Guiding Manufacturing Companies Towards Digitalization

A methodology for supporting manufacturing companies in defining their digitalization roadmap

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Abstract— *Within the era of Industry 4.0, digital technologies are seen as the main drivers for manufacturing industry transformation. In fact, many sustain that manufacturing companies will be able to obtain many benefits and opportunities from the digital transformation. If on one hand manufacturing companies have to be able to "ride" this wave of transformation in order to remain competitive, on the other hand, before investing in digital technologies, they have to understand what their current situation is and what their needs are with respect to both digital technologies and organizational processes in different functions. Indeed, the success of the transformation process mainly depends on the company ability to be ready to apply the technological change that some of these digital technologies envision. From these considerations, after having figured out their current readiness level for starting the digital transformation fostered by the Industry 4.0, it is possible to state that the next step manufacturing companies have to undertake is to define their transformation roadmap. With the aim to guide them towards this transformation process, a maturity model, called DREAMY (Digital REadiness Assessment MaturitY model) and based on the inspiring principles of the CMMI (Capability Maturity Model Integration) framework, has been developed and utilized. The objectives of this model are twofold. Firstly, it allows the assessment of the current digital readiness of manufacturing companies and the identification of their strengths and weaknesses with respect to implemented technologies and organizational processes. Secondly, it enables the identification of a set of opportunities offered to companies by the digital transformation, considering their strengths and aiming to overcome their weaknesses. Through the application of this methodology into case studies, it has been possible to reach two main results. On one hand, the analyzed manufacturing companies have been aware of their digital readiness level, of their strengths and weaknesses and of the main opportunities they can exploit from the digitalization process starting from their current situation. On the other hand, empirical evidences were gathered on the current level of manufacturing companies' digital readiness and on the possible common traits among the identified opportunities.*

Keywords—Smart manufacturing; roadmap; maturity model; digitalization

I. *INTRODUCTION AND PROBLEM STATEMENT*

Nowadays, manufacturing companies stand on the cusp of the fourth industrial revolution: smart production becomes the norm in a world where intelligent ICT-based machines, systems and networks are capable of independently exchanging and responding to information to manage industrial production processes, which is enabled by the arrival of new digital technologies. There are many breakthroughs that the adoption of such technologies envision, such as the possibility to be closer to customers' needs through new customized services based on smart products [1], the improvement in internal performances through smart manufacturing plants and processes and the new markets opportunities enabled by new business models [2]. In a futuristic and disruptive vision, the "digital" enterprises will work together with customers and suppliers in industrial digital ecosystems. To this end, the challenge is firstly to create the awareness regarding the added value generated by the in-factory implementation of the Industry 4.0 technologies and let manufacturing companies become the central part of any improvement strategy and secondly to guide manufacturing companies in defining their transformation roadmap. However, manufacturers still lack a concrete methodology allowing them to define their transformation roadmap and to choose and prioritize emerging technologies that aid in the creation of smart manufacturing systems and factories [3]. On top of this, manufacturers may need to implement organizational and process improvements to realize the full benefits from these technologies [3]. Existing methods such as the Supply Chain Readiness Level [4] and MESA Manufacturing Transformation Strategy [5] exist, but they largely ignore the use of information and communication technologies (ICT) as a primary foundation for making those improvements [3]. There are existing works, which study the impact of Information Technology (IT) adoption to businesses (also known as business & IT alignment). However, each study typically focuses on evaluating a single technology such as Enterprise Resource Planning (ERP) system or Manufacturing Execution System (MES) [3]. In contrast, in this new context, manufacturing transformation process usually requires the implementation of different technologies. These enabling technologies can be grouped in 9 main clusters [6]: 1) Advanced Manufacturing Solutions, 2) Additive Manufacturing, 3) Augmented Reality, 4) Simulation, 5) Horizontal/Vertical Integration, 6) Industrial Internet, 7) Cloud, 8) Cyber-security, 9) Big Data and Analytics.

In addition, past studies have not taken into account other aspects of the organization that can affect the impact of the respective technology adoption. Indeed, not only companies implementing digital technologies will increase their competitiveness [6], but especially the ones which are not able to innovate will risk to remain out of the market. One might also question if is it necessary for manufacturing companies to adopt all the presented technologies at once or they can apply a step-by-step strategy. On the other hand, the digital transformation cannot be done in a holistic way at once. These technologies should be implemented in a scalable way, starting from where higher benefits can be taken for the company [7]. Last, but not least, at the moment of investing, a manufacturing company is assumed to be aware of its current situation, in order to be sure of where, how and how much to invest in its way to the digital transformation. From these considerations, it can be stated that, before investing in digital technologies and beginning the transformation process, it is fundamental for manufacturing companies to understand what is their current situation and to build their own digital roadmap according to the current digital readiness level. This means that the benefits of the transformation mainly depend on the readiness of the company to apply the technological change that the digital technologies envision. Indeed, a deep understanding of the current status of capabilities in digitalizing processes is a first step for a successful digital transformation. Once organizations have a clear perspective of their digital maturity, they should explore opportunities triggered by digital technologies. Based on the identified opportunities, manufacturing companies should develop a clear vision and agenda, which have to be shared and accepted by all senior executives. The next step should be to prioritize the transformation domains based on the perceived business benefits and ease of implementation. Following this approach, manufacturing companies will be able to define a digital roadmap, containing phase-wise transformation details.

II. Maturity Model for Assessing Manufacturing Company Digital Capabilities

Some on-line tools exist, allowing companies to self-assess how much they are ready for the digital transformation. Nevertheless, even if these tools allow companies to assess maturity indexes indicating their level of digitalization, they do not provide them a sort of structured "guide" on how to encounter the digital transformation, accordingly to their current situation. To the best of the authors' knowledge, it is possible to state that a model able to "guide" manufacturing companies towards the digitalization process has not been found either on-line or in literature. To this aim, a maturity model, called DREAMY (Digital REadiness Assessment MaturitY model) and based on the inspiring principles of the CMMI (Capability Maturity Model Integration) framework, has been developed. In order to define the model structure, manufacturing companies' strategic process areas for the digital transformation have been identified and structured according to a modular and scalable architecture. The focus of the DREAMY is on the factory itself, as principal unit of analysis. To this end, the chain of activities that generate value through the management of the product - process – plant cycles are taken into account. In the end, manufacturing companies' processes are grouped in five main areas: Design and Engineering; Production Management; Quality Management; Maintenance Management; Logistics Management.

Each area contains some key macro-processes, which in turn are defined by single processes, that are relevant to consider when analysing practices and capabilities of manufacturing companies. Each abovementioned area can be considered as a self-contained module that can be taken into account or not for the definition of the relevant processes depending on the company's characteristics. It is also possible to add new areas in case of need with no impact on the macro-structure foundation. Transversally to these areas, the model architecture includes the Digital Backbone, which considers the software tools enabling and facilitating the exchange of information and data between the abovementioned areas. A representation of the structure of the identified areas and of the related macro-processes is given in Fig. 1.

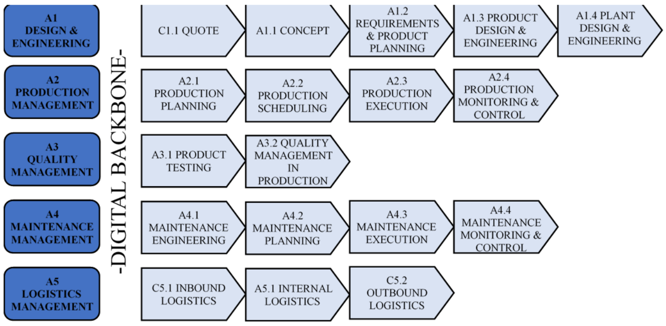

Fig. 1 *DREAMY process structure*

As already stated, the digital readiness of a manufacturing company is defined through a scale of maturity levels. These levels describe a proper set of company capabilities which are able to provide a snapshot of their current abilities. The digital readiness levels are based on the inspiring principles of the CMMI framework [8,9]. The main reason of this choice is that the CMMI provides a defined structure of maturity levels (inspiring what developed in our model, see Fig. 2), specifying what capabilities a company has at each level, as was already done in previous works [9,10]. In this way, the five-scale CMMI maturity levels have been re-adapted in order to gather the definitions of the digital readiness maturity levels.

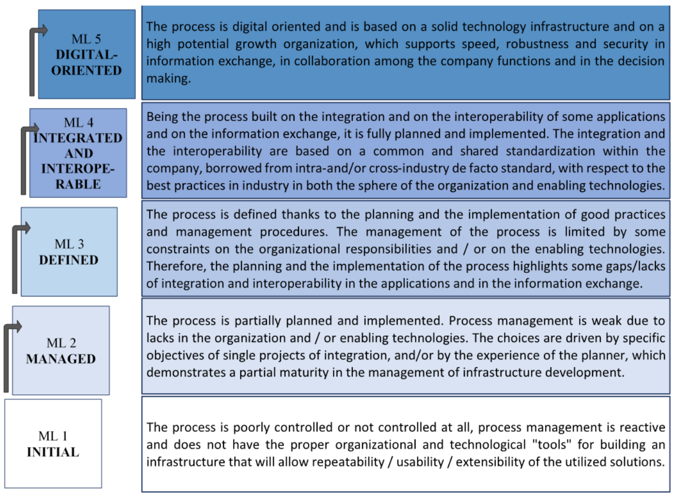

Fig. 2 *Maturity levels' definition*

When evaluating the digital capabilities of a company, not only the technologies used to support the processes have to be considered. Indeed, without structured processes and defined organization structures a company would not be able to exploit the opportunities these technologies offer. Starting from the evidences reported in literature [8,11–19] and considering the objective of the model, it was decided to evaluate the digital readiness of manufacturing companies through four analysis dimensions: Process, Monitoring and Control, Technology and Organization. In particular, "Process" covers how the processes are carried out within the company; "Monitoring and Control" include how a process is monitored and controlled; "Technology" regards the systems, hardware and/or software used to support the processes' execution and "Organization" considers organizational aspects of the processes/company.

In order to gather useful information for the model application, an assessment tool (i.e. a questionnaire) has been developed. This questionnaire is made of about 200 questions that have been structured according to the DREAMY process areas, and aims at assessing the company capabilities according to the identified analysis dimensions. Each questions is connected to standard normative answers, that are structured according to an increasing level of maturity, following the five-scale digital readiness maturity levels previously described. These scores span from 1 (the lowest maturity level) to 5 (the highest maturity level). In this way, a standard scoring method is obtained.

The maturity assessment model for manufacturing companies presented in this section has been used as a key element in a methodology developed to address the gap presented in the "Introduction and problem statement" section: the lack of a guidance for manufacturing companies on the roadmap to the digital transformation.

III. THE PROPOSED METHODOLOGY

The developed methodology is composed of four main steps (represented in *Fig. 3*).

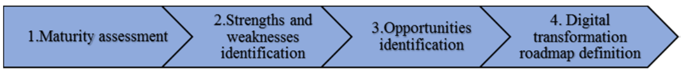

Fig. 3 *The proposed methodology: the steps*

A. STEP 1: Maturity assessment

During the first phase of the methodology, the digital maturity of a certain manufacturing company is assessed. The presented DREAMY model and questionnaire are applied to evaluate the maturity indexes of each company's process area. In this phase, the model is used with a descriptive purpose [20–23]. In fact, a descriptive model is seen as single point encounters, with no provision for improving maturity or providing relationships to performance. Maturity models with this purpose, want to assess the as-is situation of the organization/process.

In particular, before the interview, the analyst prints one copy of the questionnaire with the normative answers that he/she will use to conduct the interview and copies of the questionnaire without the normative answers, which will be used by the interviewees. During the interview, the analyst asks how a certain activity is performed in the organization of the interviewee, who is free to describe the organization processes without being influenced by the normative answers or the analyst. After the interview, the analyst compares the collected information and notes collected for each question with the normative answers and identifies the normative answer that better explains the real use case situation. On the basis of the answers given by the respondents, the maturity level for each question is extracted and used to compute the maturity indexes. A graphical representation of how the indexes are computed is given in *Fig. 4*.

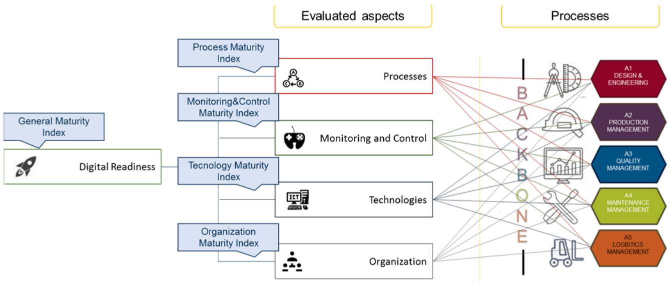

Fig. 4 *Representation of the maturity indexes calculation*

Once these indexes are identified, they are presented to the company through multidimensional radar charts on two levels. On the first level, the overall company maturity is presented, like shown in *Fig. 5*. On the second level, the maturity is broken down for each process area.

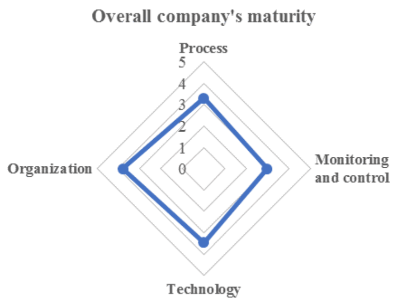

Fig. 5 *Overall company's maturity representation - Example*

B. STEP 2: Strengths and weaknesses identification

The second phase of the methodology is the identification of the strengths and weaknesses, in terms of how mature the interviewed manufacturing company is in each process area, basing on the respondents' answers to questionnaires. Indeed, if the answer provided is associated with a maturity level (ML) lower then 2, the associated process will be considered a weakness. Whereas the ML associated is higher than 4, the process will be considered a strength. A ML 3 answer is evaluated either a strength or a weakness depending on the context. In addition, even the extra information provided by the respondents during the interview are used in order to enrich the list of the identified strengths and weaknesses.

In this way, the list of strengths and weaknesses is obtained for each macro-process and for each analysis dimension within each area. This analysis allows, firstly, to understand on which processes the company has potentials (or needs) to concentrate improvement efforts and, secondly, to have a first insight of what can be the companies' opportunities to improve their processes' maturity.

C. STEP 3: Opportunities identification

The third step of the methodology is the opportunities identification. To this end, on the basis of the identified strengths and weaknesses, the opportunities are identified and so the company obtains a concrete overview on what are the suggested actions to undertake in order to improve processes' maturity. In this phase, the maturity model is used with a prescriptive purpose [20–23]. In fact, a prescriptive model focuses on the domain relationships to business performance and indicates how to approach maturity improvement in order to positively affect business value i.e. enables the development of a road-map for improvement.

D. STEP 4: Digital transformation roadmap definition

After that all these results are obtained, with the aim to analyse the identified opportunities, it is important to have a discussion session with the company. If some of the identified opportunities are unfeasible, it is important to understand why. Some of the reasons might be related to the presence of barriers or to the lack of resources (for example money or people) or even lack of real interest of the company for the digital transformation. After that this "feasibility/unfeasibility" filter is applied, the company should rank the feasible opportunities according to the benefits they can bring. In this manner, the logic behind the ranking exercise should be clarified. Finally, also the applications, which will allow the company to take advantage of these opportunities, need to be discussed. This process is presented in *Fig. 6*.

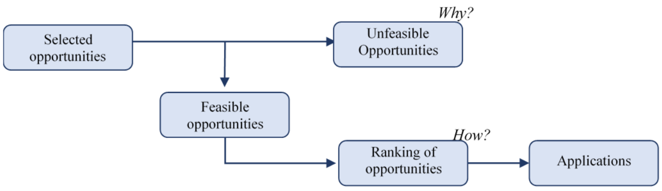

Fig. 6 *Digital transformation roadmap definition*

IV. Application of the Methodology

In this chapter, the aim is to present which have been the empirical evidences gathered from three case studies. These analysis have been performed by interviewing C-level managers during a two-day visit to the companies premises. The objectives are 1) to identify possible actions or opportunities the manufacturing companies analysed could take advantage of and 2) to collect empirical evidences on possible common traits between the results obtained from the application of the DREAMY and the related framework.

A. CASE A

Case A is a company operating in the food industry. In particular, the plant, unit of analysis, is specialized on the production of confectionary products and high quality chocolate. It produces with a Make-To-Stock production strategy.

In Case A, the analysed process areas are illustrated below:

- Design and Engineering: Plant design and engineering
- Production Management
- Maintenance Management
- Logistics Management

In *Table 1*, the relevant points emerged from the analysis of this case are reported.

Table 1 Case A: Relevant emergent points

Relevant emerged points	Explanation
Continuous improvement has to be enhanced	The continuous improvement can be enhanced in: • Plant design, (re-) engineering, by better mastering the tracked problems in the frame of a prevention strategy, • Production management, by analysing trend of production performances in the frame a prevention strategy, • Maintenance management, by analysing failures and maintenance economics in the frame of a prevention strategy.
Model Base System Engineering through (factory/plant) simulation	Model-based systems engineering should be introduced in the: • Plant engineering phase. Thanks to the acquisition of various type of supporting systems, it will be possible to develop the layout considering equipment, operators, flows and material information, and to develop accurate capacity/process models, • Production management. Model-based systems engineering through simulation could support production planning and scheduling, which are now based on mean values.
Enhance the retrieval and use of real time information	Scarce real time information about: • Production information (order progress status/state of the machines) • Orders information If available, they could allow the company to perform real-time analytics on these data.
Data Analytics has to be performed	A poor analysis of data is observed: • In the production management, where the analysis on trend of production performances is not performed. It could be used in order to prevent problems before they occur, • In the maintenance management, where the quantitative analysis on failures should be used for the definition of the best frequency for the preventive maintenance plans.
MES system has to be potentiated	The MES system should be improved in order to: • Support the order control, monitoring and execution,

	• Support the retrieval of real-time information, which can be used to enhance the reactivity of scheduling.
Integration between company's and suppliers' systems has to be enhanced	The company could enhance collaborative management systems with suppliers.
Improve the maintenance management system	The company could improve the maintenance management systems in order to enhance the retrieval and the analysis of data.

B. *CASE B*

Case B is a company operating in the mechanical engineering industry. In particular, it is specialized in the production of three different product types: about 75% of the revenues come from the production of transmitters, about 20% from the production transducers and the remaining 5% from the production of parts and accessories. About 70% of the transmitters are produced with an Assembly-To-Order production strategy. To this aim, the major part of the information gathered about this case are related to this type of product.

In Case B, the analysed process areas are illustrated below:

- Design and Engineering
- Production Management
- Quality Management
- Logistics Management

Maintenance Management was not analysed since it is externalized. In *TABLE 2*, the relevant points emerged from the analysis of this case are reported.

TABLE 2 CASE B: RELEVANT EMERGED POINTS

Relevant emerged points	Explanation
The introduction of a PLM system is important to introduce more integration of the processes and for model-based systems engineering	PLM system in this case is important for: • Product and Process Design &Engineering in order to: - Keep track and control of cost and delivery lead times, together with the respective deviations w.r.t. what quoted, - Validate the delivery lead times during the requirements planning, - Integrate customers' feedbacks in the concept and requirements planning phase, - Reuse of similar projects in the concept and product design/engineering phase, - Easy access to product's information by product clustering, - To support the model-based engineering since the product concept (i.e. Hardware libraries not systematically used), - Integrate the information on manufacturing (tools to use) within the production scheduling tools, - Integrate process-planning data to products/product clusters, - Integrate methodologies for process planning (further developing existent ones, VSM, TMC, standard times). • Plant Design & Engineering, in order to introduce model-based systems engineering through both the digitalization of the plant layout-process engineering and the simulation for capacity planning, • Quality Management, in order to facilitate the access to quality data and tests documentation connected to products information.
Production management system has to be improved to be responsive to the variability	A more responsive production management system could be achieved with: • The integration of the planning procedure to define an already-feasible plan, • Model-based systems engineering through simulation, in order to support production planning and scheduling, which are now based on mean values, • A reactive sequencing with a more automatic tracking and insertion of changed constraints (e.g. labour), • The tracking of operators' competences/equipment information for manufacturing execution, • An informed decision making, considering the status of WIP/intermediary inventories, • Extended functionalities for manufacturing execution at shop floor (e.g. order dispatching, reworks management, job routing plans communication to shift supervisors, etc.), • Performance analysis, systematically performed on production data.
Enhance the retrieval and use of real time information	Scarce real time information about: • Production information (order progress status), • Quality of products (non-conformities), If available, they allow to perform real-time analytics on these data.
Data Analytics has to be performed	A poor analysis of data is observed in: • Design and Engineering. Analysis on forecast and marginalities are not performed. This types of analysis could be performed if a company will introduce a product clustering system, • Production Management. Analysis on production performances are not performed. They can be used and analysed in a frame of prevention-continuous improvement strategy, • Quality Management. Analysis on data from the production are not performed. They could be analysed in order to measure and discover correlations along the production process.
Integration between company's and suppliers' systems has to be enhanced	Systems for the collaboration of the relevant suppliers could be developed.

C. *CASE C*

Case C is a company operating in the electric power industry. In particular, it is specialized on the production of transformers. It produces with an Engineering-To-Order production strategy.

In Case C, the analysed process areas are illustrated below:

- Design and Engineering: Quote, Concept, Requirements and Product Planning, Product Design and Engineering
- Production Management
- Quality Management
- Maintenance Management
- Logistics Management

In *TABLE 3*, the relevant points emerged from the analysis of this case are presented.

TABLE 3 CASE C: RELEVANT EMERGED POINTS

Relevant emerged points	Explanation
The introduction of a PLM system is important to introduce more integration of the processes.	PLM system in this case is important for: • Design & Engineering (especially for quoting and concept development) supporting the Electrical and Mechanical Design departments in order to: - Standardize and cluster the products, in order to facilitate the research and to allow the retrieval of historical information about electrical parts and mechanical parts in a unique tool, - Support the requirements planning and validation, - Support the automatic handover from design and engineering to production department, since the BOM could be automatically inserted in the ERP. • Quality Management: in order to integrate data related to product tests and quality in production with the products' ones.
Production management system has to be improved to be responsive to the variability.	In this case the production management system composed by the company's MES and the scheduler, could be integrated: • With quality management, in particular, with quality charts coming from the production. In order to increase their responsiveness using this information in a proactive/continuous improvement perspective, • With the ETO process, in order to have more accurate delivery time, even during the quotation phase (here a PLM system is necessary), • With the sales operations, in order to automatically receive the information about orders, • With the shop floor, having visibility on the exact status of the WIP, being integrated with the picking of material and having a sequencing. This will permit to have a higher responsiveness of the shop floor operations, • With the information about the "personnel" resource, in particular regarding the engineering team, so that they can be considered during the planning process.
Enhance the retrieval and use of real time information.	Scarce real time information about: • Orders information (since they are managed with excel files), • Production information (order progress status/state of the machines) • Quality of product (non-conformities). If available, they allow to perform real-time analytics on these data
Data Analytics has to be performed.	A poor analysis of data is observed in: • Production management. Production information tracking and analysis is not performed in the frame of a problem prevention strategy, • Quality management. Analysis is not performed on data coming from quality cards. If performed, this could allow to prevent problems, before they occur.
Integration between company's and suppliers' systems has to be enhanced	Systems for the collaboration of the relevant suppliers could be developed.
A maintenance management system should be introduced.	The company doesn't have a robust maintenance systems which permits to define appropriate maintenance plans and to track indicators.

D. Results

The emerged points can be synthetized in seven main opportunities/needs (*TABLE 4*).

In general, three main evidences were gathered:

- Some emerged opportunities/needs are recurrent and transversal to the companies interviewed. These are for example the need of real time information, the need to perform analysis on data and finally the need of having a more integrated collaboration system with the suppliers.
- On the other hand, some of these opportunities/needs are strongly dependent to the production strategy of the company (i.e. ETO, ATO and MTS). Indeed, it has been noticed that the DREAMY application facilitates the emerging of some drivers (i.e. opportunities), fundamental for the competitiveness of each specific case. For example, it emerged that a PLM system is more important for an ETO/ATO company rather than for a MTS.
- Finally, it emerged that some of the identified opportunities are related to practices/technologies of Industry 4.0. Other opportunities, instead, are related to practices/technologies which stand behind and are prerequisites for the Industry 4.0. In particular, in *TABLE 4*, the opportunities related to Industry 4.0 are marked in orange, whereas the ones which stand behind Industry 4.0 are marked in light blue.

TABLE 4 OPPORTUNITIES IDENTIFIED FROM THE CASE STUDIES

Identified needs/opportunities	MTS (Case A)	ATO (Case B)	ETO (Case C)
Introduction of a Product Life Cycle Management (PLM) system		x	x

Improvement of the Maintenance Management System	X	N/A	x
Enhancement of Real Time Information Retrieval	X	x	x
Introduction of Data Analytics	X	x	x
Enhancement of the Responsiveness of the Production Management System		x	x
Introduction of a decision support using Model Based System Engineering approach through simulation	X		
Introduction of more Advanced Collaboration Systems with Suppliers	X	x	x

The opportunities highlighted in *TABLE 4* are here discussed more in details.

1) Introduction of a Product Life Cycle Management (PLM) system

The need of a PLM system emerged from Case B and Case C, which operate respectively with an ATO and ETO production strategy. A PLM system in these cases is of primary importance as it gives the opportunity to integrate data coming from the design and engineering with the production and the quality departments. Within the interviewed companies, the tendency was not to have a proper PLM system, but rather a document management system, which was not enough to support the big amount of data due to the high variety of products. Therefore, this type of system could help them to support the management and retrieval of historical data, facilitating the reuse when a new product has to be designed and engineered.

It can be said that the PLM system is a prerequisite of Industry 4.0. This concept is well explained also in the White paper presented by NTT DATA ([24]), in which PLM is described as an enabler of Industry 4.0, since it provides a solid structure to manage what will be an end-to-end digital chain from product development, production planning, production and logistics, through to the services.

2) Improvement of Maintenance Management System

In almost all the analysed companies, what emerged is that maintenance management is far from being digitized. In particular, in Case C, maintenance management was poorly managed in general, since there was the absence of a real system supporting it (like a Computerized Maintenance Management System - CMMS). On the other hand, in Case A and B, it was noticed that a maintenance management system was even used, but in a standard way. Indeed, failures data were not used to predict possible trends and therefore to prevent some problems, or to optimize the frequency of maintenance plans. In addition, even condition based maintenance was poorly used.

The maintenance systems analysed in these case studies are in a state which are far to be ready for the digitalization. They have firstly to be improved, in order to embrace the digital technologies of Industry 4.0.

3) Enhancement of Real Time Information Retrieval

The need of real-time information emerged in all the case studies. More precisely, it was detected a scarce real-time retrieval of various type of data (for example: orders information, progress status of the products in production, state of the machines, etc.). The opportunity of having real-time data is fundamental to enable the real-time analysis of them.

This opportunity deeply depends on the pre-existing automation level of the company itself. For this reason it is different from the previous ones. As an example, in a company where orders information is exchanged via Excel files, the use of a system enabling the retrieval of real time information about them, cannot be considered Industry 4.0. Whereas, systems enabling the retrieval of real time information about machines status, from anywhere in the world, can be considered an Industry 4.0 technology. In the end, it can be stated that the retrieval of real-time information is very important to support real-time decision making [6].

4) Introduction of Data Analytics

Another opportunity transversally detected within the analysed companies is data analytics. The majority of the interviewed people stated that, even if they have some data, they do not perform analysis on them, in order to understand possible trends and therefore prevent errors before they occur (especially in production).

As previously mentioned, analytics is one of the main pillar of Industry 4.0. In this respect, here the words of William P. King, CTO of the Digital Manufacturing and Design Innovation Institute at the University of Illinois, are reported [25]:

"*One of the biggest disruptions of Industry 4.0 is the ever-increasing value and importance of data. Companies need to think about data as a precious raw material. Therefore, companies will need to change the way they think about and manage large amounts of data and information. This will be one of the biggest challenges for traditional manufacturing companies*."

From these words, it is clear how manufacturing companies have to learn to manage and use big amount of data. In this manner, advanced analytics should be performed in order to transform these data into information supporting the decision making.

5) Enhancement of the Responsiveness of the Production Management System

Where the sources of variability were high, the need of a responsive production management system emerged. In particular, this was detected in Case B and C. In these cases, the opportunity of having a production system able to integrate data coming from different sources (i.e. quality information, planning information, actual status of the resources, operators' information, etc.) would allow these companies to responsively react to the variability and therefore decrease the lead time. Here the importance of having a flow of real-time information can be found again, which, in this case, can be exploited by the production system to be more responsive. On the contrary, the need of such a system did not emerge from the Case A, where the variability was low.

These types of systems are in line with what dictated by the Industry 4.0. Indeed, as reported in the White Paper presented by McKinsey Digital ([25]), the responsiveness will be a key factor for manufacturing. For this reason, systems able to gather and integrate more data at the same time, will be the solution to have a responsive production system.

6) Introduction of a decision support using Model Based System Engineering approach through (factory/plant) simulation

The need of model-based systems engineering approach through simulation emerged more where the production strategy is led by the process rather than the product. In particular, this was detected in Case A, operating with a MTS strategy. For them, it is important to have a simulation system, since it will give the opportunity to develop accurate capacity/process models during the plant engineering phase and to support production planning and scheduling, which are now based on mean values. Once again, it emerges here the importance of a real-time flow of information, which can be used within such simulation systems.

Even this identified opportunity could be considered in line with Industry 4.0. As stated in [6], the simulation systems will leverage more and more on real-time data to mirror the physical world in a virtual model, which can include machines, products, and humans. This will allow, for example, operators to test and optimize the machine settings for the next product in line in the virtual world before the physical changeover.

7) Introduction of more Advanced Collaboration Systems with Suppliers

Finally, what emerged in all of the analysed companies is the lack of collaboration systems facilitating the exchange of information with the suppliers.

These collaboration systems could be considered in line with Industry 4.0. Indeed, as stated in [6], with Industry 4.0 companies, suppliers and customers will need to be closely linked.

E. Validation of the results

After the presentation of the reports to the companies, a final discussion with people involved during the interviews was carried out. The first fundamental output, emerged from these discussions, was that, in general terms, what came out from these reports was in line with the company's perceptions about the actions they should implement to start the digitalization process. This is an important result as it proves that the methodology is robust enough to let considerations consistently emerge with companies perceptions.

From these discussions, it emerged also that the companies were more interested in the identification of strengths and weaknesses, and in the suggested opportunities, rather than in the maturity indexes themselves. This is mainly due to the fact that, thanks to the strengths and weaknesses identification, they realized exactly where they needed to act. In addition, another consideration was that companies would also like to have a benchmark comparison with other companies operating in their same sector. Nevertheless, only when more data are available, it will be possible to perform a structured benchmark so to understand where the single companies are positioned in comparison to the average position of companies belonging to the same industrial sector. Finally, it is important to underline that the companies were impressed by how the model permitted to obtain such detailed and complete results, with only one day and a half of interviews. This is mainly due to the completeness of the questionnaire, which permitted to investigate all the relevant processes of the companies, with a high level of detail.

V. CONCLUSIONS

Two main results were achieved with the applications of the proposed methodology. On one hand, the analysed manufacturing companies were "guided" towards the understanding of their digital readiness and the identification of the main opportunities they can exploit from the digitalization process. On the other hand, empirical evidences on the current digital readiness of manufacturing companies and on the possible common traits between the identified opportunities, were identified.

The considerations drawn from the discussion sessions conducted with the companies can be synthetized in the following points:

- The identified strengths and weaknesses and opportunities were in line with the companies perceptions.
- Companies were more interested in the identification of strengths and weaknesses and in the suggested opportunities, than in the maturity indexes themselves, since they provide a sort of guide on the possible steps to follow, in order to start the digitalization process.

These considerations were useful to prove the goodness of the methodology.

Regarding the empirical evidences gathered from the application of the methodology to three different case studies, the main opportunities (or needs) are identified in the following points:

- Introduction of a Product Life Cycle Management (PLM) system;
- Improvement of the Maintenance Management System;
- Enhancement of Real Time Information Retrieval;
- Introduction of Data Analytics;
- Enhancement of the Responsiveness of the Production Management System;
- Introduction of a decision support using Model Based System Engineering approach through (factory/plant) simulation;
- Introduction of more Advanced Collaboration Systems with Suppliers.

Among these opportunities, three main considerations were gathered:

- Some identified opportunities are recurrent and transversal to the analysed companies.

- Some of the identified opportunities are strictly related to the type of production strategy the company has.
- Some of the identified opportunities are related to technologies/practices dictated by Industry 4.0, others instead are related to technologies/practices which stand behind Industry 4.0.

These considerations lead to some more general conclusions. Indeed, on one hand, it can be stated that manufacturing companies, before facing the fourth industrial revolution, should complete the third one. Indeed, the investments in technologies with stand behind Industry 4.0 should be prioritized. On the other hand, it can be stated that the investment in digital technologies start from the most strategic process areas for the company. Indeed, it emerged that the opportunities manufacturing companies can exploit may vary according to their production strategy. In this way, it seems remarkable to state that ATO/ETO companies appear to be more driven to invest in activities related to the "product", instead MTS companies appear to be more driven to invest in activities related to the "process".

Future developments of this work will regard the application of the methodology to other case studies. This will permit to:

- Further standardize the methodology. Indeed, the DREAMY will be calibrated with information coming from different kinds of companies, reaching a high level of standardization.
- To include other value-added process areas such as Supply Chain Management, Sales, Marketing, Customer care, Human Resource Management, etc. in order to extend the scope of the analysis. In addition, due to the high relevance of the topic, which is also seen as one of the enabler of manufacturing companies' digital transformation, also *Skills of Personnel* should be considered as analysis dimension when assessing company capabilities.
- To perform a structured benchmark, thanks to the availability of more data, and so to use the model with a comparative purpose [20–23]. In this way, the analysed company will be able to understand where it is positioned, in comparison to the average position of other companies belonging to the same industry sector.
- To have more evidences to compare with the ones drawn from this research, thus effectively validating the first evidences presented within this paper.
- To develop an opportunities' identification catalogue so to upgrade the model and utilize it with a prescriptive purpose.

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