

RESEARCH ARTICLE

DESIGNED

Designing industry 4.0 implementation from the initial background and context of companies [version 2; peer review: 3 approved]

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Abstract

Industry 4.0 is a promising concept that allows industries to meet customers' demands with flexible and resilient processes, and highly personalised products. This concept is made up of different dimensions. For a long time, innovative digital technology has been thought of as the only dimension to succeed in digital transformation projects. Other dimensions have been identified such as organisation, strategy, and human resources as key while rolling out digital technology in factories. From these findings, researchers have designed industry 4.0 theoretical models and then built readiness models that allow for analysing the gap between the company initial situation and the theoretical model. Nevertheless, this purely deductive approach does not take into consideration a company's background and context, and eventually favours one single digital transformation model. This article aims at analysing four actual digital transformation projects and demonstrating that the digital transformation's success or failure depends on the combination of two variables related to a company's background and context. This research is based on a double approach: deductive and inductive. First, a literature review has been carried out to define industry 4.0 concept and its main dimensions and digital transformation success factors, as well as barriers, have been investigated. Second, a qualitative survey has been designed to study in-depth four actual industry digital transformation projects, their genesis as well as their execution, to analyse the key variables in succeeding or failing. 46 semi-structured interviews were carried out with projects' members; interviews have been analysed with thematic content analysis. Then, each digital transformation project has been modelled regarding the key variables and analysed with regards to succeeding or failing. Investigated projects have consolidated the models of digital transformation. Finally, nine digital transformation types have been identified.

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Keywords

Industry 4.0; Digital transformation models; Digital technology; Readiness models;



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REVISED Amendments from Version 1

This new version aims at clarifying the research questions, the digital transformation model and its related nine types of digital transformation, the consequences of the results regarding the theoretical maturity models and the further research to be undertaken.

A correction has been made in the title of Table 11 that was not consistent with Table 10.

Any further responses from the reviewers can be found at the end of the article

1. Introduction

“Industry is central to Europe’s future progress and prosperity” states European Commission in a recent policy report (EC, 2020a). Since 2004, European industrial and research organisations have pointed out the urgency to transform industry by relying on digital enabling technology (Manufuture, 2004). The German manufacturers next formalized the Industry 4.0 concept (Acatech, 2013) before being joined by every developed country (Brissaud *et al.*, 2013). New digital technologies such as cyber-physical systems, robotics, big data, modelling, and simulation tools as well as virtual and augmented reality are at the core of the fourth industrial revolution. They enable industrial companies to meet new customers’ expectations with smart, mass-customized, and resource-efficient products. They also enhance production systems that become more flexible and learning oriented (Acatech, 2013). Yet, the implementation in companies does not achieve the expected performance in many cases and digital transformation project stands at the pilot phase (Kroll *et al.*, 2016; McKinsey, 2018; Tecknowlogy Group, 2019). In 2018, the Digital Manufacturing global survey carried out by McKinsey firm consulting has shown that only 30% of companies have moved from a digital manufacturing pilot phase to a complete digital solution implementation (McKinsey, 2018). Impact at scale has not been achieved and the main reason reported by industrialists is the lack of return on investment (ROI) with regards to the costs of implementing digital manufacturing solutions. The performance of industry 4.0 is not clear for companies. Even if digital technology is considered as the main success factor to succeed in the transition towards industry 4.0, other aspects such as strategy, industrial organisation, and work and competencies issues have been highlighted in scientific literature and should be considered when it comes to running digital transition projects. From these findings, maturity models have been designed to support companies to achieve it (Biegler *et al.*, 2018; Carreiro Santos & Martinho, 2018; Pessot *et al.*, 2020). These maturity models aim at describing from a theoretical point of view what a company should do when implementing industry 4.0 technologies and processes. They take into consideration the different areas that a company has to deal with such as technology, organisation, strategy, and human resource issues and define the different steps to achieve a complete industry 4.0 implementation. Moreover, several studies have investigated barriers that hinder the uptake of industry 4.0 solutions by industry and then looked

for identifying success factors when implementing industry 4.0 technology (Da Silva *et al.*, 2020; Kroll *et al.*, 2016; Pessot *et al.*, 2020; Sony & Naik, 2020; Tecknowlogy Group, 2019). These barriers are diverse and related to the different areas of a company; it could be about lack of strategy, technical and IT issues, lack of skills, market uncertainties, cost of investment, and performance assessment. Yet, according to several recent industry and policy reports, the industry 4.0 implementation is slower than expected (Ortt *et al.*, 2020; Tecknowlogy group, 2019). Current approaches are either too theoretical (one single digital transition model is addressed for any type of company) or too empirical (key variables are too various and linked to specific industry sectors) for companies and especially for Small and Medium enterprises (SMEs), to appropriate the concept and implement it in actual situations. Moreover, they do not consider companies’ backgrounds and context when it comes to implementing industry 4.0. Our hypothesis is that initial companies’ background and context is crucial when designing industry 4.0 projects. The result is that there would be several digital transformation types resulting from companies’ initial background and context.

Against this background, the following research questions (RQs) have been posed:

RQ1: How do companies implement digital transformation project?

RQ2: What are the key variables?

The ambition of the paper is to understand and analyse the way companies implement and manage digital transformation projects and what are the key variables they deal with. It also aims at contributing to scientific literature on digital transformation in industry, the key success factors and the diagnostic tools to support it. It relies on the results of a qualitative survey carried out in four French industry companies that vary in terms of size, activity sector, products, and market. It identifies key variables and their combination considering the company’s background and context. The novelty of the research lies in 1) analysing in-depth actual digital transformation projects to identify key variables in succeeding or failing; and 2) characterising nine digital transformation types resulting from the combination of the key variables. The paper is featured in five sections. Section two reviews the research background. Section three describes the methodology of the survey designed to answer the research questions. Results are presented in section four and finally, section five discusses the results and concludes the study.

2. Research background

2.1. Industry 4.0 concept definition

Industry 4.0, also called “Fourth Industrial Revolution”, “Smart Factory” or “Factory of The Future”, is now well detailed (Da Silva *et al.*, 2020; Ghobakhloo, 2018; Osterrieder *et al.*, 2020; Oztemel & Gursev, 2020; Pereira & Romero, 2017; Pessot *et al.*, 2020; Xu *et al.*, 2018). It is characterised as the convergence of physical and virtual world, known as a cyber-physical system, to reach a new level of production systems’ performance

(Fatorachian & Kazemi, 2018; Monostori *et al.*, 2016; Thoben *et al.*, 2017). To achieve this, it relies on innovative digital technologies such as the industrial Internet of things, cloud computing, big data, virtual simulation, augmented reality, additive manufacturing, advanced robotics, or cybersecurity that allow machines, products, and people to provide and exchange data in a seamless way. The real-time availability of data allows production systems to be optimised in real-time over the value chain (Alcácer & Cruz-Machado, 2019). This enables production flexibility and makes it possible to meet the order variability for small batches or even unique products. New industrial organisation methods have been designed to reach a new industrial performance (Moeuf *et al.*, 2018; Qina *et al.*, 2016). The factory of the future is a smart factory defined by a vertical integration of processes, a horizontal integration of the supply chain, and an integration of the whole product life cycle (Alcácer & Cruz-Machado, 2019). Implementing these disruptive digital technologies has been considered for a long time as the main dimension and the main implementation success factors in succeeding in digital transformation (Ghobakhloo, 2018; Liao *et al.*, 2017; Lichtblau *et al.*, 2015; Osterrieder *et al.*, 2020). Nevertheless, several studies have considered that the implementation of digital technology especially in SMEs faces many other challenges such as organisational and economic issues (Brettel *et al.*, 2014; Kroll *et al.*, 2016). Indeed, industry 4.0 is far from being reduced to digital technology. It encompasses economic, social, and organisational dimensions (Ortt *et al.*, 2020; Pessot *et al.*, 2020). New strategy is expected with its related business models leading by innovation capacities in developing new smart products (Müller *et al.*, 2018; Porter & Heppelmann, 2014). It also entails huge changes in work, skills, and competencies areas required to manage increasingly complex systems (Bonekamp & Sure, 2015; Fantini *et al.*, 2020; Hecklau *et al.*, 2016; Kaasinen *et al.*, 2020). From a rigorous quantitative analysis of publications dealing with industry 4.0 in their description, Nosalska formalizes the concept with a coherent definition that try to encompass all the dimensions more or less: "Industry 4.0 is a concept of organizational and technological changes along with value chains integration and new business models development that is driven by customer needs and mass customization requirements and enabled by innovative technologies, connectivity and integration" (Nosalska *et al.*, 2018). Nevertheless, if large companies are quickly transforming their production systems over the last few years (Arnold *et al.*, 2016; Müller *et al.*, 2018), SMEs have more difficulties engaging a digital transformation and need to be strongly supported by identifying barriers and success factors in implementing digital transition (Moeuf *et al.*, 2018).

2.2. Barriers and success factors in implementing the industry 4.0 concept

Several studies have looked for identifying barriers that hinder the implementation of industry 4.0. (Da Silva *et al.*, 2020; Kroll *et al.*, 2016; Pessot *et al.*, 2020; Sony & Naik, 2020; Tecknowlogy Group, 2019). These studies are based on empirical-based evidence and not on a theoretical analysis of what a company should do to implement industry 4.0 as described by Verband Deutscher Maschinen und Anlagenbau (VDMA) German Engineering Federation in its 'Guidelines Industrie 4.0'

(VDMA, 2016). In 2016, the European Commission released a substantial report from an in-depth analysis of literature as well as qualitative and quantitative surveys on manufacturing companies, aimed at identifying the main drivers and barriers of European companies for adopting advanced manufacturing technology (AMT) (Kroll *et al.*, 2016). Four barriers were raised: 1) difficulty to assess the performance of AMT and its business return; 2) high cost of investment for AMT acquisition and lack of financial resources; 3) lack of skilled personnel to integrate and use AMT; and 4) market uncertainty and turbulence. More recently, in 2019, a survey carried on 204 large manufacturing companies (>500 employees) has found that the first challenge they face is the 'cost of investment' in implementing digital technology for 58% of companies, the second is 'building the business case' for 48%, and the third is 'lack of skills' for 47% (Tecknowlogy Group, 2019). Similarly, Da Silva *et al.* (2020) identifies a set of main barriers through a literature review of empirical studies related to 1) financial issues due to the high cost of ICT technology; 2) technological issues due to the complexity of technology itself and its management; 3) organisational issues due to the lack of multidisciplinary knowledge, diversity of suppliers, methodological procedures to implement industry 4.0, and understanding of the concept and potential benefits; and 4) internal resistances to organisational changes and lack of skilled labour (Da Silva *et al.*, 2020). Even though it is difficult to compare the results of surveys with each other because of their different methodologies and target audiences, it is noticeable that the main barrier is not only technology. This observation is reinforced when it comes to identifying critical success factors in implementing the industry 4.0 paradigm. A qualitative survey carried on in the framework of the European-funded Boosting Innovation in Factory of the Future Value Chain in the Alps (BIFOCALps) project identified five main critical success factors to succeed in implementing the industry 4.0 paradigm (Biegler *et al.*, 2018): 1) strategy: It refers to the capacity of an industrial company to define and share a long-term strategic vision and set-up the right means to get it; 2) technology: it refers to the capacity of an industrial company to define, plan, and invest in the most relevant industry 4.0 technology according to its strategic vision; 3) capacity for innovation: it refers to the capacity of an industrial company to develop innovative activities and the means to get it; 4) ecosystem support for innovation: it refers to the partnerships of an industrial company to benefit from cross-company innovation; 5) skills and change management: it refers to the skills required for successfully implement industry 4.0 practices. Similarly, Sony has listed 10 critical success factors from an in-depth analysis of 84 scientific publications: 1) align the industry 4.0 initiatives with organisational strategy; 2) the top management shall support the industry 4.0 initiatives wholeheartedly; 3) employees will be important for the success of industry 4.0; 4) make your products or services smart; 5) make efforts to digitize the supply chain; 6) digitize the organisation; 7) change management; 8) project management; 9) managing cyber-security; 10) industry 4.0 and sustainability. (Sony & Naik, 2020). These studies have clearly shown that digital transition addresses many dimensions, and its success involves the company as a whole. These results have allowed us to define industry 4.0 models.

2.3. Industry 4.0 readiness models

Following the definition of the industry 4.0 concept, many diagnosis tools have been designed to support companies in their digital transformation more or less formalized. Industry 4.0 readiness models are a kind of diagnosis tools that can be characterised by their degree of structuration that is more important than just a list of advices or tips to succeed in digital transformation. (Pessot *et al.*, 2020; Schumacher *et al.*, 2016). They are composed of different dimensions and levels that figure a domain or a process and describe the path to reach the maximum level that is considered to be the most mature state of the domain (Carreiro Santos & Martinho, 2018). In the industry 4.0 context, they aim to assess the status of a company in terms of digital technology, strategy, human resources and financial aspects, against an industry 4.0 theoretical concept to define the different steps a company must follow to achieve the digital transformation. These reference models are most often built from an industry 4.0 theoretical framework based on both research literature and consulting reports (Lichtblau *et al.* 2015; Schumacher *et al.*, 2016) and complemented by experts' interviews and industry workshops. All of them mainly focus on new digital technologies implementation as the main enablers to achieve the transition towards industry 4.0 (Carreiro Santos & Martinho, 2018; Schumacher *et al.*, 2016). Furthermore, other aspects are taken into consideration such as organisation, culture, and human resources as well as specific company's characteristics related to the product and service offers (Carreiro Santos & Martinho, 2018). For each part and dimension, a set of figures are listed and considered as prerequisites. Nevertheless, they equivalently consider each dimension and do not take into consideration a company's background to manage digital transformation. The result is that the industry 4.0 concept and its readiness models do not address the complexity of companies' situations. They lack, to some extent, the objective to support companies' digital transformation projects.

2.4. Lessons learnt

The industry 4.0 concept has been analysed in numerous scientific publications since its launch in 2013 by German manufacturers (Alcácer & Cruz-Machado, 2019). Even if the concept is complex, it can be defined through at least four dimensions: technology, organisation, strategy, and human resources. For each of these, a set of variables have been identified from both deductive and inductive approaches that constitute different sorts of industry 4.0 models. They are more or less formalized and detailed in terms of variables to be considered and the way to achieve the industry 4.0 implementation. Finally, maturity models have been designed to support companies and especially SMEs that face huge challenges in managing the digital transition. Yet, industry 4.0 is not as spread as expected although its benefits are no longer discussed.

Two main lessons can be drawn from this scientific background. First, industry 4.0 maturity models are mainly built from theoretical approaches. They are to some extent too far from actual industrial situations and do not consider industry diversity. The result is that more or less only one single digital transformation model is considered in the literature, and each dimension is considered as equal. Second, when it comes

to identifying barriers and success factors, the results are most often an eclectic list extracted from experts' interviews. They rely on empirical-based approaches performed into particular industry sectors and cannot be generalised. Moreover, success factors are not tested in actual digital transformation projects and thus validated as being relevant for any type of implementation projects. Finally, it does not allow for the option to support industry efficiently because the models used are either too simplistic (one single digital transition model) or too empirical (eclectic list of success factors). We hypothesise that several digital transition types exists that result from a combination of a shortlist of key variables.

Against this background, we present the results of an in-depth qualitative survey carried on four French industrial companies, which is aimed at analysing actual digital transformation projects and identifying the key variables when implementing digital transformation projects.

3. Methods

The main objective of the research was to analyse different actual industry digital transformation projects in an in-depth way to identify and analyse key variables in implementing industry 4.0 through the four industry 4.0 concept's dimensions (technology, organisation, strategy, and human resources). This issue involved gathering data about industrial performance, digital technology and its implementation, and human factor in order to encompass the different dimensions. A research consortium was created with complementary skills to meet the complexity of the issue. First, the project was initiated by a consulting firm dedicated to industrial performance that wanted to anticipate the impacts of new digital technologies in the industries. They contacted a research laboratory expert on industrial organization and digital technologies for industry 4.0 and asked it to take the lead of the project. Next, a regional public agency dedicated to work conditions was asked to join the consortium in order to assess the impact of industry 4.0 digital technology on work organisation. They had developed work programmes on digital transformation and its impacts on work and jobs in industry. The project grounded on the knowledge and experience previously capitalised by these three organisations. Each of them was focused on these issues and can contribute concretely on the project. Furthermore, all of the organisations in the research consortium should have been situated in the Auvergne Rhône-Alpes region to benefit from funding from a regional public body. Regarding industrial companies they were selected according to a different set of criteria. These criteria were in sequence: geography, the age of the industry 4.0 project, the sector, the company size, the type of production and the size of the project. First, for practical reasons, companies had to be situated in Auvergne Rhône Alpes region so as the project could benefit from regional public body funding. Second, companies were required to have implemented industry 4.0 technologies less than five years ago to be able to identify the genesis of the project with all the involved stakeholders; Third, they had to be from different sectors to avoid bias related to the sector specificity; Fourth, the companies' size had to be varied to avoid bias related to the resources dedicated to implement industry 4.0 project; Fifth,

the type of products manufactured had to be different to avoid the investigated projects be too similar due to the type of process and finally the digital project size to get a varied sample and not focus on an only type of industry 4.0 projects, small or large. In this study, the companies selected with the inclusion criteria were numbered one to four while their related digital projects will be listed as P1, P2, P3, and P4. (Rocchi, 2021).

Against this background, we present the results of a qualitative survey carried on four French industrial companies, which outline first, the different ways of implementing digital transformation and the criteria that characterise them. The analysis criteria of the digital transformation projects were defined as outlined in Table 1.

A qualitative approach was favoured based on an observation phase in-situ and semi-structured interviews. To have an in-depth analysis of each project, all people involved in the digital project were targeted: Director, Human Resource director, Financial director, Functional directors (industrial, engineering, logistic, and IT), HSE manager, project manager, technicians (maintenance and IT) and operators. Operators and technicians were selected by production manager of each company surveyed according to two criteria, age and seniority, and of course

their willing to answer the survey. It was important to have varied operators' profile according to these criteria to mitigate age or seniority effect that constitute a bias in itself. Operators and technicians were interviewed in group to limit the impact on production activity. Then, about fifteen semi-structured interviews per company depending on the project and its structure have been carried out. Eventually, 46 interviews were performed. Interviews did not address ethical issues and therefore no ethical approval were requested. However, interviews and all related collected data are strictly confidential because they refer to the companies' strategy. The research consortium committed to not circulate collected data and keep strictly confidential all information provided by companies. At the beginning of each interview, interviewee was asked if they agree to participate in the study and the research consortium committed to keep interviewees data confidential.

The interview guide (Rocchi, 2021) was designed by the three partners in the research consortium and tested internally. It was structured in four main parts as described in Table 2. Questions were adapted to each category of interviewed people to fit in with their work areas in each company. The objective was to stress some dimensions according to the role of each interviewees in the company. Directors were particularly interviewed about strategy, engineers and technicians about

Table 1. Digital transformation projects analysis criteria.

ANALYSIS CRITERIA	DESCRIPTION
Context	External and internal socio-economic and strategic context in which the company launches the digital transformation
Project organisation	When, how and with who the project is built and run
Industrial organisation before the project	Existing industrial organisation targeted by the digital transformation project.
Industrial organisation after the project	New industrial organisation set up following the digital transformation project
Technology implemented	Technology 4.0 implemented in the industrial process
Work organisation before the project	Existing work organisation in the digital transformation project boundary
Work organisation after the project	New work organisation following the digital transformation project

Table 2. Interview guide. (Rocchi, 2021).

INTERVIEW GUIDE DIMENSIONS	DESCRIPTION
1. Genesis and running of the project	The first part dealt with: context and project organisation (cost, project team composition, technology implemented, relation with techno-provider, etc.)
2. Impact on organisational dimensions	The second part dealt with: description of the digital transformation given the existing industrial organisation and its results after technology implementation
3. Impact on work and skills and competences	The third part dealt with: description of existing work organisation including workers and their related skills and competencies and the new work organisation following technology implementation
4. Benefits and disadvantages of the new organisation (social and economic)	The fourth part dealt with: assess the benefits and disadvantages of the digital transformation in its economic and social aspects for the company and each group of interviewed people

technological issues, human resource about work organisation and training, financial staff about cost and investment and operators about impacts on workstation and jobs. The interview phase was carried out by the first-named author, a female Ph.D, research engineer at G-SCOP laboratory and sociologist by training. Moreover, each partner brought additional expertise focused either on industrial organisation, work conditions, or industrial performance. This configuration allowed further in-depth insight to some advanced topics. Previously the study, research teams went into each company to present and explain the research objectives. Then companies asked all people involved in digital transformation projects to be available to answer semi-structured interviews. Managers asked operators if they agreed to be interviewed and organized timeslots for answering the survey. At the beginning of each interview, the research objectives were explained to the interviewees and they were ensured that all information would keep confidential. Nobody but researchers and interviewees were present. Each company was surveyed during two or three consecutive days depending on the availability of interviewed people. Interviews were all performed in a face-to-face way by three researchers depending on their expertise and lasted around 1,5 hours each. Operators were interviewed in groups so as not to disturb industrial processes with the same considerations for the technician groups. All interviews were recorded with the systematic agreement of interviewees requested at the beginning of each interview and provided that their use would be restricted to the research teams' members. Field notes were written down. Analysis work was based on the content analysis method defined by Braun and Clarke, and Bardin (Bardin, 2018; Braun & Clarke, 2013). The first step was to process rough material within the research team. All interviews and observations were partially written down because of the cost of a complete transcription. These notes were then discussed within the research team in a brainstorming mode and finally clear in order to keep only data related to the digital transformation

project. Some additional information mainly about project's strategy as well as resources dedicated to its implementation was requested from the project manager for clarifying any misunderstanding. Interviews were not returned to interviewees, but restitution was made to the project teams by the research team during a meeting where all the project's stakeholders attended. Discussion between the research team and project teams added some new useful understanding. In a second step, interviews were reviewed and edited in order to keep only information related to the research questions and then they were coded fully in a research-data way based on the research framework (Braun & Clarke, 2013). No software was used. According to the thematic content analysis method, the unity of coding was the theme. A theme is a meaning unit that is cut up from interviews by researchers because it is considered as an indicator of attitudes and practices related to the investigated domain that are defined by research questions (Bardin, 2018; Braun & Clarke, 2013). In the third step, codes were selected from each interview and clustered in order to identify large categories gathering several themes describing the digital transformation projects according the analysis criteria as described in Table 1. In a fourth step, key variables of digital transformation projects and their indicators were inferred from the analysis of the categories with regards to the two research questions and their related concepts, and according to the analysis content principles (Bardin, 2018; Braun & Clarke, 2013). Finally, similar variables had been merged in order to build a model that allows to characterise digital transformation projects with only two dimensions. Data saturation was not discussed because the study approach did not allow for getting easily new interviews. The results are presented in Section 4. The methodology is summarized in Figure 1.

Four digital transformation ideal-typical projects were built from the methodology process described previously. They are characterized in Table 3. Each project is described according

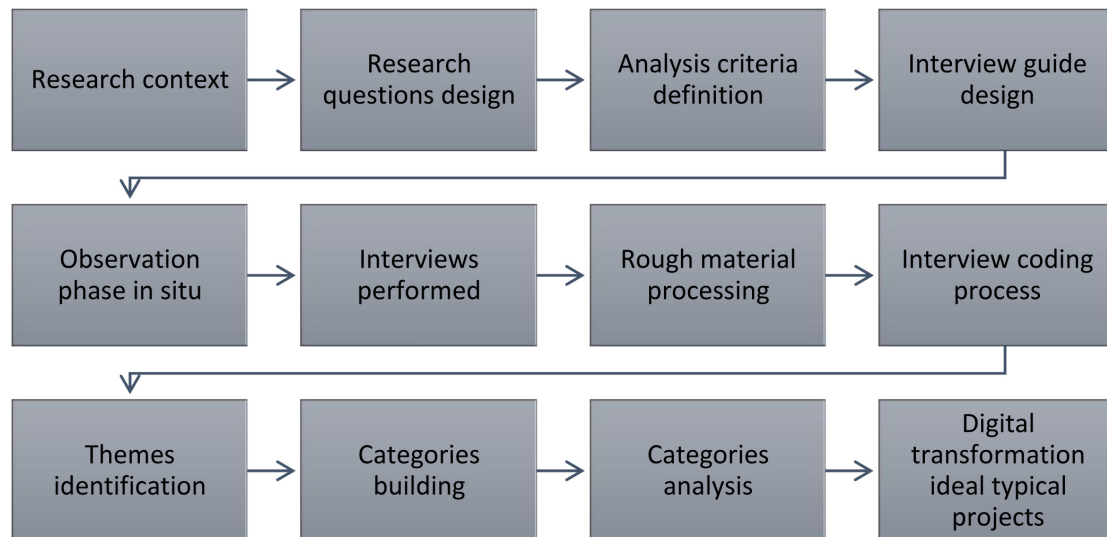


Figure 1. Methodology flowchart.

to four main elements: enterprise category by business size, industrial sector, the investment amount of the digital transformation project, and industrial area in which the project happened. Table 4 gives the list of the interviewed individuals across the project roles at each company.

4. Results

The project's findings allow us to answer the research questions:

RQ1: How do companies implement digital transformation project?

RQ2: What are the key variables?

The analysis of the 46 interviews and the project digital transformation-related documents has allowed us to analyse the way companies implement digital transformation project and identify four structuring variables. They are strategy, digital transformation project management, investment amount, and level of digital maturity. They are key issues that the four companies have dealt with all along with their digital transformation projects. Moreover, these key variables cannot be managed independently by companies. They are strongly interlinked, and their combination is much more important for succeeding than just managing them separately from one another. First, we present the variables and how each investigated digital transformation project have been dealt with. Second, we characterise each digital transformation project according to the variables.

Third, we gather the four variables into two main variables and analyse the effects of their combination on the digital transformation project to be successful. Finally, we characterise nine types of digital transformation projects.

Table 5 presents the definition of the variables.

Regarding the strategy variable, P1 and P2 were launched following the growth of one of their products that had required each company to dramatically transform its production system. On the contrary, P4 was only launched for cost shrinking due to the market competition and P3 was looking for means of improving lead time. Regarding the digital transformation project management variable, P1 and P2 were ambitious as they aimed at setting up completely new data-driven production systems on a large scale. The project teams were big, gathering all the department impacted by the project (IT, production, engineering, logistic, human resource, and financial) with regular meetings and experienced with every required skill and competency committed. In P3, the digital transformation project was less ambitious, improved maintenance activities with connected tablets instead of papers, but the project management was strong with a skilled team in computing and engineering dedicated to build the new maintenance database. In P4, it was about setting up a pick-up robot at the end of a production line. It was very new for the company, but they did not invest in project management tools to manage it properly. Another important variable is the investment amount considering direct

Table 3. Characterization of the digital transformation projects.

	Company	Company size	Industrial sector	Investment for the digital project	Industrial process analysed
Project P1	1	Mid-cap	Furniture	> 40 M€	Cutting and machining process
Project P2	2	Large	Health	< 5 M€	Diagnostic kits packaging
Project P3	3	Large	Semi-conductor	< 500 K€	Maintenance activity
Project P4	4	Large	Packaging	< 200 K€	Pet food flexible bag manufacturing

Table 4. Interviewed persons for each project.

	Interviewed persons								Total interviewees
	Director	HR director	Financial director	Functional directors	HSE manager	Project manager	Technician	Operator	
Project P1	1	1	1	1	1	1	5	5	16
Project P2	1	1	1	1	1	1	4	4	14
Project P3	2	-	-	2	-	2	-	-	6
Project P4	1	1	1	1	1	1	2	2	10
Total interviewees	5	3	3	5	3	5	11	11	46

and indirect costs. A large project requires a high budget to fund technology, but it also allows considering a better supporting change for workers directly impacted by the new digital technology. P1 and P2 were willing to support change along with the project. It was not the case in P4 where no support has been set up. In P3, the project cost was not a limitation, but the focus was put only on technology development without consideration for work and workers. Finally, the level of digital maturity is a key variable. In P1 and P3, the two companies were used to implement new ICT technology and they got the required skills and competencies to do it. In P2 and P4, the project to transform handling tasks into digitally assisted ones was very challenging as previously workers didn't use technology at all. They could not rely on existing technology and workers were very far from the required skills and competencies. To overcome the initial situation weakness, P2 strengthened the project management including strong efforts to support change whereas P4 did not invest in project management, had no digital competencies internally, and did not work closely with the technology provider.

Considering these first results, it is possible to characterise the digital transformation projects according to the four variables and their related values (Table 6).

The four variables present some similarities and can be gathered in order to model digital transformation projects. The project management and investment amount variables both relate to the

resources involved to run and achieve the digital transformation project. They are merged into one single variable, to characterise the project ambition. Likewise, strategy and digital maturity level variables refer to the company initial situation when the project is decided. Therefore, they are merged into one single variable called company situation. Each variable is composed of three modes: strong, weak, and ambivalent. They are described in Table 7 and Table 8. The combination of the two variables allow for building a model that results in at least four theoretical digital transformation projects classic configurations. Given the industry is a high-intensive capital type of company, the hypothesis is made that projects with high ambition in a strong company situation are successful and projects with low ambition in a weak initial situation would fail or at least do not fully meet the objective. At these classic configurations, five others are added resulting from the combination between ambivalent mode and the two other modes; strong/high and weak/low. The hypothesis is made that ambivalence cannot recover a weakness in ambition or situation. The most interesting point is to know if an ambivalent company, meaning that the company is in a delicate position or has not mobilized adapted means, can succeed in their transformation and so overpass to a much better position or generally fail and so continue to struggle to survive (Table 9).

Then investigated projects are characterised according to the two variables in Table 10 and Table 11; project ambition and company situation. The combination of these two variables that constitute our model results in nine types of digital transformation

Table 5. Project characterisation variables.

VARIABLES	DESCRIPTION
Strategy	Set of arguments, such as socio-economic aspects, that could be internal and/or external, positive or negative, that makes the project possible with regards to these.
Digital transformation project management	Three sub-variables a- Project management experience b- Type of technology 4.0 implemented and its impact on existing production systems c- Adapted resources involved to manage the project
Investment amount	Budget devoted to the implementation of technology 4.0 including direct costs such as the purchase of technology and indirect costs as training, specific development, prototypes, etc.
Digital maturity level	Company capacity to running implementation of new ICT technology with regards to the existing production system (equipment and IT) and the internal existing skills and competencies.

Table 6. Digital transformation project characterisation.

Projects	VARIABLES			
	STRATEGY	PROJECT MANAGEMENT	INVESTMENT	DIGITAL MATURITY LEVEL
P1	Growth	Large	High (>40M€)	Strong
P2	Growth	Large	High (>4M€)	Weak
P3	Growth	Large	Low (<500k€)	Strong
P4	Decrease	Small	Low (<200k€)	Weak

Table 7. Project ambition variable modes.

PROJECT AMBITION VARIABLE MODES	DESCRIPTION	INTERPRETATION
High	Combination of “large project management” and “high investment” variables	Coherency of the level of the resources dedicated to the project at a high level
Low	Combination of “small project management” and “low investment” variables	Coherency of the level of the resources dedicated to the project at a low level
Ambivalent	Combinations of “large project management” and “small investment” variables or “small project management” and “high investment” variables	Management and investment dedicated to the project do not fit well together

Table 8. Company situation variable modes.

COMPANY SITUATION VARIABLE MODES	DESCRIPTION	INTERPRETATION
Strong	Combination of “growth strategy” and “strong digital maturity level” variables	The business development of the company leans on digital experience
Weak	Combination of “decrease strategy” and “weak digital maturity level” variables	The company is on the defensive and does not benefit from digital experience
Ambivalent	Combination of “growth strategy” and “weak digital level maturity” variables or “decrease strategy” and “strong digital level maturity” variables	Delicate situation of the company, which has strong assets on weaknesses

Table 9. Digital transformation project model.

	COMPANY SITUATION*		
PROJECT AMBITION	Strong	Weak	Ambivalent
High	Success	??	??
Low	??	Failure	Failure
Ambivalent	??	Failure	

*“??” here has been used to indicate where it is not possible to foresee the results of a combination across two variables.

Table 11. Digital transformation projects.

	COMPANY SITUATION VARIABLE		
PROJECTS	Strong	Weak	Ambivalent
P1	x		
P2			x
P3	x		
P4		x	

Table 10. Digital transformation projects.

	PROJECT AMBITION VARIABLE		
PROJECTS	High	Low	Ambivalent
P1	x		
P2	x		
P3			x
P4		x	

projects. These projects are characterised in Table 12. From this, companies were categorised as either successful or failed with their digital transformation projects. Investigated projects are characterised in Table 13.

The main results allow us to answer our RQ1. We have identified nine types of digital transformation projects, characterised by the combination of two variables, project ambition and company situation. They also answer RQ2. The key variables are company’s background and context. Moreover, the success or the failure of the digital transformation projects depends on two key variables of project ambition and company situation,

Table 12. Digital transformation projects.

PROJECT AMBITION	COMPANY SITUATION		
	Strong	Weak	Ambivalent
High	P1		P2
Low		P4	
Ambivalent	P3		

Table 13. Digital transformation models.

PROJECT AMBITION	COMPANY SITUATION		
	Strong	Weak	Ambivalent
High	Success (P1)		Success (P2)
Low		Failure (P4)	
Ambivalent	Success (P3)		

their combination, and the company capacity to overcome the identified weak points and mitigate them. If the well-defined project (strong situation, high ambition) and ill-defined project (weak situation, low ambition) results are as expected with success and failure respectively, it can be seen that the projects with a variable that is not well defined can also succeed in their transformation project. A strong situation can make a project win even if the project ambition is not well aligned as it is the case for P3. The same, a high ambition can pull an ill-prepared situation toward success as it is the case for P2.

5. Discussion

Even if a great number of companies are now convinced of the industry 4.0 potential to reach new levels of performance such as dramatically increasing productivity, meeting customer's expectations more quickly, and entering into new markets, they are still struggling in implementing digital manufacturing solutions and often do not achieve the expected impacts. Several studies have tried to identify barriers and success factors, and then design maturity models to support digital transformation. Nevertheless, companies, particularly SMEs, lag. Maturity models are theoretical and define one-size-fits-all digital transformation while identified barriers and success factors are too eclectic to be fully operative. Moreover, company's background and context are rarely considered while implementing digital transformation projects. Our research aims at answering two research questions (RQs): 1) How do companies implement digital transformation project? 2) What are the key variables? We hypothesise that firstly background and context of companies are key variables when implementing digital transformation and therefore lead to several types of digital transformation projects and secondly success depends on several interlinked variables based on company's background and context.

Four actual digital transformation projects have been investigated in an in-depth way that allows us to examine beyond the issues in terms of barriers and success factors to be avoided or favoured when implementing industry 4.0. The analysis has identified four variables strategy, project management, investment amount, and digital maturity model while implementing digital transformation project. These four variables can be gathered in two key variables: Project ambition (project management and investment amount) and company situation (strategy and digital maturity level). Each variable has been characterised according to three modes (high-low-ambivalent; strong-weak-ambivalent). The combination of the two variables and their different modes has shown that combinations result in either success or failure or ambivalent position. Next, each investigated digital transformation project has been characterised with regards to each variable and finally to the digital transformation model built from the two variables combination. They are consistent with the model. Finally, our research has identified nine types of digital transformation projects resulting from the combination of the two variables. Findings allow answering the two research questions. At least, nine types of digital transformation exist when considering company background and context. The key variables to succeed in digital transformation project are company situation and project ambition.

Analysis has highlighted that some combinations between the two key variables lead to success, others to failure depending company situation and project ambition. These findings query the way companies approach digital transformation issues. Indeed, several approaches occur and sometimes within the same company. Some companies launch multiple small projects in different industrial areas (design, engineering, production, and logistics) by implementing digital technologies such as sensors, augmented reality devices, or additive manufacturing equipment. Most often, these projects are carried out only at a factory level by a limited team without connection with the IT or engineering department. Selected technology relevance is not assessed. Other ones act the opposite manner and launch one big project that transforms processes in a whole. Sometimes, the project relies on a strategy shared by all in the company but sometimes not. Digital technology implementation can be tasked to a technology provider or an integrator but can also be managed internally by the technical department. There is a great number of industrial situations that cannot be covered by one single model and do not foresee digital transformation project success or failure. The digital transformation model built allow for companies stressing a short number of variables when implementing digital transformation projects while considering their own background and context. Moreover, the model favours a holistic approach that do not disqualified a priori the digital transformation project because it does not lean with maturity model theoretical requirements. Any weakness point can be balanced or reinforced by another stronger point. For example, the P2 project have balanced an ambivalent situation by a high project ambition and then have succeeded in its digital transformation project. Likewise, the P2 project could have overpassed an ambivalent project ambition because of their strong company situation. On the contrary, the P4 project should

have balanced its weak situation by a high project ambition. They did not make it and then failed to transform their process. Some first guidance can be formulated from the research findings. Firstly, a company starting a digital transformation project has to identify the context in which the project is launched: growth or decrease? The benefit of industry 4.0 stands in its capacity to increase the value of existing products or creating new products and business models, not mainly to streamline costs. Secondly, the implementation of disruptive digital technology requires assessing companies' digital maturity levels. If a company has steadily implemented new technology and can manage it, the new project is easier to roll out. If the gap is too significant, the company has to put in place strong technical supports and change management actions to face transformations. Thirdly, the project management has to be properly dimensioned and consistent with the previous assessment. If a company is in a difficult economic situation to some extent or wants to set up a completely new workshop, the project will require the company to aggregate many competencies to address issues regardless of the implemented digital technology characteristics. Fourthly, investment has to be consistent with project objectives which require assessing the relevance of the selected digital technology, as well as the company's identified weaknesses. Investment is not only bought technology but also consider change management if necessary. Nevertheless, the model is not still achieved and need to be tested and validated with new digital transformation projects.

The research findings and especially the digital transformation model highlight variables that companies deal with when implementing digital transformation projects that are not really identified and considered in literature. Regarding the contribution to literature, the paper aims at complementing industry 4.0 readiness models by introducing background and context variables that are not address by the latter. Likewise, it allows for defining two main variables that structure a list of barriers and success factors into a more operative way.

Limits and further research

First, our research is limited by the literature reviewed and the companies' included in this sample. Four digital transformation projects do not allow us to generalise findings and design a methodology. This research needs to analyse more digital transformation projects in different kinds of companies (size, sector, and market etc) to investigate the nine types and support results in across a broad range. Secondly, analysis has been made once the projects were finished and interviewed people could misrepresent the facts. It is a real hindrance in reconstructing the project pathway and analysis could be distorted. Nevertheless, the number of interviewed people can greatly mitigate this problem.. The next steps in the research will be to keep on modelling different types of actual digital transformation projects and to test, adjust and formalize the model regarding the success or failure of the digital transformation projects before designing guidelines for companies to support them in implementing digital transformation. Investigated digital transformation projects should be as diverse as possible in terms of size, industry sectors, investment amount and strategy. The research approach should favour in-depth surveys to dive

into the genesis and progress of the project. The objective is to be able to consider company's digital transformation project characteristics while implementing more formalized industry 4.0 approaches based on theoretical models.

Conclusions

Industry 4.0 is no longer a very long-term objective and dedicated to only innovative companies. It must be implemented by most of them and especially by SMEs to keep on with strong growth. Although several studies allow them to deploy a digital transformation project, some critical issues remain as a black box. We have tried in this article from an in-depth analysis of four actual projects to identify different types of digital transformation projects by identifying key variables to help companies to succeed in implementing industry 4.0. Yet, many companies and especially SMEs lag behind. Researchers have identified success factors and barriers that hinder uptaking of industry 4.0 benefits while developing several readiness models to assess company's initial situation to support them in rolling out digital transformation. These findings and related diagnostic tools do not take into consideration a company's background and context that are of great importance when implementing the industry 4.0 concept. This article aims at analysing actual digital transformation project to understand how companies manage digital transformation projects and what the key variables are. Research findings identify two main variables as being key and moreover that their combination can lead to success or failure depending how the companies deal with identified weaknesses. Finally, nine different types of digital transformation have been identified and characterised. This paper aims at contributing to a better understanding of digital transformation in industry and its key success factors and enriching literature by considering company's background and context when assessing the company's digital transformation maturity.

Data availability

Underlying data

Collected data in this research project refers to companies' industrial and economic strategy that constitutes a significant advantage in terms of competitiveness. These latter do not agree that all collected data was made public. Moreover, data does not allow for de-identifying the companies themselves as well as workers because of their specific role within the companies. Therefore, raw data are restricted and only synthesis of each case as well as the interview guide can be accessed on the Dryad platform by using the link below. Interviews did not address ethical or personal issues and therefore no ethical approval were required for this study.

Dryad: Designing industry 4.0 implementation from the initial background and context of companies. <https://doi.org/10.5061/dryad.qrfj6q5h6>. (Rocchi, 2021).

The project contains the following underlying data:

- Project P1 synthesis. (The document features the company, the context, the strategy, the digital transformation project implementation and its impact on work organisation and industrial performance in a synthesis way).

- Project P2 synthesis. (The document features the company, the context, the strategy, the digital transformation project implementation and its impact on work organisation and industrial performance in a synthesis way).
- Project P3 synthesis. (The document features the company, the context, the strategy, the digital transformation project implementation and its impact on work organisation and industrial performance in a synthesis way).
- Project P4 synthesis. (The document features the company, the context, the strategy, the digital transformation project implementation and its impact on work organisation and industrial performance in a synthesis way).

Data are available under the terms of the [Creative Commons Zero “No rights reserved” data waiver](#) (CC0 1.0 Public domain dedication).

Extended data

Dryad: Designing industry 4.0 implementation from the initial background and context of companies. <https://doi.org/10.5061/dryad.qrfj6q5h6>. (Rocchi, 2021).

This project contains the following extended data:

- Semi structured interview guidelines.pdf. (English version of the interview guide used in this study).
- Guide d’entretien semi-directif.pdf (Original French version of the interview guide used in this study).
- Read me.pdf (small introduction to the dataset in this project).

Data are available under the terms of the [Creative Commons Zero “No rights reserved” data waiver](#) (CC0 1.0 Public domain dedication).

Reporting guidelines

Dryad: COREQ checklist for Designing industry 4.0 implementation from the initial background and context of companies. <https://doi.org/10.5061/dryad.qrfj6q5h6>.

Data are available under the terms of the [Creative Commons Zero “No rights reserved” data waiver](#) (CC0 1.0 Public domain dedication).

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Patrick Martin 

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No further comments to my previous review.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: manufacturing engineering, integrated design and manufacturing, health and safety of workers

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 04 January 2022

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Sebastian Schlund 

Institute of Management Sciences, Vienna University of Technology, Vienna, Austria

Thank you very much for addressing the comments. I'd just suggest to correct some minor typos in section #5:

- [...] do not disqualified (?) a priori the digital transformation project because it does not lean with maturity model theoretical requirements. [...]

- [...] still achieved and need(s!) to be tested and validated [...].

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Production Management, Ergonomics, Human-Machine Interaction, Work Organization

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 22 December 2021

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Gil Goncalves 

Faculty of Engineering, University of Porto, Porto, Portugal

The paper uses a double approach (deductive and inductive) to propose modes of digital transformation. Starts with a literature review to define industry 4.0 and to identify digital transformation success factors, as well as barriers. Secondly, builds on results collected from four industry digital transformation projects to demonstrate that the digital transformation's success or failure depends on the combination of two variables related to a company's background and context. As a result nine digital transformation types have been identified and proposed.

The work is clearly and accurately presented, citing current and relevant sources. The proposed methodology, based on the double approach, is appropriate, the work is technically sound and the details of methods and analysis allow replication by others. However, full reproducibility is not possible because only partial source data is available. This is due to confidentiality issues.

The conclusions are adequately supported by the results and the arguments can be understood by non-academic.

This is important because the work proposes solutions to actual real-world challenges and these solutions can actually be implemented in practice.

I have some additional comments to the paper:

- In section 2.3 (Industry 4.0 readiness models) examples of the "readiness models" should be included and discussed.
- In section 2.4 (Lessons learnt), in the first paragraph, the "set of variables", the different industry 4.0 models" and "maturity models" should be identified and summarised.

- In fig. 1 (methodology flowchart) the "steps" identified in the text should be included.
- In table 9, there is one "black" cell; is this correct of a formatting issue?
- Would it make sense to swap the order of the RQs? looking at the rationale in section 5 (Discussion) it would be better for the argument if it starts with discussing the variables (currently R2) and then concludes with the how to implement (currently R1).
- In section 5 (Discussion) at the end of page 11, in paragraph "Likewise, the P2 project could have overpassed an ambivalent project ambition because of their strong company situation." it should read P3 instead of P2?
- In section 5 (Discussion) it would be interesting to elaborate how the proposed research findings could complement the existing readiness models; if these are detailed in section 2.4 this would be easier to explain in section 5.

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?

Not applicable

Are all the source data underlying the results available to ensure full reproducibility?

Partly

Are the conclusions drawn adequately supported by the results?

Yes

Is the argument information presented in such a way that it can be understood by a non-academic audience?

Yes

Does the piece present solutions to actual real world challenges?

Yes

Is real-world evidence provided to support any conclusions made?

Yes

Could any solutions being offered be effectively implemented in practice?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Smart Manufacturing, Industry 4.0, Industrial automation and robotics.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 1

Reviewer Report 29 November 2021

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Sebastian Schlund 

Institute of Management Sciences, Vienna University of Technology, Vienna, Austria

The paper presents a profound and comprehensive description of four case studies about implementation projects within the context of industrial digital transformation. It is very well written and provides very interesting insights into real I4.0 implementation projects. The authors claim to close the research gap of state of the art publications about industry 4.0 implementation being either too theoretical or too empirical. Therefore, in-depth analysis of four French companies and their respective Industry 4.0 projects is carried out using a qualitative approach with 46 interviews. Based on a categories analysis a model is presented that puts in order the projects according to their company situation and the project ambition. The approach, method and conclusions are of theoretical relevance for digital transformation research and for the planning of practical implementation projects.

Despite the relevance and value of the results it is strongly recommended to rephrase (and reframe) the research question and the claim according to the actual results. The claim to close the research gap between too empirical and too approaches cannot be fulfilled by the provided results. For example RQ2 is not answered to a sufficient extend as there is no real evaluation of the proposed model in chapters 4 and 5. Therefore, the model should have been evaluated according to its performance and success in actual application. As long as this issue is not addressed the value of the paper is in the better understanding of the company background and context for the success of digital transformation projects. The ambition to give support to companies is therefore at the moment rather descriptive than guiding action.

Precisely, I suggest to rethink the ambition of the paper and the research questions and to formulate them more towards a claim of better understanding digital transformation projects within companies. Furthermore, the description of the two-dimensional model in chapter 4, its

possible limitations and the conclusion need more explanation (e.g. about the consequences of the nine models of digital transformation) and a straightforward outlook towards further action needs.

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?

Not applicable

Are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions drawn adequately supported by the results?

Partly

Is the argument information presented in such a way that it can be understood by a non-academic audience?

Yes

Does the piece present solutions to actual real world challenges?

Yes

Is real-world evidence provided to support any conclusions made?

Yes

Could any solutions being offered be effectively implemented in practice?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Production Management, Ergonomics, Human-Machine Interaction, Work Organization

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 02 Dec 2021

Valérie Rocchi, Grenoble University, Grenoble, France

Dear reviewer,

Thank you for these meaningful insights and recommendations.

The paper does not claim to fulfil the research gap of the state-of-the-art publications being either too theoretical or empirical. To avoid all misunderstandings, the paper is going to be clarified in its phrasing and research approach.

Competing Interests: No competing interests were disclosed.

Author Response 16 Dec 2021

Valérie Rocchi, Grenoble University, Grenoble, France

A new version of the paper has been published taking into account the recommendations. First, the ambition of the paper and research questions have been clarified and reformulated according to the suggestion.

Second, the digital transformation model has been clarified and detailed especially its links with the nine types of digital transformation.

Third, discussion, limits and further research and conclusion sections have been clarified and detailed.

Competing Interests: No competing interests were disclosed.

Reviewer Report 23 November 2021

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Abstract

Industry 4.0 is a promising concept that allows industries to meet customers' demands with flexible and resilient processes, and highly personalised products. This concept is made up of different dimensions. For a long time, innovative digital technology has been thought of as the only dimension to succeed in digital transformation projects. Other dimensions have been identified such as organisation, strategy, and human resources as key while rolling out digital technology in factories. From these findings, researchers have designed industry 4.0 theoretical models and then built readiness models that allow for analysing the gap between the company initial situation and the theoretical model. Nevertheless, this purely deductive approach does not

take into consideration a company's background and context, and eventually favours one single digital transformation model. This article aims at analysing four actual digital transformation projects and demonstrating that the digital transformation's success or failure depends on the combination of two variables related to a company's background and context. This research is based on a double approach: deductive and inductive. First, a literature review has been carried out to define industry 4.0 concept and its main dimensions and digital transformation success factors, as well as barriers, have been investigated. Second, a qualitative survey has been designed to study in-depth four actual industry digital transformation projects, their genesis as well as their execution, to analyse the key variables in succeeding or failing. 46 semi-structured interviews were carried out with projects' members; interviews have been analysed with thematic content analysis. Then, each digital transformation project has been modelled regarding the key variables and analysed with regards to succeeding or failing. Investigated projects have consolidated the models of digital transformation. Finally, nine digital transformation models have been identified. Industry practitioners could design their digital transformation project organisation and strategy according to the right model.

General comments

This paper is based on a sound scientific review and industrial cases analysis. Its multidisciplinary approach with organizational, strategy and human resources added to technology aspects allow to get a general view of the problem and constraints to deployment of the Factory of the Future in enterprises. The method and results allow to help enterprises or stakeholders for decision making. So this paper has merit to be published.

Comments

I have only some comments in order to enrich the discussion.

- It will be interesting to summarize the literature review (§2) by a table or a drawing which can introduce the work done, to justify the different points of the interviews and the key parameters identified.
- More in this paragraph the granulometry of the analysis has to be precise. The level of the analysis (machine, production cell, workshop, factory, expanded enterprise) can be different following each domain or point of view.
- Before moving to digitalization, in order to get success results, it is necessary to have a good knowledge of the production organization, product flow, data flow (input or output of the workshop), workplace organization, skills and competencies of workers. This point merit to be discussed.
- For Industry 4.0 objectives, add social dimension wellbeing of workers or answering to citizen needs.
- Digital approach have two dimensions: digital technologies (internet of objects, communication, sensors,...) in order to get relevant information in real time, and virtualization (software's based on scientific knowledge in order to model and take decisions, to extract relevant data,...)
- For virtual manufacturing don't forget that the physical laws and manufacturing process models (more or less detailed) is important, more data measured in real time gives the

variation and uncertainty of the context of the manufacturing process (equipment's, product's complexity,...) .

- § 2.4: It is necessary to separate maturity level of the technology with its technological intensity (general view) and specific technology maturity of the enterprise or workshop.
- § 3 Four dimensions' approach (technology, organization, strategy, and human resources) is relevant, it will be interesting to go deeper in the taxonomy.
- § 3, figure 1: It will be interesting to enrich the figure by adding input/output of each activity, resources/ model supporting them.
- § 5 In order to present the analysis 'results to the enterprise or the decision- maker, It will be interesting to summarize the results by a diagram, a table, (SWOT, radar,..)

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?

Not applicable

Are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions drawn adequately supported by the results?

Yes

Is the argument information presented in such a way that it can be understood by a non-academic audience?

Yes

Does the piece present solutions to actual real world challenges?

Yes

Is real-world evidence provided to support any conclusions made?

Yes

Could any solutions being offered be effectively implemented in practice?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: manufacturing engineering, integrated design and manufacturing, health and safety of workers

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.
