digital maturity is a combination of the digital intensity (investment in technology to change how the company operates) and transformation management intensity (developing the capabilities necessary to drive digital transformation). Newman [11] defines digital maturity as a goal, always changing and improving. Kane et al. [4, p.6] define maturity as “(...) *a continuous and ongoing process of adaptation to a changing digital landscape*”.

To Schumacher et al. [14, p.162] the difference between readiness and maturity is that readiness should be used for assessment “*before engaging in the maturing process, whereas maturity aims to assess the as-it-is situation whilst the maturing process*”. As the characteristics of the companies analyzed in this research is unbalanced, i.e. some of them are already embracing the fundamentals of Industry 4.0, while others are starting to engage, both terms were used.

2.2. Challenges towards increasing digitalization digital transformation

New technologies (digital or mechanical) are not seldom developed and implemented without the whole organization being ready to fully utilize its potential [9]. Some global surveys are indicating that companies from various sectors are getting more mature on the digital transformation [4], and it is possible to identify similar patterns, and also similar challenges and barriers, listed in Table 1.

Table 1. Characteristics and challenges of maturing companies.

Characteristics of more mature companies	
Make digital a core part of organization - clear digital strategy	Build skills, talents, and capabilities to implement the strategy
Flexibility and ability to adapt	Decentralized decision-making
Strong and digital fluent leadership	Use KPIs for machine learning
Challenges*	
1. Improve automation of individual or even all business processes	2. Distributed decision-making systems
3. Reengineer existing business models	4. Integration of the organizational structure
5. Competitive pressures to change	6. Workforce with different ages
7. Find the right technology	8. Lack of digital skills
9. Balance between tactical, strategic, operational and financial KPIs, used to anticipate the future.	10. Develop incentive systems shared for all the partners involved
Barriers per maturing stage	
Initial: lack of strategy; too many priorities; lack of management understanding.	
Developing: too many priorities; lack of strategy; insufficient tech skills.	
Maturing: too many priorities; security concerns; insufficient tech skills.	

Source: [4, 5, 13, 16, 20]

* the reference numbers will be used in table 2.

Westerman’s et al. [13] found that companies, being more mature in leadership, are more profitable and generate more

revenue through their resources. The leadership capabilities are: Vision - have a strong vision framing in people's minds about the future; Governance - investment in rules and coordination mechanisms to improve efficiency and to ensure that the digital efforts are moving in the right direction; Engagement - employees' engagement in a shared vision; IT-Business relationships - redefining the business supported by a digital agenda.

The McKinsey Survey also listed barriers involved in digital transformation: breaking the walls between functions across the entire organization; lacking courage to achieve the changes required; lacking the necessary skills and expertise and fear about working with third-party providers; concern about sharing data and IT security on the partners' side or in transit; lack of business cases to justify the investments in data and systems structure [15]. Therefore, investing in technology will not make a company succeed or become more mature in digital transformation, because the digital strategy and purpose should lead the digital transformation [16, 17].

3. Methods

This exploratory research was developed in three phases: data collection using the self-check tool called 'Industry 4.0 readiness online self-check for businesses', developed by the IW Consult and FIR at RWTH Aachen University [10]; workshop to present general results and evaluate the use of the self-check tool and other insights; case study to explore challenges and enablers towards Industry 4.0.

The seven companies' participants of the self-check belong to different industries: aviation, machining processes, plastic packaging, heavy vehicles, and automobile. About companies' size: 4 are classified as large (500 or more employees), 1 as medium (100 to 499 employees), and 2 as small (up to 99 employees).

3.1. Industry 4.0 readiness online self-check for business

Analyzing the survey results presented by Lichtblau et al. [10], the self-check tool was considered a relevant reference for benchmarking and comparison, in total 602 manufacturing industries joined the survey. The tool is based on the 'The Readiness Model', formed by six dimensions and 26 questions regarding: strategy and organization; smart factory; smart operations; smart products; data-driven services; and employees; and, six levels: Outsider, Beginner, Intermediate, Experienced, Expert, and Top performers (details about the levels are provided in Appendix A).

The results presented are from the self-check assessment and some inputs from Lichtblau et al. [10]. In the questionnaire, an extra question was added in order to further investigate the challenges for Industry 4.0 implementation. The extra question was developed based on Kane et al. [4].

3.2. Workshop

The workshop was held at one of the companies, as part of the project meeting agenda. First results from the readiness

assessment were presented and discussed between all participants (from companies and research partners), and first insights were collected.

The purpose of readiness assessment was also to test the 'Industry 4.0 readiness self-check for businesses', which was chosen due to its adherence with the SMART PM project's scope. In the workshop and in the feedback the participants share their experience, both related to the process of answering the questions, and about the results provided.

3.3. Case studies

Case studies offer opportunities for a better understanding of contemporary and complex issues and a deeper understanding of the topic [18,19]. The case study was conducted at one company, and limitations of a single case study was mitigated through:

- Case selection - defined by the project group, based on the representativeness of the company in its sector and internal projects that the company is developing towards increasing digitalization.
- Multiple respondents – 6 interviews in total including different levels with: Management Systems & Data Analysis Director; Manufacturing, Projects, IT and Maintenance Managers; and Electronic engineer.
- Multiple sources of evidence – secondary document analysis; semi-structured interviews; direct observation.
- Multiple researchers: 2 researchers conducted data collection. Excluding the document transcription of the recorded interview (single), other products of evidence gathering (e.g. individual notes) were compiled and validated by the researchers in a single document.

The interview protocol was divided in 5 parts: Digital Strategy; Digital Maturity Models; Digitalization; Investments; Data Analysis and KPI's. Details about the company will be provided in the next section.

4. Results

This section is structured in 4 parts: (1) results from the readiness assessment and comparison; (2) companies' insights from the results and feedback about the readiness assessment tool; (3) case study; (4) discussion.

4.1. Industry 4.0 Readiness Check

First of all, it is important to highlight that not all results from the self-check assessment will be provided in this paper. The focus will be to report the overall evaluation of the companies, followed by some results related to strategy and organization, smart factory and operations, data-driven services and employees. The comparison results were provided by the self-check tool for each company connected to their respective comparison group (e.g. manufacturing and number of employees). First, the overall evaluation for each company and their comparison group's results will be presented.

Between the small companies, the overall evaluation was Level 1 (Beginner). In the comparison group 26% are in the same level (1), 64.8% are in Level 0, 6.8% in Level 2, 1.6% in Level 3, and 0.8% in Level 4. The Medium company was assessed as Level 0 (Outsider), and in the comparison group 45.8% are in the same level, while 40.9% are in Level 1, 11.5% in Level 2, 1.7% Level 3. The overall evaluation for the large companies was not the same, Large company 1 reached Level 1(Beginner), Large 2 and 3 reached Level 2 (Intermediate), and Large 4 reached Level 3 (Experienced). In their comparison group 30.8% of the large manufacturing companies are in Level 0, 45.2% in Level 1, 19.8% in Level 2, 3.9% in level 3, and 0.3% in Level 4. There were no companies in Level 5 in any of the comparison groups.

According to Lichtblau et al. [10] the main obstacles for Levels from 0 to 2 are similar: little or no knowledge about Industry 4.0 and its economic benefits; little or no market needs; very few or no skilled staff; and, lack of corporate culture. For Levels 3+ the obstacles are: lack of financial resources; norms, standards and legal frameworks; and, skills. The authors also highlighted that it will be difficult for a company to reach a higher level of readiness without partners along the value chain, and that the engagement of the management team, leading the strategy development is critical.

The seven companies were also invited to identify challenges that they are facing to increase digitalization and to compete more effectively in a digital environment. Results confirmed those extracted from the literature (Table 1), and Table 2 presents results from each case, excluding Large company 2 that did not answer but added a new item in the list, “IT/OT infrastructure I4.0 maturity”.

Table 2. Challenges in the perspective of the sample companies.

Cases	1	2	3	4	5	6	7	8	9	10
Small 1	x				x		x		x	x
Small 2	x			x	x		x		x	
Medium	x	x	x	x			x	x	x	x
Large 1	x	x			x	x	x		x	
Large 3	x	x	x	x		x	x	x	x	x
Large 4	x	x	x	x		x	x	x	x	

Some points that call for attention to the results listed in Table 2 is that lack of skills (8) was not listed by the small companies and Large 1 (Beginners), one hypothesis is the little or no knowledge about the topic, which make difficult to identify the skills required. Beginners also pointed competitive pressures to change (5) as a challenge, and one hypothesis is the impact of the market and the power of large enterprises. Finding the right technology and experiment and define balanced and smart KPI's (1 and 9) were chosen by all companies, and hypotheses to be investigated are: fear of taking risks; no financial support; lack of skills; little or no systems integration and IT infrastructure; lack of data analytics capabilities.

The self-check also allowed evaluation of each one of the dimensions. Table 3 presents the maturity level for each

dimension and the results of comparison groups for the same level in brackets (provided by the self-assessment report):

Table 3. Assessment and comparison of each dimension*.

Cases	Strategy	Smart Factory	Smart Operations	Data-driven	Employee
Small 1	0 (75.9%)	2 (10.1%)	2 (36.1%)	0 (92.3%)	1 (23.5%)
Small 2	2 (6.5%)	1 (10.3%)	1 (4.8%)	0 (92.3%)	2 (10.5%)
Medium	0 (70.1%)	0 (58.1%)	2 (38.8%)	0 (92.6%)	0 (39.3%)
Large 1	2 (15.8%)	2 (25.6%)	3 (16.7%)	0 (92.6%)	2 (2.9%)
Large 2	2 (15.8%)	1 (30.8%)	3 (16.7%)	0 (92.6%)	2 (2.9%)
Large 3	2 (15.8%)	2 (25.6%)	3 (16.7%)	0 (92.6%)	2 (2.9%)
Large 4	4 (2.6%)	2 (25.6%)	4 (0%)	0 (92.6%)	4 (14.7%)

*Source: companies' individual Self-Check report

Table 3 results are aligned with the ones reported by Lichtblau et al. [10], that there is a correlation between the size and the readiness level, i.e. large companies are a step ahead in implementing Industry 4.0 than small and medium enterprises (SME's). Possible reasons are: SME's are waiting to see the advantages; lack of competence and resources; uncertainties about risks/opportunities. In the 'data-driven services', both Swedish and German companies are underperforming in this dimension.

A list of actions was provided for each company, and due to the relevance of the 'digital strategy' for reaching a higher level of maturity, this paper presents in Table 4, as an example, the roadmap to improve this dimension.

Table 4. Actions to improve the readiness of the Digital Strategy dimension

Level	Actions
0	preparing for Industry 4.0 in the departments, then work toward developing a digital strategy; introduce a system of indicators to further implement Industry 4.0; start by introducing a systematic technology and innovation management in one area and gradually expanding it to all areas.
1	use the pilot initiatives to develop a viable Industry 4.0 strategy; introduce a system of indicators to further implement Industry 4.0; expand the systematic technology and innovation management in other areas with the goal of integrating them.
2	continue developing the strategy and formulate a specific Industry 4.0 strategy with initial implementation measures; introduce a system of indicators to further implement Industry 4.0.
3	identify units in which the Industry 4.0 strategy has not yet been implemented and establish Industry 4.0 there as well; ensure that system of indicators is incorporated into the strategic process.

4.2. Industry 4.0 Readiness Workshop

A total of four companies provided feedback about the experience with the readiness assessment. To all companies the results reflected their current state, and the guidelines useful. Two of the four companies considered the

questionnaire not comprehensive enough, and also that the topics were not covered adequately. Two companies used team work to answer the questionnaire, including: maintenance, logistics, industrialization (Large 1); manufacturing engineering, project management, maintenance, and quality & safety (Large 3).

There were also some specific comments about the question, terminology and understanding: *“Questions are very open and based on what reference and insight you have the answers may differ a lot”* (Large 2); *“We have different experiences, language and knowledge and may not be aware of solutions at other parts of the organization* (Large 3). All companies considered the use of a readiness assessment relevant: *“(…) is important to identify what areas we need to make sure we cover and support to make things happens. It’s good when you do the mapping to understand* (Large 3). In the workshop, a number of insights came up:

- Defining the scope is a critical issue for maturity assessment, e.g. the whole organization or a specific unit?
- Concepts and language alignment are necessary before starting the assessment and for the implementation process;
- The assessment needs to be done following a consensus process involving cross-functional teams and top management engagement.
- The level of digitalization is increasing but, in most of the cases, is not aligned with the business strategy.
- A systemic view of the manufacturing process is a fundamental concept for Industry 4.0 implementation.

4.3. Case Study Large Company 3

The company ‘Large 3’ is a Swedish heavy machine industry, with factory in several countries. The analyzed unit has around 1000 employees. The company started to discuss digitalization at the management level focusing on increasing processes speed: *“(…) in the last 4 years the company is discussing it, and in the last 2 years some projects started to be implemented and a year ago become part of the strategic agenda”*.

The company is running a global project towards digitalization including a mix of people from production, maintenance, assembly, welding, IT, management systems, electronics, project manager, etc. from different plants. The purpose of the team is to identify competences, challenges and opportunities, develop use-cases approach. All interviews were conducted with members of the local team, where the readiness assessment was conducted.

The company considers its digital strategy to be under development: *“Not mature enough to define the requirements yet”*. The starting point of the discussion was what digitalization means to the company and the answers included: *“To collect, analyze and monitor our equipment and processes”* (IT, Project, Maintenance and Electronics); *“So far, is really technology focused”* (Director); *“Is not about the machines, it’s about using the technology for communication, solving competences and gaps”* (Manufacturing).

Reasons for increasing digitalization listed were: safety, quality (both of data and output), decision-making, efficiency (IT and Director); identifying machine conditions (Maintenance); collect and use the data (Project); controlled and stable process; increase efficiency (Director); close the resource gap, increase speed and be able to analyze the data that we are already collecting (Manufacturing).

The enablers identified were: freedom to develop innovative solutions; improve understanding of own production; break down the boundaries between functions; have the same language; create a culture; communication. The challenges listed were: culture (users resistance based on fear of the new and about how the data will be used); data-driven culture governance (ensure that the data will not be misused); lack of internal knowledge (about needs and benefits with the use of the technologies, internal capabilities of the areas, and how other areas can work together developing projects); communication (lack of a common language and organizational distances); resources (few people with right competences and few investments); to integrate all the systems; different levels and needs between the units; partial support from the top management.

Regarding best practices, the company listed: working with a cross-functional teams and improve transparency to show and share initiatives; having specialists mapping competences and needs; prepare the organization identifying important areas that will bring the company to the next level; optimized and shared projects; regular team meetings to prioritize and create a shared language and view; during the implementation processes promote discussions and demonstrations to help the operators and managers, also making clear that the solution will not be used against them.

5. Final discussion and Conclusions

The results confirm that many companies, which are focusing mainly on the technology, forget to start at the “right” point. Companies are jumping into technical matters, which could be necessary to show its possibilities and benefits, but it may be problematic if they forget to do the investigation about what they want to achieve, how the competitive priorities can benefit from digitalization, and what changes need to be performed.

The journey towards digitalization is a long road, e.g. even starting to discuss the topic 4 years ago, Large 3 is facing obstacles (technical and managerial) that are preventing the company to take the next step. The challenge can be even harder for small companies, but the challenges for the large ones for integration and establishing a common strategy can also be hard due to the higher level of complexity and different goals.

The benchmark indicates that the majority of the Swedish companies analyzed are overall in the same level of the German manufacturing industries, i.e. taking the initial steps towards digitalization and facing similar challenges. Lack of knowledge is still an obstacle. This indicate that companies need to increase efforts on training, identifying internal competences and promoting strategic hiring processes. Data-

driven processes are a gap for all types companies and configures one of the main challenges.

Besides cost and speed, companies also need to look to other benefits of digitalization in terms of other competitive priorities (e.g. flexibility, quality, deliverability and sustainability) Winroth et al. [21] showed that it is essential for achieving sustainable production to measure performance efficiently, which calls for more automatic collection and treatment of data.

The purpose of this paper was to investigate the digital readiness of a set of manufacturing industries and the results indicate a majority are in the initial maturity levels. Challenges, barriers, enablers, and best practices were identified. Future research include extend the case studies to all companies, and a further study about the development of a new digital readiness assessment model also is relevant.

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Appendix A. Summary of IMPULS maturity levels

Level 0 Outsider: Company does not meet any of the requirements for Industrie 4.0.

Level 1 Beginner: Pilot initiatives and investments in a single area; Few production processes supported by IT systems; Equipment infrastructure partially satisfies future integration; System-integrated limited to a few areas.; Skills needed are found only in a few areas.

Level 2 Intermediate: developing a strategy and indicators to measure the implementation status; Some production data is automatically collected and being used to a limited extent.

Level 3 Experienced: Company has formulated an Industrie 4.0 strategy; IT systems in production are linked through interfaces and support the production processes; Data in key areas automatically collected; Equipment infrastructure is upgradable; Extensive efforts to expand employee skill sets.

Level 4 Expert: Already using an Industrie 4.0 strategy and monitoring it with appropriate indicators; IT systems support most of the production processes and collect large amounts of data, which is used for optimization; In relevant areas, the company has the necessary skills.

Level 5 Top Performer: Industrie 4.0 strategy implemented; Regularly monitors the implementation status of other projects; Comprehensive IT system support in its production and automatically collects all the relevant data.

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