A Framework for assessing manufacturing SMEs Industry 4.0 maturity

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Abstract: Assuming the multiple benefits that the Fourth Industrial Revolution will bring multiple benefits for the industrial sector, this work focuses the adoption of Industry 4.0 and its underlying components. Because these benefits can be opportunities as much as threats, we also assume that adopting Industry 4.0 seems unavoidable in the long run also for SMEs. Changing to adopt Industry 4.0 will entail natural struggles and creates difficulties for companies to immediately embrace this revolution. In fact, according the current status of research, most companies fail to grasp the essence of this concept and, especially, SMEs which have a hard time when it comes to start adopting Industry 4.0. This work proposes a maturity model with increased detail in Industry 4.0 maturity level in order to help SMEs embracing this concept.

Key words: Key words: Industry 4.0, Small and Medium Enterprises, Maturity model

1. Introduction

Europe is currently undergoing an industrial revolution that goes by the name of Industry 4.0 [1], [2] [3]. Regardless of the name used to identify this revolution, there is a general acceptance between companies, researchers and institutions, that the Fourth Industrial revolution is here, and it’s here to stay.

This revolution will bring multiple benefits for the industrial sector as well as for the society itself. Although the adoption of Industry 4.0 and its components seems unavoidable on the long run, there are several struggles that prevent companies to immediately embrace this revolution. SMEs have especially a hard time when it comes to approach this concept as Industry 4.0 readiness increases sharply with the size of the company [1].

On a first approach, the present dissertation analyses the suitability of the already published maturity/readiness models for the SMEs, followed by a dissection of the main hurdles that SMEs encounter when implementing Industry 4.0 measures. Incorporating both of these analyses and assembling six different maturity/readiness models for Industry 4.0, a maturity model for Industry 4.0 is developed. This model contemplates a framework that structures its dimensions, an input in the form of a questionnaire, and two different outputs in the form of netcharts. Furthermore, this model’s applicability is demonstrated though a real case study application in a non-repetitive production SME. In this regard, two simple digitalization propositions and their influence in the company’s maturity level are presented to support the claim that, although difficult, the implementation of Industry 4.0 is indeed reachable. Finally, the developed model is compared against the most quoted model in the literature to confirm the premise that, the former model has a higher degree of granularity in Industry 4.0 initial maturity levels, allowing it this way, to be suitable for companies being introduced to this concept, especially SMEs.

2. State of art

This chapter addresses the concept of Industry 4.0, while taking into consideration its design principles and associated technologies. A literature review of the main maturity/readiness models of Industry 4.0 and the main hurdles that companies have in approaching this concept is also made. This chapter ends with an analysis of whether these tools are suitable for Small and Medium Enterprises.

2.1 Previous Industrial revolutions

Being Industry 4.0 a new concept, which is not only composed by several innovative technologies but also by changes in business models and organizations [2] [4] [5], we will assume that Industry 4.0 concept as an innovation itself.

2.2 Industry 4.0 and its innovative technologies

It has been stated that, by tackling this concept as early as possible, these First movers have an insurmountable advantage over the rest of the market [3] – there is thus an urge to take part of the Fourth Industrial Revolution to benefit from competitive advantages and lead the way [3] or at least, not to get left behind.

Industry 4.0 concept has been widely approached by the literature in the past years. The term Industry 4.0 was introduced by the German government as one of the key initiatives of its high-tech strategy in 2011 [2]. In October of the following year, a working group set up by the Research Union Economy - Science of the BMBF handed over the first ever report of Industry 4.0 [Plattform4.0]. Since this
concept presentation in Hannover fair in 2013 [6] there have been a number of attempts to define it. Although there is still no clear definition of this concept, there is a general acknowledgement of its importance not only to the industry sector but society itself [7], Moeuf et al. in 2017, cited by Buer et al., states that recent studies have found more than 100 definitions of Industry 4.0 [8].

The technological concepts comprehended by Industry 4.0 are: Additive Manufacturing – 3D printing, Cloud, Manufacturing Execution Systems (MES), Internet of Things (IoT) and Cyber Physical systems (CPS), Big Data, Sensors, e-value chains, Autonomous Robots. From the research performed, seven of the mentioned technologies seem to be in accordance with the literature, but there are several sources agree in giving enough importance of each element of “CPS and IoT”, attributing to each one of them the notion of technological concept.

2.3 Design principles of Industry 4.0

As already referred, although there is still not a clear definition for what Industry 4.0 is, Hermann et al. in the years of 2015 and 2016 sought to define the design principles that this concept comprehends [7], [9]. The process that these authors followed, consists of four steps: Identification of relevant literature; Quantitative text analysis; Qualitative literature review; Nominal group workshop [7]. The results of these works are a list of 3 key features of this concept – CPS, IoT, Smart Factory – and 4 design principles – Interoperability, technical assistance, Decentralization, Information transparency. These described design principles allow a common understanding of Industry 4.0, which is needed for a reasonable scientific discussion on the topic [7]. From this point on, when Industry 4.0 term is used in this dissertation, these four design principles should be always taken into consideration.

2.4 Data as a pillar of Industry 4.0

Data can be defined as “… symbols that represent the properties of objects and events.”, while information can be interpreted as consisting of “… processed data, the processing directed at increasing its usefulness.” [10]. Information can be seen as contextualized data and knowledge can be derived from data and information. This process of creating knowledge was defined in 1994 by Nakamoto, in their model called SECI. Its name stands for the stages that it is composed off: Socialization, Externalization, Combination and Internalization [11].

Rosmiati et al. define information as the most valuable resource of an enterprise [12]. In the context of Industry 4.0, data is considered to be one of the most important assets a company can possess. To take the most out of this data, a company should share it internally and externally. In this Fourth Industrial Revolution, the collaboration of the entire value chain is not only necessary but also beneficial [4] [1] [2]. Although, as defended by Schumacher et al., efficiency related advancements are focused especially in individual firms, rather than in the whole supply chain [13]. One of the ways to increase efficiency in a company are IT-solutions. On this regard, Verkatraman proposes a model that contemplates the stages enabled by the implementation of IT solutions in companies Business Models [14].

2.5 Industry 4.0 implementation hurdles and mistakes

In the process of implementing Industry 4.0 related measures, companies encounter several obstacles and undertake some mistakes. Consulting firms are one of the most important contributors to this concept’s implementation. Therefore, the most extensive lists of hurdles and mistakes presented in the researched literature are from this type of companies. In this dissertation an assembly of the most usual hurdles that companies confront in the process of implementing Industry 4.0 is performed.

2.6 Maturity Models

At this moment, the literature provides already multiple tools to ease and help the implementation of Industry 4.0. These tools do not provide an easy way to overcome the hurdles mentioned in the previous section, but when used properly, can help companies avoiding them.

The literature provides several definitions for the notions of maturity and maturity models. Essentially, the basic goal of a maturity model is to describe stages or paths to reach maturity and to describe the characteristics of each stage or level as well as the logical relationship between successive stages [15] [16]. The literature presented a definition for three different types of maturity models: Descriptive, Prescriptive, and Comparative.

In the context of Industry 4.0, maturity models are especially important, as they contribute to the dissemination of the concept and provide companies with a broader understanding and implementation proposals to deal with this revolution [17]. Schumacher et al., in their works suggest two different types of maturity – maturity and readiness – and contextualized notion of maturity in an Industry 4.0 environment [13].

The present dissertation analyses 13 works on maturity/readiness models for Industry 4.0. In this analysis, the notions of maturity levels and model’s attributes are clarified.

2.7 Suitability of Industry 4.0 maturity models for manufacturing SMEs

All of the maturity models for Industry 4.0 mentioned in the previous section serve the purpose to help enterprises to implement this concept in their day-to-day business and to embrace the digitalization endeavour in this sense.

Schumacher et al. in 2016 [13] defend that new methods and tools are needed to provide guidance and support to align business strategies and operations. The latter source grounds its statement with the outcomes of several strategic workshops, which are 1) the serious difficulty that companies have in grasping the concept of Industry 4.0 and 2)
particular concepts hereof [13]. While referring this need of development of new tools, the same source also states that, a special attention needs to be given to Small and Medium Enterprises [13] – which is exactly the contribution that this work wants to achieve.

Moreover, the IMPULS model assumes that large enterprises are more advanced in implementing Industry 4.0 than small medium sized businesses [Imp], which confirms this need for special attention regarding SMEs. From the research made, only two assessment tools specially developed for SMEs. Nevertheless, none of them provides a holistic approach of the assessment regarding maturity levels considering SMEs. The goal of this current work tackles manufacturing Small Medium Enterprises, as it develops a model that is a synthesis of maturity models for Industry 4.0, especially adapted for this type of companies.

3. Dissertation research’s approach
3.1 Goals of this work

The present work has two main objectives. To start with, this dissertation has the goal to understand which tools exist in the literature to help the SMEs implementing Industry 4.0 – within these tools the focus are maturity/readiness models. To accomplish this objective, a literature review of the maturity/readiness models for Industry 4.0 is made, along with an analysis of the characteristics that these tools should have to suit SMEs. This review reveals that most models fall short helping SMEs in this implementation. The second main goal appeared after this latter conclusion. Since none of these models are broad enough to tackle the concept of Industry 4.0 as a whole, nor have enough granularity in the initial maturity levels, the decision was made to develop a maturity model that incorporates six maturity/readiness models for Industry 4.0, while being especially developed for manufacturing SMEs.

3.2 Definition of Small and Medium Enterprises

SME’s are indispensable in all economies, they can be described as a driving force of business, growth innovation, competitiveness, and are also a very important employer [18].

The European commission already provides a definition for enterprise and well as which constrains an enterprise should have in order for it to be categorized as micro, small, or medium size.

3.3 Contextualization of hurdles

The purpose of this analysis is to bundle and to categorize the hurdles, in order to get a better sense of what the main categories of hurdles that SMEs have, are. This analysis is taken into consideration throughout the development process of the model presented in the next chapter. Taking these categories of hurdles into regard, is one of the ways to create a model that is directed towards SMEs

From the analysis performed in section 2.5 it is possible to conclude which are the hurdles that appear the most in the literature, in order to obtain a top or the most common hurdles that appear in the literature. Some of the hurdles have a different description, but they represent the same idea. Because this work aims for a development of a maturity model that takes into consideration companies’ hurdles, we opted to group these hurdles in similar groups – this way, the model is related with the idea behind the hurdles, not the obstacles themselves [1].

The importance of a hurdle can be interpreted as the amount of times that a category was enunciated in the literature. This deduction is based on the premise that, for a hurdle to be enunciated in a scientific work, the authors must have considered it important enough to choose that particular hurdle and not any others. It is thus possible to extract from the table above the most important categories of hurdles that should not be missed out in the development process of an Industry 4.0 maturity model when adapting it to enterprises being introduced to the concept, especially SMEs. The most important categories are “Skilled labour” and “Economic benefit”. Followed by “Financial budget”, “Internal Problems”, “Lack of clarity” and “Data security”.

3.4 Analysis of maturity models

As clarified in section 2.6, the notions of maturity level and model’s dimensions are distinct. This current section analyses the researched maturity/readiness models in terms of both notions.

For the development of this work, thirteen models from the literature were chosen. Naturally, each author has their own perspective of Industry 4.0 and its constituents. Each work comprehends different aspects of Industry 4.0. There are no wrong models, just different perspectives and applicability scenarios that were taken into consideration, when each model was developed. Even if different authors perceive the same pillar of Industry 4.0, they might give it different names. It was assumed in this analysis, the name of the dimension is not important, the idea behind the dimensions is what matters, if a meaningful model is to be created.

The analysis of the models’ maturity levels allows a better understanding of which stages of process are considered by these models until the full implementation of Industry 4.0. Due to this reason, this analysis is decisive in a development process of a model. After this analysis, two examples are provided with the intend to explain the effect that the lack of granularity has in the placement of companies in the models’ maturity/readiness levels. In fact, companies that have different characteristics and different levels of aptitude to implement Industry 4.0 are considered in the same level of maturity.

3.5 Gap exposed from the literature

After understanding the lack of granularity that maturity/readiness models can have, an analysis of the two models that seem to have tried to overcome this issue is performed.
It’s possible to deduce from this analysis that a more detailed and supported approach of the initial maturity levels is lacking but is, at the same time, possible, and it should consider the best detail of each maturity model for all concerned levels. This approach is important because the current ineptitude of the maturity/readiness models is also related to the lack of granularity in these models’ levels.

To conclude, there is a need for a comprehensive model that, not only has a more detail, i.e. granularity, especially in the initial levels than the ones presented in the literature, while keeping its holistic approach to the concept, but also considers the hurdles and obstacles that SMEs have when implementing Industry 4.0 initiatives.

3.6 Approach followed in this dissertation

This methodology can be seen as the research approach was used in this dissertation. This work aims to contribute for a correct assessment of an SME maturity level in Industry 4.0. For this evaluation to be accurate, the used tool needs to be suitable for companies that are being introduced to Industry 4.0. For the maturity model to be useful and applicable for SMEs, it should take into consideration the already developed and used models, and the hurdles that this type of companies have, need to be kept in mind, during its development process.

The used methodology has five sequential main steps which are: Research, Defining, Model, Questionnaire, Implementing.

Following the proposed methodology, allowed not only the development of a maturity model of Industry 4.0 that is suitable for SMEs as well as other types of companies that are in the beginning of the implementation journey, but also the implementation of this tool. This implementation allowed the company to have its maturity level of Industry 4.0. This level is important if goals for each area of the company are to be set [17].

4. Maturity model’s framework

In this chapter, a framework containing the dimensions and sub-dimensions of a maturity model that is directed to SMEs by aiming to help them adopting Industry 4.0 in their respective businesses, is proposed.

4.1 Development process of the proposed model

The previous chapters two and three highlight thirteen works on maturity/readiness models for Industry 4.0. In the development process of the current maturity model for Industry 4.0 that considers SMEs, only six of these works were taken into consideration. The explanation of the reasons to select these models is put forward. Within these chosen models, there are different approaches to this concept. These approaches reflect the amount of detail provided by each models’ sub-dimensions. Some models focus in the technology used in the production sites as well as in the product itself, while other models’ aim is to assess which kinds of change are allowed by these technologies. This section presents a description of each chosen model as well as a comparison of each model’s attributes.

4.2 Description of the model’s dimensions

The dimensions and sub-dimensions that this model comprehends, which are described in this current section and 4.5, are inspired in three main aspects: 1 – an analysis where we extract the most important dimensions related to Industry 4.0 for these sources, which should be assessed in any a company; 2 - the combination of the outcomes of this analysis with the main categories of the hurdles that SMEs experience, through the process of implementing Industry 4.0; 3 - the level of granularity that this model should have, in order to be suitable for SMEs.

The framework that encompasses the developed model dimensions and sub-dimensions is composed by six main elements. Each element represents a model’s dimension. The chosen dimensions are:

Technology – What will foster this change?
Production Processes – What created value in this change?
People – Who will drive this change?
Smart Product – What will allow this change?
Organization – How will the enterprise change?
Change – What are we changing?

As explained, all of these dimensions came from existing models for Industry 4.0. Although 3 of the models mentioned above also consider this dimension, they call it “Strategy”. In this proposed model, this dimension is named “Change”, as this name better captures what is really being assessed. The term “strategy” can originate a misinterpretation due to the notion of “business strategy”, when we know that the authors of both models are considering the strategy related on how to change, so, for the sake of clarity, it will be simply referred to as “Change”.

4.3 Model’s dimensions framework

The Figure bellow illustrates the developed framework where the dimensions of the present model are integrated between themselves. This representation is based on the work of David Siepmann in 2016 “Industrie 4.0 – Grundlagen und Gesamtzusammenhang” where in section 2 of his work “Komponenten der Industrie 4.0” the author proposes a methodology for Industry 4.0 division and presents a scheme/figure representing it [19].

This visual mapping of the proposed model’s dimensions helps clarifying its structure and the connection of its core dimensions. There are
essentially 3 main parts, each related to one of the 3 layers presented by David Siepmann [19]. The first level is represented in this figure by "Technology", the second level by "Production Processes" and the third by "Change". As already explained, these levels are the basis for the development of the framework’s scheme proposed in the present dissertation. With these six described dimensions, and according to all models referred in Chapter 2, the proposed model covers all main areas of Industry 4.0. This way, an enterprise can be assessed in holistically, rather than only partially.

Culture is a very important component in any organization that would like to embark in Industry 4.0 [4] – 3 out of the 6 chosen models have it as a dimension. In fact, the ability to analyse the prevailing corporate culture is critical to success [4]. Nevertheless, culture was not chosen as a separate dimension for this particular model. This decision is based on the fact that “Culture” dimension would not fit in the developed framework, that assembles all of the dimensions. Nevertheless, “Culture” is considered by this model, just not as a fully independent dimension.

4.4 Description of the model’s sub-dimensions

In the maturity model for Industry 4.0 developed in this work, each dimension is constituted by several sub-dimensions. For a correct assessment of the maturity level of a company, this increased degree of detail is necessary, in order to create a transparent and incisive model. In fact, the dimensions presented above are essentially a categorization of the sub-dimensions of the model. One of the fundamental differences between models is the way each categorizes its own sub-dimensions, so it is thus important to understand the idea behind each sub-dimension.

It is worth to emphasize that out of 26 sub-dimensions 25 are indeed grounded on at least one of the six chosen models. The 26th sub-dimension “SMEs commitment” is a proposition from this dissertation, since it is considered crucial to assess what are the intentions of the company at any point, throughout this change process. The focus of this sub-dimension is the company’s commitment, that is, how far is the company willing to go in the path towards the full implementation of Industry 4.0. A company undertaking an IT-enabled business transformation can be assessed in two different ways, internally and externally [14]. These two different strategies are assessed in order to understand which efforts are linked to the internal change of the company “Digital transformation” (exploitation) and which are being made towards the external change “Adaptation of business model” (exploration). Although Verkatraman’s assessment model was developed for any type of company [14] its applicability to SMEs was already proven by Levy et al. in 2002 [20].

4.5 Combination of sub-dimensions and hurdles

This section contains a clarification of the reasoning behind the impact that the contextualized hurdles presented in section 3.3 have in this model, more specifically, in its sub-dimensions. The combination of these two aspects allows a greater transparency of this work. With the description of each matching between main hurdle’s categories and the model’s sub-dimensions, it becomes clear that this model targets SMEs.

4.6 Level of granularity

One of the main objectives of this dissertation is the development a model is suitable for enterprises being introduced to Industry 4.0, especially SMEs. To achieve this goal, not only must this model offer a holistic approach to this concept, but also an increase in its level of detail, when compared to the other models. This increase in granularity allows the model to be appropriated for SMEs to use it, because different types of companies will have different levels of maturity.

This work considers the notion that exist two main ways to increase the granularity level, in comparison to the models presented in the literature, which were found in the process of analysing the existing models, while performing a literature research, and in the own development process of the proposed maturity model. There methods are: (i) Increasing the number of steps that a considered sub-dimension is initially divided in, and (i) dividing one sub-dimension in two or three other sub-dimensions.

It is worth to notice that, in the process of increasing the model’s detail, both of the above described methods can be used individually or in combination. Since the target of this model are companies being introduced to Industry 4.0, especially SMEs, the sub-dimensions that were left out, are not suitable to be assessed in their context. Considering that these types of companies are still in the earlier phases of this process’s sub-dimensions as, for example: Autonomous processes, Existence of modern ICT, Share of revenue of data-driven services, Self-optimizing processes, Decentralization of processes.
4.7 Pictographic comparison of maturity models

In this section, a comparison between the six models used to develop the proposed maturity model and the model itself is performed. This analysis is essential when a model has been based on other models for its development, because it is possible to take conclusions out of the model’s comprehensiveness.

From this analysis, it is clear that no other considered model covers all of the sub-dimensions of the currently proposed model. These comparisons show that the developed model, not only considers this model more sub-dimensions when compared to all of the other models but at the same time, these sub-dimensions are increasingly targeted to SMEs, since almost half of them took into consideration categories of the main hurdles that SMEs have when implementing Industry 4.0 (see the previous section 4.6).

4.8 Final remarks about the proposed framework

This chapter presents a framework for the dimensions of the maturity model developed in this thesis. This model focused on companies that are being introduced to Industry 4.0, especially SMEs. This artefact is essentially a synthesis of six maturity/readiness models for Industry 4.0 presented in the literature. All of these models’ dimensions were taken into consideration by this framework and grouped in a way that makes clear the connection between them.

The three main features that make this model suitable for this type of companies are: 1 – The influence of the main hurdles that SMEs have when implementing this concept, in the choosing the model’s dimensions; 2 – The amplified level of granularity in the initial levels, provided by its sub-dimensions; 3 – The fact that, although there is an increased amount of detail offered by the model, it still grants a holistic assessment of the company at stake overall.

5. Proposed maturity model’s inputs and outputs

This chapter presents the inputs that this model receives and the outputs it provides.

5.1 Proposed maturity model’s inputs

The inputs come in the form of a questionnaire. This work does not provide the questions themselves, because there might be different ways to ask the same question depending on the receiver. i.e. depending on its knowledge about Industry 4.0 and the overall understanding of the company’s business. The same question should thus be asked in different ways to different employees. Therefore, this questionnaire provides a field/item upon which a question should be asked rather than the question itself. Moreover, to ease the process of attributing a maturity level to each sub-dimension, each question comes along with 6 pre-defined answers – which can also help in the formulation of the question.

5.2 Proposed maturity model’s outputs

In the process of researching and understanding the maturity/readiness models for Industry 4.0 – how they perceive Industry 4.0, how they divide this concept (their dimensions), and which output they generate – a conclusion was reached. Contrary to what was thought at the beginning of this journey, the overall maturity level of Industry 4.0 is not the most important information to extract from maturity assessment. In fact, there is no substantial outcome to be obtained from an overall level of maturity, in the sense that, there is not any tangible step for an enterprise to take in order for it to get more involved in Industry 4.0.

This proposed model has two outputs, one net-chart that presents the maturity levels of the model’s dimensions, and another one, more insightful, that displays each sub-dimension levels.

In this chapter, an example of how to use the information provided from this second output is present. This example confirms the powerfulness of this concept: the seemingly impossible objectives of today, might be tomorrow’s achievable goals.

Some models have a section of their assessment destined for the comparison between companies [1], [13]. This section has two main purposes: 1) it is responsible for a more precise benchmark of the companies that use this model (as referred in this section of this chapter, this is done for more accurate scientific results); 2) it affects the practicability of the results taken from the model. By having this section, it is possible to ease the statistic process that is adjacent to the post-analysis of maturity assessments, since, when the assessment is done, it is already described which type of company and which sector the company is in.

This model, however, does not contemplate this section. Because all of the main areas seem to be covered, this type of conclusions can be taken with an evaluation of the model’s outputs. A constraint affecting this model, is that maturity levels of companies from different sectors are not easy to compare. Nevertheless, as explained in this chapter, through the research performed throughout this work, a conclusion was reached: the overall maturity level of Industry 4.0 is not relevant if useful insights are there to be extracted.

5.3 Conclusions

To conclude, the purpose of this model is to provide as an output the maturity level of Industry 4.0 from the companies it assesses. No adaptation or adjustment is done to, neither the dimensions nor the sub-dimensions maturity levels. If conclusions are to be made, either regarding the company or its comparison to other companies (from the same sector or not), they should be performed a posteriori of this assessment.
6. Case study of the proposed model's application

The purposes of this chapter are to expose the actions took to validate the developed maturity model application, and to highlight its contribution to the literature.

6.1 Chosen SME’s maturity assessment

The company chosen for this case study fits in the definition and characteristics highlighted in section 3.2.

At the first glance, this company does not seem suitable to embark in the endeavour that Industry 4.0 is. In fact, Strandhagen et al. 2017 have pointed out in their work that repetitive production companies have an easier transition to Industry 4.0 than non-repetitive production enterprises [8]. It is important to underline that, the model created in this dissertation was not developed specifically for this company.

Within the company’s workforce, the (1) production chief, (2) the responsible for the planning, (3) the COO, and (4) an IT department worker and expert in Business Intelligence (BI) were chosen and gently accepted to be a part of this assessment. The four different workers cover all of the areas from the company assessed in this model.

From the answers given by these four elements, the maturity level of the company, as well as, each dimension and sub-dimension was calculated. The figure below shows the enterprise sub-dimensions’ maturity level in Industry 4.0.

After measuring the company’s maturity level, it was presented to the COO (3) in a meeting. The feedback received from this collaborator was positive. In this meeting, on one side, the COO affirmed that he could review his company in the measured maturity level, which is a first confirmation that the maturity level given to the company represents this company over the respective assessed concept. But, on another side, at a first glance, he thought that the company’s maturity level would be lower than the one presented. This feedback gives a first hint that the developed model is targeted for companies being introduced to Industry 4.0.

6.2 Digitalization proposition 1 – Streamlining a process

The company has a “fast track” service that consists in pre-developed standard modules for fast delivery to the customer. The enterprise has an internal process outlined for this service. The purpose of this proposition, it is not to suggest a new way of performing the already established process, since the aim is not the process re-engineering. What is being proposed, is the way people deal with the required information for the process to happen.

What is being suggested in this section is a way to centralize the information using mainstream technologies. With the use of a cloud-based freeware website/application called “Trello”, it is possible, without changing the way the process is being done and any information that each card has, to digitalize these boards and cards. Although, what is being suggested here is merely the digitalization of the current process, it is possible to understand the opportunities that this shift provides the process. Digitalizing this process is just the “tip of the iceberg” for the streamlining of this process in particular. In fact, two thirds of the companies surveyed by Bearing point see potential in further streamlining their processes through digital innovation [21].

The figure below shows the influence that the implementation of this proposition would have in the enterprises maturity level.

6.3 Digitalization proposition 2 – extracting data

In this section, a second and last digitalization proposition is done. In contrary to the last section, the goal of this suggestion is not to achieve a higher
efficiency in the affected process, but to allow data (passive and real time) to be extracted from it – the efficiency will be a consequence of this digitalization, but it is not the aim of this suggestion. The process that is going to be target here in this section is the production order, i.e. how the order to produce one product is given to the workers in the shop-floor.

The aim of this section is to suggest a way to perform this process, which would allow the company to have six new reliable indicators. Essentially, there are two main changes, one is purely related to a digitalization, and the other changing the way the workers register their working hours. First, it is worth to know that the production document exists in a spreadsheet format which is printed every time there is a modular construction to re-arrange. Three of the six indicators that this proposition would create are real time. Real time data does not have a very high level of digitalisation, but it is very important [21].

The figure below illustrates the impact that the implementation of this proposition would have in the enterprise’s maturity level.

![Figure 4 - Maturity level of Industry 4.0 after second digitalization proposition](image)

6.4 Final remarks on both digitalization propositions

Both of these suggestions, but especially the second one, are presented in this work in order to reveal that it is not necessary to implement very complex and expensive technologies to achieve a higher level of maturity. This is only possible because the level of maturity of this company is rather low, and therefore, to increase it is somehow easy. The higher the Industry 4.0 maturity level, the more expensive and complex implementations it entails. Once the target of this model are companies that are in the beginning of the Industry 4.0 adoption, their maturity level is low, therefore, the technological implementations might be from the type of these two that were presented.

6.5 Maturity level comparison

In this section, a comparison between the most quoted model in the literature and the model developed in this work is performed. This analysis is constituted by three parts. First, a comparison of which part of the Industry 4.0 implementation’s process from both models is performed. Then, the assessed company’s maturity level of Industry 4.0 from both models is contrasted. And lastly, an analysis of the [1] assessment’s sensibility to the implementations of the digitalization propositions presented in this chapter is performed.

With these three comparisons, the premise that the model created in this work is targeted to enterprises entering the sphere of Industry 4.0 by granting a higher degree of detail in the initial maturity levels of Industry 4.0 can be confirmed.

6.6 Conclusions

This chapter serves the purpose to confirm the applicability of the maturity model developed in this work, as well as to reveal that Industry 4.0 entry barriers of might not be as high as they initially appear.

The level of Industry 4.0 maturity for a non-repetitive production company was successfully attributed by means of the information gathered by the application of the questionnaire developed in chapter 5 and introducing it in the framework developed in chapter 4.

The last part of this chapter includes a comparison of the maturity level measured in the beginning of the chapter, but from IMPULS model [1]. This comparison permits an analysis of the different level of detail that each model has, as well as the placement of the developed model in the whole process of implementing Industry 4.0 – from its introduction until the full implementation. It is clear from the analysis performed in section 6.4 of this chapter that the [1] model does not have a granularity degree as the model developed in this dissertation. The latter model is targeted to companies that are being introduced to the concept, especially SMEs, so its degree of detail of the former’s initial levels is higher.

7. Conclusions and future work

The present dissertation had two primary objectives. In a first approach, an analysis of the current maturity and readiness tools and their suitability to SMEs, as well as a dissection of the mistakes and obstacles that this kind of companies encounter when implementing this concept. Once understood the different attributes that each model has and what is needed for a model to be suitable for SMEs, the second goal of this dissertation emerged. The second main objective aims at a development of a comprehensive synthesis maturity model for Industry 4.0 which is targeted to companies that are being introduced to this concept, especially SMEs. To confirm the model’s applicability, a real case application was performed in a non-repetitive production SME, where its maturity level was successfully attributed by the model.

From the analysis performed in the first part of this dissertation, three main characteristics that models should have in order to properly
accommodate SMEs aroused. These three main characteristics were found to be the most important to be taken into consideration in the development stage of a maturity model especially developed for this type of companies. These characteristics are the following: (i) the influence of the SMEs most important hurdles when carrying out Industry 4.0 initiatives; (ii) the high level of detail in Industry 4.0 initial levels requirements; and (iii) providing a holistic assessment approach of this concept in an enterprise. The literature research did not find any model that clearly contemplated these three characteristics in its development stage. Therefore, the decision taken of developing a comprehensive maturity model for Industry 4.0 with the proper features to accommodate SMEs.

Moreover, an analysis of the model’s degree of detail in Industry 4.0 initial levels was performed, as well as a comparison of the comprehensiveness between the most quoted model in the literature and the proposed model. It was made clear that the proposed model does not contemplate the whole process until the full Industry 4.0 implementation, because it is more focused the introduction of this concept. In this way, the model is more focused on the initial Industry 4.0 levels of, allowing it to have a more detailed assessment of these maturity levels’ requirements. Through a pictographic comparison between the proposed model and the six chosen models for its development, the higher comprehensiveness level of the created maturity assessment tool is clear.

Furthermore, model’s applicability was tested and confirmed with a real case study in a Portuguese SME, where its Industry 4.0 maturity level was successfully measured. In order to illustrate that entry barriers of Industry 4.0 might not be as high as they initially seem, two digitalisation proposals were presented. While one proposal focuses on streamlining an existing process through the use of free software – without changing it, the second aims to collect data taken from a fundamental process in the company – by introducing just one digitalisation and one minor change in the process. Both of these proposals increased the company’s Industry 4.0 maturity level.

Using this methodology revealed most important characteristics that maturity/readiness models should have. A maturity model aggregating six other models while considering these characteristics was put forward as well as the confirmation of the applicability of this model in a real case scenario. It is thus possible to confirm that both initial objectives of this dissertation were reached.

7.1 Future work

First, we suggest the full application of this model across one or more manufacturing sectors. One of the major challenges is to get a personalized assessment for the measurement of the maturity level in each company. This application would have three goals in mind: the benchmark of the level of maturity within each manufacturing sector; the model’s continuous improvement; and its validation. The process until full validation is outlined by Becker et al. through the requirements needed for a proper development of maturity models. Since these requirements are sequential, then can be seen as the next steps to perform, in order for this model to be validated.

We also suggest carrying out simple Industry 4.0 initiatives, as the ones proposed in chapter 6, and measure their influence on the maturity level of the company. This kind of simple digitalisations have shown to be helpful when tackling the Industry 4.0 concept, as well as insightful for the companies implementing it, as presented in the previous chapter.

Finally, we suggest developing a roadmap for the introduction of Industry 4.0 in companies as well as sectors. This tool would take advantage model proposed here, since its purpose is to accommodate companies introducing industry 4.0, especially SMEs.

8. References


