Evaluating the Smart Readiness and Maturity of Manufacturing Companies Along the Product Development Process

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Abstract. Nowadays, manufacturing industries are compelled to go down the river of Industry 4.0 to either become or remain competitive on the market: in this context digital technologies represent the most important means for manufacturers to drive their transformation. However, investing in this kind of technologies could be not enough to go through this transformation in an effective way: manufacturers need to realize which is their actual digital status and at the same time to evaluate how they support their product development process. In addition, it has not to be neglected the importance of how the process of product development is organized and managed throughout the several functions involved. So far, different methods and maturity models have been proposed in literature to help practitioners to evaluate the readiness and maturity of either their smart level or their design and engineering process. Nevertheless, a suitable combination of these tools still needs to be implemented to fully and systematically measure and gauge a company under a PLM and digital perspective: to do this, a case study has been conducted.

Keywords: Industry 4.0 · Assessment method · Readiness model · Maturity model · Process waste · PLM · Case study · DREAMY · CLIMB · MyWaste

1 Introduction

The advent of digital technologies is strongly affecting manufacturers' behaviour, always more pushed to enhance their manufacturing systems. Gathered under the umbrella of Industry 4.0 [1], they can contribute to address a threefold scope: (i) Digitization and integration of vertical and horizontal value chains, (ii) Digitization of product and service offerings, (iii) Digital business models and customer access.

In particular, these technologies have been grouped in 11 different types (among which IoT platforms, 3D printing, smart sensors, augmented reality), leading to a huge amount of practical applications for manufacturers. However, investing in this kind of technologies could often not be enough to improve competitiveness on the market and to move effectively towards the Industry 4.0 transformation. Manufacturers need to realize first of all which is their actual digital level: a model, DREAMY (Digital REadiness

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Assessment MaturitY model) [2–4], already exists. It is able to assess a manufacturing company's readiness level to trigger its digital transitioning process and also to identify a manufacturing company's strengths, weaknesses and opportunities, creating a roadmap for investments in digitization and transitioning to smart manufacturing.

Moreover, manufacturers need to understand and to evaluate how these new digital technologies are used to support their product development process along the entire company. Indeed, in order to deliver successful solutions in the market, companies can choose among various best practices to apply in their development process. CLIMB (Chaos-Low-Intermediate-Mature-Best practice) model [5] measures maturity in product development activities: it aims at concretely supporting the identification and selection of the most suitable best practices to be implemented in the product development process. Indeed, the final aim to obtain a faster and more effective process could be achieved applying lean techniques in product development. In this context, MyWaste and MyTime [6, 7] are formalized and structured methods to identify wastes and to lead designers to improve and streamline the process.

Therefore, as shown above, so far different methods and maturity models have been proposed in literature to help practitioners to evaluate the readiness and maturity of either their smart manufacturing level or their design and engineering process and to analyse the existing wastes along the development process. Nevertheless, a suitable and systematic combination of these tools still needs to be implemented to fully measure and gauge a company in a complete way: to do this, a case study has been conducted. Indeed, this paper aims at analyzing the AS IS situation of the order development process of a selected company, Company A, with particular attention to the digitization level of the areas involved. The main result of this study is represented by a systematized integration of the models and methods so far proposed in literature and presented in Sect. 2: DREAMY and CLIMB models and MyWaste and MyTime methods. Section 3 reports a detailed description of the adopted methodology used to combine these different approaches: formerly the used criteria in the case study approach are reported, then an introduction of the assessed company is also given. Section 4 explains the results of the study, also presenting the analysis of the specific company, and Sect. 5 is dedicated to their discussion. Finally, Sect. 6 concludes the paper, triangulating results with theory and providing further researches and limitations.

2 Research Context

With the aim of being able to perform a complete evaluation and assessment of the actual status of a company, before introducing the models and methods adopted in the case study, it is necessary to clarify the research context they refer. Models as DREAMY and CLIMB were selected since capable to perform an assessment based on a comparison with consolidated best practices codified according an advancement/maturity degree. While, analysis methods as MyWaste and MyTime, have been chosen to gather data regarding the AS-IS company situation according to a referring format. In order to detect the touching points among them, it is necessary to provide a definition of heterogeneous concepts, on one side readiness and maturity and on the other value and waste related to Lean Thinking and continuous improvement:

1. ‘smart manufacturing readiness’ is the capability of a manufacturing company to deploy smart manufacturing concepts;
2. ‘smart manufacturing maturity’ concerns how well a manufacturing company has employed smart manufacturing concepts or its smart manufacturing capability;
3. Lean Thinking is based on the idea to give the customer what he wants, when he wants it and at the right amount he desires. It means companies must create value, intended as everything the customer is willing to pay for, and banish waste, which literature classifies in 8 macro-classes (Overproduction, Inventory, Waiting, Motion, Transportation, Defects, Processing, Unused employees creativity) [8–10]. The entire process is based on and guided by the continuous improvement concept [11].

In the following sub-sections, the single approaches, based on these concepts and used in this study, are shown.

2.1 DREAMY

DREAMY is an assessment model based on the idea that, to be able to invest in digital technologies, companies should know their *status quo*. The model evaluates a manufacturing company’s digital readiness and maturity along four dimensions: Process, Monitoring and Control, Technology, and Organization [2]. These dimensions can mutually involve five areas (A1. Design & Engineering; A2. Production Management; A3. Quality Management; A4. Maintenance Management; A5. Logistics Management), composing together the digital backbone of the company and affecting the value generation along the key processes (Fig. 1). The main output of this model consist in the categorization of the company analyzed: this is presented in both a 5-levels maturity scale and a radar chart composed at its angles by the four dimensions considered.

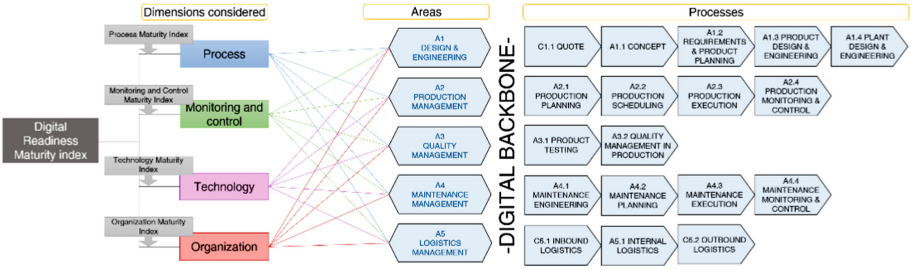

Fig. 1. DREAMY (adapted from [2])

2.2 CLIMB

CLIMB is a maturity assessment model based on a selection of the prevalent product development best practices from literature. Its aim is twofold:

(1) to create awareness and understanding in academia and industry, on the existing best practices in product development – thanks to the product development best practice framework;
(2) to retrieve an AS-IS picture of the practices usage in the industrial context, providing practitioners with the possibility of self-assessing their processes: this represents a support for their improvement initiatives and to benchmark with what is believed best in literature and eventually with other industrial cases.

The model is structured into a questionnaire, an evaluation scale made of five maturity levels and a radar chart. The questionnaire is semi-structured, based on the proposed product development best practice framework, and each of the questions investigates one of the best practices. The framework categorizes 107 product development best practices, across eight areas: 1 activities and flow, 2 decision making, 3 training, 4 roles and collaboration, 5 knowledge management (KM) process, 6 km techniques, 7 methods, 8 computerization and software. These areas are grouped into four categories (Table 1):

1. Process (how the flow of the development process is managed, the activities performed, the decision-making methods, the orientation to the client and the value, and the methods used),
2. People (how the development process is structured, which are the actors involved, the respective roles and competences),
3. KM (methods and tools used in the company to support knowledge management, accumulation, maintenance and reuse of the same)
4. tools (tools used to support the product development process and to improve the data integration level along it).

In this categorization, the process, tools and people vision are considered independent from KM, crucial in product development.

Table 1. CLIMB: Categories and Constructs

Category	Construct
1. Process	1. Activities and flow
	2. Decision making
2. People	3. Training
	4. Roles and collaboration
3. Knowledge Management (KM)	5. KM process
	6. KM tech
4. Tools	7. Methods
	8. Computerization and software

2.3 MyWaste

MyWaste is a simple methodology that companies can use in order to improve their New Product Development (NPD) processes in a continuous fashion: it allows to evaluate and rank a given library of product development wastes. The methodology is composed of 5 steps which can be recursively applied in order to continuously improve: companies are led through NPD process waste and criticalities analysis and removal, resulting in better performances of the whole development process. The method improves an existing process under lean perspective, reflecting lean principle of pursue perfection through progressive improvement actions. Figure 2 shows the framework of the methodology. The 5 steps can be grouped into 3 macro-activities: MyWaste Analysis, Map-it Process and Change Implementation.

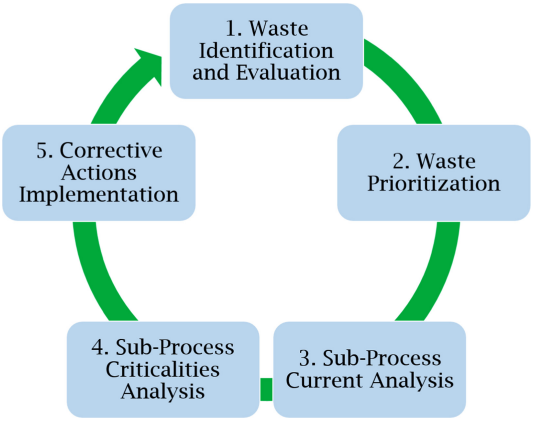

Fig. 2. MyWaste method

2.4 MYTIME

MyTime is a method aimed at measuring through a questionnaire how time along the NPD process is spent. It analyzes how time of the actors involved in this process is divided among main activities (design and test), knowledge recovery (through traditional sources or informatics ones), specification and documentation development, data input in informative tools, coordination with other colleagues or partners and other activities. In the meanwhile, it also detects and ranks the main problems faced by actors working along this process, unveiling how time allocation is perceived by each of them.

3 The Case Study: The Methodology and the Company

In order to practically investigate the maturity level of manufacturing industries to integrate digital technologies along their value-adding processes, with a special focus on NPD, an explanatory case study has been conducted. The study conducted followed

the embedded single-case design approach and included semi-structured interviews to gather data [12]. Based on the primary aim of the research, the first step has been the definition of the unit of analysis. The choice fell on Company A and in particular on its two main embedded macro-areas: on one side, production and ICT were considered to assess the digital readiness and maturity of the company, on the other technical department and R&D were chosen to evaluate the design and engineering process, appraising its readiness and analyzing its main criticalities. More than 15 interviews and 3 workshops were conducted in the company, with a total duration of about 53 h. Interviews were distinguished in two categories, based on the embedded unit of analysis of the company considered. Actors from production, supply chain, operations and ICT were involved to go through the DREAMY model. Instead, CLIMB required technical director, managers of product platform department, system engineering, R&D, service, electrical/SW BU and mechanical BU. Instead, MyWaste and MyTime were submitted to all of them. In addition, the workshops were useful to raise the awareness of both CEOs and top management regarding the topics coped along this study and to calibrate and align the objective of the study to the needs of the company.

More specifically, Company A is an Italian engineering to order company, specializing in packaging systems flowpack allowing a small wrapper to wrap a single product or group of products with a plastic film. Among the various sectors in which these types of packaging are used, there is first of all the food sector (industrial baking monotype and assorted biscuits, chocolate, products for breakfast, sweet and savory snacks, bread substitutes, coffee pods for automatic and semi-automatic coffee maker, cheese, frozen products), but also non-food, cosmetic and pharmaceutical industries. The packaging arena, fueled by more demanding customers requiring creative and innovative solutions, has contributed to the ever growing complexity of projects, and has driven the increase of system performance specifications and guarantees. To operate in this new arena and to offer to their customers the best service, simultaneously optimizing development steps and workflow management, Company A wants to analyze its order development processes and to identify critical factors with a particular attention to the digitalization level of the areas involved. Finally, the company would like to find the correct solutions to intervene on them.

Therefore, the research approach adopted (Fig. 3), composed by the integration of DREAMY and CLIMB models with MyWaste and MyTime methods, defined in Sect. 2, was used to conduct the case study, providing the following results.

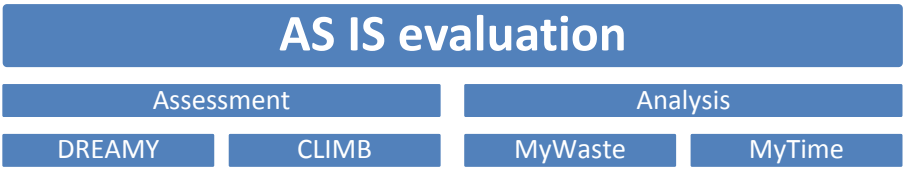

Fig. 3. AS IS evaluation research approach

4 Results

The first main result of this research is the positive outcome obtained with the application of the approach reported in Fig. 3 through the case study selected. The joint use of the models and methods selected, adequately put together and shown in Fig. 4, resulted able to grasp the data needed to evaluate the maturity level of manufacturing industries to integrate digital technologies along their value-adding processes, providing a special focus on NPD.

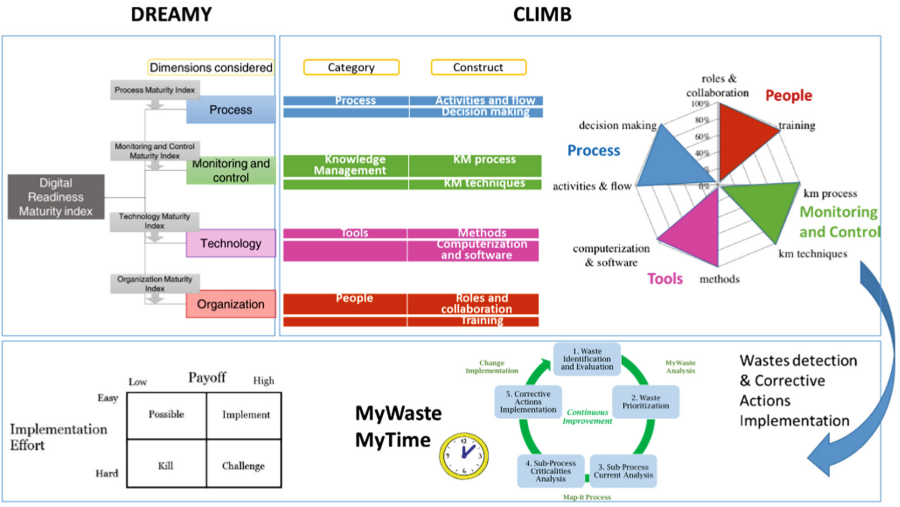

Fig. 4. The lifecycle approach evaluation

First of all, the models DREAMY and CLIMB, seemed to be compatible since structured on the same four pillars: process, monitoring and control (supported by KM practices), technology (consisting in tools, methods and computerization level) and organization (concerning roles, collaboration and training of people). This allowed authors to cross the results coming from the two models. Thanks to this integration, a more complete perspective of each of these four dimensions were obtained and the related main issues were detected, briefly reported in the following:

- Process: a macro-perspective in the management of processes' is often opposed and upset by recurrent and more operative revisions, generating extra-activities and subtracting value to the overall process. Formal methods able to manage the process and facilitate value-added activities along it are not adopted.
- People: the skills available are high and strongly technical. However, there are inefficiencies in roles allocation along the process.
- Tools: basic tools of virtual prototyping are used and there is also a basic support of PDM. However, the functionalities of these tools are not strictly concentrated in the technical office and are not shared efficiently with all the functions.

– Monitoring and Control & KM: there is a widespread tendency to an over-control of operative activities, linked to the issues raised above in the people dimension. On the other side, there is a significant problem in the formalization of knowledge and its sharing: apart from the basic IT tools, no other methods for storing, accumulating and sharing knowledge are used.

Moreover, MyWaste and MyTime methods contributed to confirm and enrich these results. The main wastes along the NPD process (grouped in the 8 macro-categories according to the lean theory) were detected. The two most relevant wastes are related to the conduction of an inappropriate process, i.e. waits along the process (for decisions, people, resources, data, etc.) and excessive or not necessary activities during its phases. They are followed by:

- wastes belonging to knowledge dimension, as for example incapacity to reuse already existing knowledge (with an impact on the product) and development of already designed components and products,
- organizational oversights (too many meetings with customers),
- over-engineering (development of components, materials or functionalities not required) and
- time lost in reworks and revisions.

The wastes detected were also linked, per each of the 8 macro-categories, to specific causes and effects. In general, the majority of them were triggered by organizational factors (29,1%), followed by process (25,6%), knowledge (21,9%), resources, tool (17,5%) and others (5,9%) causes. It was also found that wastes mostly lead to an increase of development costs and time and of product costs, to the generation of delays and inefficiencies, to a reduction of productivity and customer satisfaction and to repetition of errors.

5 Discussion

Based on the analysis conducted, in the company there is a good perception of what a waste entails (effects) and where it plausibly comes from (causes), for each of the eight waste areas. The vast majority of interviewees had clear impact of wastes on costs and time. Additionally, MyTime method revealed that the main issues in the NPD process are linked to the excessive time spent in codification, management, sharing and retrieval of knowledge (46%), not neglecting the time dedicated to coordination and organization (23%). Indeed, the majority of daily time (70%) resulted to be quite squeezable through the implementation of a major level of automation and digitization and a more efficient operability.

As a direct consequence of this general process inefficiency, also confirmed by DREAMY results, it emerged that Company A grounds its daily activities, both operative and adding-value, on the personal experience of its employees. Knowledge, not codified through structured mechanisms, remains tacit in people. Despite some digitalization attempts, the scarce interoperability level among the available systems cause several not adding-value activities along the process, as for example transcoding.

Again, also results from CLIMB model highlighted that, while the company should be organized according to a product-centric holistic approach, its knowledge appears scattered in separate silos, lacking hence of a paramount process perspective.

Finally, dedicated resources to be allocated on knowledge management and the continuous improvement of both the process and the organization could represent the first step to start reducing the detected wastes and issues. Together, digital tools and codified methods could further support the enhancement of both process efficiency and effectiveness, fostering an integrated, cooperative and collaborative management of the product knowledge along the order process and its lifecycle.

6 Conclusions and Further Researches

This paper has been aimed at practically investigating the maturity level of manufacturing industries to integrate digital technologies along their value-adding processes, with a special focus on NPD process. To achieve this result an explanatory case study has been conducted in an engineering to order Italian company, Company A, following an embedded single-case design approach. The research method adopted was designed with the intention of consistently combining four already existing models and methods aimed at evaluating and assessing different aspects in the company, unveiled as complementary for the achievement of the final objective of the research.

Assessment models (DREAMY and CLIMB) and analysis methods (MyWaste and MyTime) have been chosen and put together: they are based on concepts of readiness and maturity concerning digitization and design practices but also of waste and continuous improvement related to the Lean theory. The first main result of the study has been the positive systematic combination of these approaches in a more complete integrated one. Together, they resulted to be able not only to provide a complete assessment of the company adding-value processes but also to detect and raise the main issues and wastes occurring along them. These wastes currently hamper the company transition towards an industrial digitization and compromise its order development process effectiveness and efficiency. However, if adequately managed, they represent the key for the company to switch toward a more proficient product centric knowledge management and continuous improvement approach: this unveil the capacity of the joint method adopted and presented to outline a plan of possible interventions through which the existing situation could be improved.

On the contrary, the research method adopted has also limitations: it is all based on interviews, requiring several hours both from companies and researchers side. Moreover, compared to the single approaches, the joint method proposed in this research requires from the company side the involvement of different and heterogeneous profiles and from researchers side a big effort to analyse and put together the results obtained (that needed to be fully integrated and triangulated among them). Moreover, it has to be specified that the scope of each single method used is limited by definition. Each of them deals with specific facets (digital readiness and maturity, NPD maturity, NPD continuous improvement) of the more complex object of the research presented in this article, i.e. the smart readiness and maturity of manufacturing companies along the product development process. This justifies the need to put together and combine different approaches, obtaining as a result a more valid and complete approach.

A further improvement of this research could be to focus even more on issues with digital tools implementation in the company, since these tools actually should drive the digitization of the companies: right understanding its opportunities and prerequisites would be vital during digitization.

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