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Assessment Model to Support the Technological Integration within Industrial Companies in the Context of Industry 4.0

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Abstract—This article describes the first stages of the development of an assessment model designed to help industrial companies building a technological roadmap in the context of Industry 4.0. Based on a maturity model for the integration of new technologies, the model enables measuring the ability of the companies to integrate new technological elements and then providing them adequate recommendations. Three main dimensions are identified as necessary for the success of technological integration projects: process maturity, change management capabilities and technological maturity. The model also considers the diversity of industrial enterprises with a classification based on their production model. Based on a literature review about Industry 4.0 maturity and readiness models, practices are selected corresponding to the three selected dimensions and associated in eight areas to form the basis of the proposed model. A case study of an automotive supplier company is presented to illustrate the implementation of this model.

Keywords— *Technological integration, technological maturity, process maturity, Industry 4.0*

I. INTRODUCTION

The adoption of new technologies within industrial companies often represents a complex issue for them. On one hand, the successful integration of new technological elements opens up new possibilities and has positive impacts on productivity [1]. On the other hand, this type of projects presents important challenges and constraints, requiring significant investments [2] without any guarantee of success. The importance of this subject is now reinforced by the emergence in 2011 and the evolution of the concept of Industry 4.0 [3], [4]. This is why industrial companies have a real need for support on their projects to integrate new technologies, in order to ensure the maximum chances of success. The construction of a model providing personalized recommendations could therefore meet this need. But in order to be able to establish this assistance, it is necessary to analyze the state of the companies and identify if they are ready to carry out technological transformation projects. This is why, in order to build this model, it is necessary to deal with this first research issue: how to measure the capacity of a company to acquire and correctly integrate new technological elements?

This model will have to assimilate the various dimensions useful for the improvement of the performance of companies and enable them to build their own “Technological Roadmap”. As the model aims to be able to face and deal with a very wide diversity of situations, whether in terms of size, trades, processes, or technological mastery. In particular, it is

mainly intended to support small companies, which generally face more difficulties identifying how to progress than large groups, which have strategy departments [2]. For this, it is required to deal with this second research issue: how to assess the impact of changes in the maturity of the company on the achievement of its objectives? The answer to this question will make it possible to draw the necessary lessons to transform the results of the diagnosis given by the model into practical recommendations. In this context, a maturity model seems to be helpful because it is a format suitable for analyzing companies and their current functioning as well as suggesting avenues for the development and improvement of their practices [5].

A first dimension to consider is the maturity of the company’s processes. Indeed, several publications emphasize the fundamental importance of mature, standardized, transparent and reproducible processes for the successful integration of new technological elements, in particular for those of Industry 4.0 [6]–[8]. This also indicates that, if immature processes are identified, it would seem appropriate to make recommendations that first lead the company towards mastering those processes before considering the acquisition of technologies to strengthen them. A second dimension to consider for the model is the ability of managing change within the studied enterprise. Change management has a strong positive influence on the success of transformation projects of companies [9], [10]. This is why the model will have to integrate this dimension and, as for the maturity of processes, direct the recommendations towards improvements on this subject, if necessary, before advice on technological suggestions. Finally, it is relevant to look at technologies that are already known and mastered within the company. This technological maturity must be considered because the greater the gap between what is known and a new element to be acquired, the more complicated its integration into the company’s processes. There are therefore three dimensions for building the model for evaluating the ability of companies to integrate new technologies: the maturity of processes they have implemented; their capabilities in change management; and their technological maturity. These three aspects are those addressed in the existing maturity models discussed in the next section. In section III, the proposed assessment model is presented and illustrated by a case study in section IV.

II. INDUSTRY 4.0 MATURITY ASSESSMENT MODELS

The concepts of Industry of the future and Industry 4.0 have been developed since 2011 in an industrial strategy document of the German government [3], [4]. They concern

the development of new production technologies offering many new possibilities for industrial companies: automation of production, interconnection of machines, additive manufacturing, ... All the processes of these companies (production, logistics, development of new products, for example) could potentially be impacted by these new technologies. They offer greater production flexibility, more possibilities for product customization, an increased ease of managing single products or small batch production. These new possibilities raise the interest of enterprises but implementing these technologies can represent a significant challenge. It requires an important investment and therefore a strong constraint [2], hence the importance of the success of these projects. For this reason, the development of models for auditing companies to support them in the acquisition of these new technologies is a topic that is currently the subject of many studies (more than 15 publications between 2014 and 2018 [2]).

Conducting a state of the art about this subject reveals different models to measure the maturity for Industry 4.0 (see table 1). According to Becker et al., a maturity model “consists of a sequence of maturity levels for a class of objects. It represents an anticipated, desired or typical evolution path of these objects shaped as discrete stages. Typically, these objects are organizations or processes.” [11]. A first model of this kind is that of Qin et al.[4], which presents an approach guiding companies towards Industry 4.0 through the development of cyber-physical systems within their product technologies. The five maturity levels displayed in this model are based on the digitalization and autonomy of the production system components but does not consider the process maturity aspects or the human aspects of technological integration. As such, it lacks crucial elements to correctly cover the integration of new technology.

organizational maturity (including the formalization of processes and the definition of responsibilities), information technology maturity (concerning the presence and mastery of different digital tools and methods), performance management maturity (focused on the management of indicators and steering) and connectivity maturity (studying the methods and the degree of information flow within the company). There are elements on process maturity and technological maturity, but the technologies evaluated are mainly those of information and communication and do not cover the whole spectrum of industrial technologies nor Industry 4.0 technologies. Moreover, change management is not considered in this model. Ganzarain et Errasti proposed a 3-step approach to transform companies into Industry 4.0 [13]: first developing a specific vision of Industry 4.0, then reinforcing the vision with characteristics of the company and designing projects, and finally implementing the transformation projects (including risk management and training for the staff). To do so, this model is based on a five-level maturity scale of the company’s Industry 4.0 strategy: Initial (no specific vision for Industry 4.0) – Managed (existence of a roadmap for Industry 4.0) – Defined (customer segmentation, value proposition and key resources defined) – Transformed (strategy broken down into specific tasks) – Detailed Business Model (business model completely turned towards Industry 4.0). They also specified which levels of business development and project portfolio management related to Industry 4.0 must be achieved to validate each level of the scale. This scale does detail maturity levels for building a technology development strategy, which is an important component of change management. Nevertheless, it does not present other elements of change management, nor the process or technological aspects that were also found necessary earlier to successfully carry out transformations within companies.

Article	Authors	Technological maturity	Process maturity	Human aspects
A Categorical Framework of Manufacturing for Industry 4.0 and Beyond	Qin J., Liu Y. et Grosvenor R.	Yes	No	No
Towards Industry 4.0: Gap Analysis between Current Automotive MES and Industry Standards using Model-based Requirement Engineering	Kannan S. et al.	Yes	No	No
An Overview of a Smart Manufacturing System Readiness Assessment	Jung K. et al.	Yes	Yes	No
Three Stage Maturity Model in SME’s towards Industry 4.0	Ganzarain J. et Errasti N.	No	No	Yes, but...
Industry 4.0: Building the Digital Enterprise	Geissbauer R. et al.	Yes	Yes, but...	Yes, but...
The Connected Enterprise Maturity Model	Rockwell Automation	Yes	No	No
Guideline Industrie 4.0 - Duiding principles for the Implementation of Industrie 4.0 in Small and Medium sized Businesses	Anderl R. et Fleischer J.	Yes	No	No
A Maturity Assessment Approach for Conceiving Context-specific Roadmaps in the Industry 4.0	Colli M. et al.	Yes, but...	Yes, but...	Yes, but...
A Smartness Assessment Framework for Smart Factories using Analytic Network Processes	Lee J. et al.	Yes	Yes	Yes, but...
A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises	Schumacher A. et al.	Yes	Yes, but...	Yes, but...

Table 1. Summary of the studied Maturity models

The model proposed by Kannan et al. is based on the industrial system standards recognized by the International Society of Automation (ISA) [12]. It proposes a 3-phase approach to identify the company’s needs to achieve these standards through the acquisition of new elements of the production system. This model is therefore mainly focused on the technologies in place within the enterprise without integrating the human or process aspects, and moreover, ISA standards can be difficult to achieve for some companies, especially small and medium enterprises (SMEs). The model published by Jung et al. develops four dimensions:

The consulting firm Pwc published in 2016 a maturity model for Industry 4.0 mainly targeting the digitalization strategies of enterprises, as it considers those as the keys for the implementation of Industry 4.0 technologies [14]. This model is based on 7 dimensions: Digitalization of the business model, Digital integration of value chains, Digitalization of products and service offerings, Data analytics, Agility of the IT architecture, Compliance with security rules, Organization, and Digital Culture. The company is then classified according to its capabilities on these dimensions between 4 levels (novice, vertical

integrator, horizontal collaborator, digital champion). These dimensions are mainly focused on technological maturity elements. There are also some aspects of process maturity (through the dimensions “Digitalization of the business model” or “Digital integration of value chains”, for example), but they are not detailed, and they are mainly considered through the implementation of digital tools enabling to apply those processes. The “Organization and digital culture” dimension responds to the need for elements on the human factor, but is only slightly developed, dealing only with the capability for collaboration and the digital means to support it. The model published by the company Rockwell Automation is also very focused on the technological aspects of transformation towards Industry 4.0 [15]. It presents four dimensions related to families of technologies considered crucial to achieve the standards of the Industry 4.0: Information infrastructure (hardware and software), Controls and devices, Networks building and interconnectivity, and Security Policies. It does not include the aspects of process maturity or change management capabilities. However, the classification of the different families of technologies may be of interest when building the recommendation system. In 2015, the VDMA (a German Engineering Industry Association) published a document presenting an approach developed specifically to accompany SMEs on their way to Industry 4.0 [16]. It takes place in five steps: Preparation, Analysis of the current situation, Creativity and definition of new business models, Evaluation and selection of technologies, and Implementation and application. This document also presents an “Industry 4.0 toolbox” presenting twelve families of technologies grouped by function (such as “Human-Machine Interface” or “Production data processing”). Each of these families is broken down into five levels of technology advancement (for example, for “production data processing”, it goes from “no data processing” at level 1 to “automatic control and planning of the production process” at level 5). These families of technologies are used as a maturity scale for the technologies implemented within the enterprise. As such, this model is focused on the technological maturity more than process maturity or human elements. There is therefore no evaluation of process maturity nor evaluation of ability to lead change, even though the authors highlight the importance of staff training when implementing new technological elements. As with the previous article, this classification of technologies can be used as a basis for the recommendation system. Another article, published by Colli et al. in 2019, reviews several models of maturity (including those from Rockwell Automation, and from Qin et al.) and underlines the importance of a more individual approach, considering the specificities of the companies. It then proposes a reference frame for the maturity assessment for digital transformation. With it, the company is evaluated on five items on a six-level scale (from a level 1 called “Basic” to a level 5, “Integrated”, plus a level 0 if they are not implemented at all). These five items cover the three aspects we consider important: technological maturity with “Technology” and “Connectivity”, change management capabilities with “Competences” and “Governance”, and process maturity with “Value creation”. However, five assessment items might not be enough to collect enough data to establish accurate recommendations. Lee et al. present an approach based on multi-criteria support tools [17]. They propose a table of criteria to assess the maturity levels of the company, divided into sub-criteria, which are themselves associated with

practices. There are many elements that measure the maturity of the company’s processes (“Production planning” or “Logistics management”, for example), without necessarily being associated with certain technologies within the company. Other criteria focus on the maturity of technologies present within the enterprise, such as the “Information system” sub-criterion, for example. However, there are very few elements on the human factor or change management capabilities (only practices in the “Leadership” criterion). In another article, Schumacher et al. propose a maturity index to calculate the level of readiness of companies for the adoption of Industry 4.0 technologies [18]. This model presents nine dimensions, taking into account the three aspects identified as important: process maturity (the “Products” and “Operations” dimensions, for example), technological maturity (the “Technology” dimension), human factor and change management (the “Leadership” or “Culture” dimensions, for example). The article also proposes examples of items for measuring maturity on each of the dimensions. Nevertheless, the aspect of process maturity is less complete comparing to the model of Lee et al. After studying these models in the literature, it could be observed that most of them do not integrate all the aspects considered necessary. Most of them focus on measuring the capabilities with different technologies, but process maturity or change management capability factors are less dealt with. The two models that reflect best these three dimensions are those of Lee et al. [17] and of Schumacher et al. [18]. The former is very comprehensive on the aspects of process maturity (thirty-six practices), which provides a good response to deal with it. However, it is less complete on technological maturity (eight practices) and even less on the change management capabilities aspect (two practices). This is why the second one, that of Schumacher et al., which presents fewer practices on process maturity (five practices) but is more detailed on the other aspects (nine practices on the human factor and change management, and eleven practices on technological maturity) was chosen to complement it and constitute a mostly complete set, even if some other practices could be taken from other models. As some practices are very similar in the two models, not all of them have been included from one or the other in order to avoid duplicates. For example, “Strategy and plan for implementing smart factory” and “Implementing Industry 4.0 roadmap” are very similar, and that is why only the second item has been included in the proposed model. Our proposed assessment model, presented in the next section, is mainly based on these two models.

III. PROPOSED ASSESMENT MODEL

A. Areas and practices

To enable an easier and faster application of this model in the industry, these practices were associated with a model adopted from a study by the Roland Berger firm [19], presenting different technologies for eight areas within industrial companies: conception, production control/management, traceability, flow management, precision/quality, flexibility, maintenance, and work organization. Each of these areas were associated with practices mainly extracted from the two models previously chosen. For example, the “Product/process design” area was linked to 9 practices from those two, like “Product design and evaluation” from Lee et al. or “Digitalization of products” from Schumacher et al. (see table 2).

Product/process design		
Practice	Original model	Aspect
Procedure of product development	Lee et al. (2017)	Process
Product design and evaluation	Lee et al. (2017)	Process
Process design and evaluation	Lee et al. (2017)	Process
Management of product information	Lee et al. (2017)	Process
Management of technical information	Lee et al. (2017)	Process
Digitalization of products	Schumacher et al. (2016)	Techno
Utilization of Product Lifecycle Management (PLM)	Lee et al. (2017)	Process
Utilization of Finite Elements Method (FEM)	Lee et al. (2017)	Process
Open-innovation and cross-company collaboration	Schumacher et al. (2016)	Process

Table 2. Practices associated with the "Product/process design" area

The same work association was made for the seven other areas (see figure 1). Some areas are more associated with some of our three aspects than with others: for example, "Product/process design" is mainly associated with the process maturity aspect, and a little the technological maturity, whereas "Work organization" is heavily associated with change management capability practices, such as "Autonomy of employees" and "knowledge sharing", but also technological maturity, with practices like "value of ICT in company". Based on these practices, the audited companies are evaluated on a five-level scale for each of the

eight areas, depending on if the practices are put in place or not.

B. Identification of priorities

In order to be able to deploy this model in all types of industrial companies, the choice was made to establish a typology of the latter, based on their production model. It is inspired by a model from Pahl and Beitz [20], which underlined the difference between the production processes according to whether the product is produced as a single piece, in batches or through mass production. This typology added One-Piece Flow production (OPF) to these three possibilities, as it has its own constraints. For each of these types of production, the importance the different areas were defined and ranked with an expert (table 3). For example, flexibility is considered the most important area for companies presenting a One-piece flow production or making unique pieces, whereas it was considered only the second to last for those producing in mass.

To enable the company to efficiently implement the recommendations issued from the results of the model, each area is associated with an importance score, depending on the company's current maturity level and the importance of the area according to its type of production. The less mature an area is, and the more important for the company it is to progress on it. To transcribe this in the calculation, a subtraction is made between the maximum level (which is five) and the current level of the enterprise. The importance

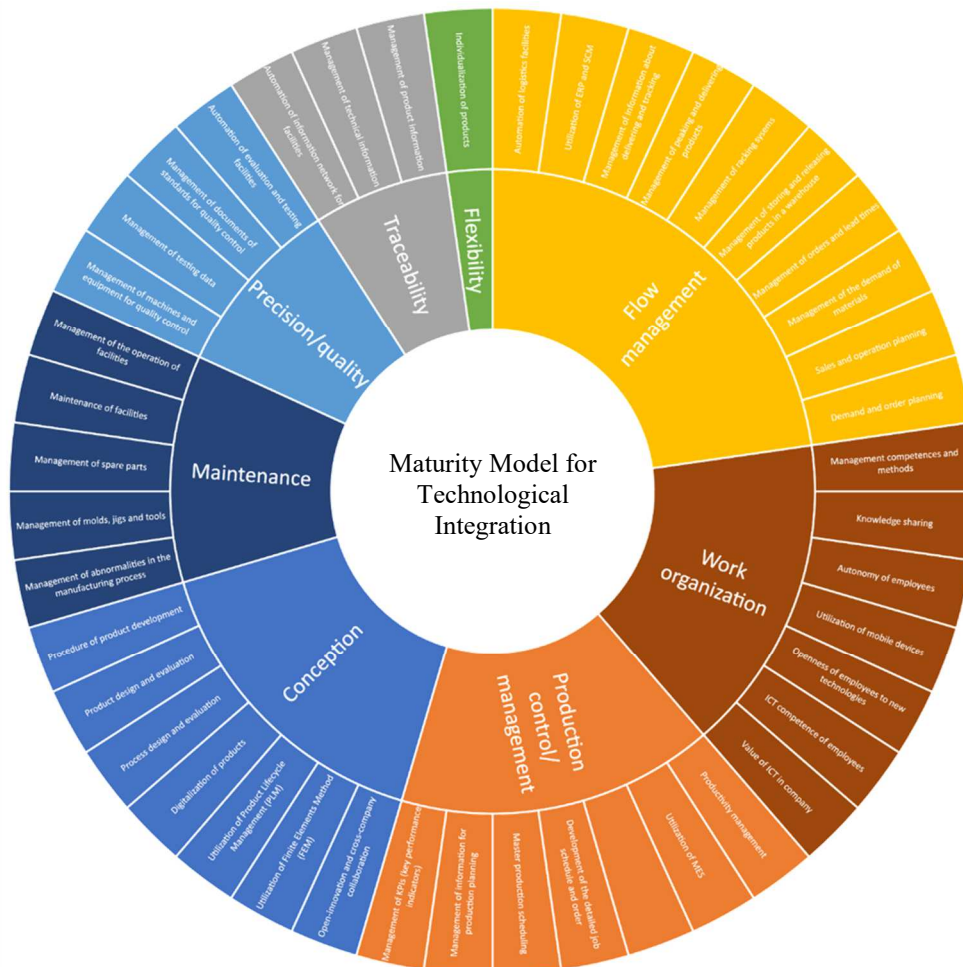


Figure 1. The eight areas and the practices associated

of the areas is considered by incorporating a factor depending on the classification according to the production typology. Thus, the priorities for two companies with the same maturity levels but different production system typology will not be the same and will be more appropriate for each of the two. The importance score of an area i is calculated as follows:

$$\text{Score (i)} = (\text{Maximum maturity (i)} - \text{current maturity (i)}) \times \text{Importance factor (i)}$$

The areas are then classified by decreasing importance score to indicate for the supported company the main areas to focus on. The enterprise thus has indications on the areas to be dealt with in priority.

	Areas importance			
	OPF	Mass	Batch	Single P.
Production control/management	2e	4e	1e	7e
Traceability	6e	6e	8e	6e
flow management	3e	3e	2e	3e
Precision/quality	5e	1e	3e	5e
Flexibility	1e	7e	4e	1e
Maintenance	4e	2e	7e	8e
Work organisation	7e	5e	5e	2e
Product/process design	8e	8e	6e	4e

Table 3. Importance of areas depending on the type of production

IV. CASE STUDY

In order to illustrate how it works, this section describes a company to which we apply our model. The selected company is an automotive supplier. It is classified as a “one-piece flow” company and doesn’t have conception activities. After the evaluation of the maturity of the company on our 8 areas, we have the following maturity levels: 5/5 in flexibility and traceability; 4/5 in precision/quality and production control/management; 3/5 in maintenance; and 2/5 in work organization and flow management. For example, it means for flow management that the company has put formalized and mature processes but has not implanted any digital technology specific to this area. In general, the process maturity is pretty high all across the board, technological maturity varies depending on the studied area, but change management capabilities are not that strong. That last one explains why one of the lowest maturity level is in the “Work Organization” area, which regroups a majority of change management capabilities practices. The maximum maturity level that could be achieved by the company is 5, and, as flow management is considered the third most important area for “one-piece flow” companies, the importance factor is 1,3. Therefore, the importance score for this area is:

$$\text{Score (Flow management)} = (5 - 2) \times 1,3$$

As such, the importance score for flow management for this company is 3,9. Similarly, the following importance score are obtained: 2,4 for maintenance and for work organization; 1,4 for production control/management; 1 for precision/quality; 0 for flexibility and traceability. Finally,

the areas are classified following their importance scores (see table 4).

Ranking	Area	Importance score
1 st	Flow management	3,9
2 nd	Maintenance	2,4
2 nd	Work organization	2,4
4 th	Production control/management	1,4
5 th	Precision/quality	1
6 th	Flexibility	0
6 th	Traceability	0
8 th	Conception	N/A

Table 4. Ranking of the importance of the areas for the company

Therefore, our model recommends the company to focus on flow management in the first place, and then on maintenance and work organization in a second time. With these results, the recommendations that would be issued from the model would be put in perspective and hierarchized, in order to indicate to the accompanied company how to build a roadmap to improve their processes.

V. DISCUSSION

The next step in the construction of the model is to conduct a test campaign of the model resulting from our literature study, in order to validate the selected practices, the maturity levels, as well as the order of importance of the areas. Moreover, thanks to the data collected during this campaign and to the study of other cases of technological transformation within other companies, a knowledge data base will be built in order to be able to link current maturity levels on the chosen practices and evolution actions to be carried out, which will be the base of the recommendation system. To complete the latter, research will be conducted on the different types of production technologies, studying the needs they meet, the practices retained in the model to which they can be linked and the maturity levels to be reached in order to be ready to integrate such or such technology. Eventually, the recommendations provided by the system will therefore include advice on how to gain maturity in practices suggestions for families of technologies adapted to the company’s maturity.

VI. CONCLUSION

This article presents the on-going process for the construction of a diagnosis and recommendation model for the acquisition of new technologies, including those of Industry 4.0, within industrial companies. Taking into account not only the technological maturity of the supported enterprises, as most of the models currently available in the literature do, but also the maturity of their processes and their ability to lead change within themselves should allow them to increase the chances of success for technological transformation projects.

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