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Defining the Roadmap towards Industry 4.0: The 6Ps Maturity Model for Manufacturing SMEs

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Abstract

In the contest of Manufacturing Industry, in order to keep competitiveness and adapt to the current trends of the market that range from the need for new Business Models up to the capability to turn their processes according to the incoming trends, Industry 4.0 is now considered a major opportunity for enhancing such transformation. However, before adapting these technologies to achieve the mentioned goals, manufacturing firms achieve specific requirements that characterize a digital transformation process. This step turns out to be particularly challenging for manufacturing SMEs which might have a biased view on both their current level of digitalization and/or lack of a clear view of the desired performances to achieve to accomplish their objectives. Hence, a clear and coherent digital transformation roadmap results crucial to move toward a smart manufacturing. In light of this, the paper presents the 6Ps maturity model (MM), developed within the MIDIH project, that aims at supporting manufacturing SMEs in the development of their roadmap towards Digitalized Manufacturing 4.0. The 6Ps maturity model is based on 6 main socio-business and technical dimensions (i.e., Product-Services, Processes, Platform, People, Partnership, Performance), 36 Industry 4.0-related areas and a 5-levels scale of digital maturity (DM). It enables a comprehensive assessment of SMEs' status-quo, the identification of the desired future maturity level and the subsequent creation of a customized migration roadmap. The model has been developed from a review of extant literature and a comparison of current MMs according to the 31 most common areas of coverage. The 6Ps MM has been tested and validated with a sample of manufacturing SMEs.

Keywords: Maturity Model, Digital roadmap; Industry 4.0; Literature Review

1. Introduction

Manufacturing companies must be able to "ride" the digital transformation to remain competitive in Industry 4.0. On the other hand, before investing in digital technologies, they must understand what their current situation is and what their needs are with respect to digital technologies and organizational processes in different functions. The progressive introduction of new technologies depends on understanding the actual readiness of the manufacturer to deploy them in its manufacturing systems; this should be assessed to master the migration process towards Industry 4.0. This is a complex exercise that requires combining different competences (i.e. knowledge of digital technology and existing technology functionalities, manufacturers' needs, manufacturing value-added processes, etc.) to be done. It also requires proper methodologies for maturity or readiness assessment with respect to digital transformation. The concept of MM has been addressed several times both by academia and business in several sectors [1, 2]. Although, due to the variety of fields and the lack of a common level of detail, even the concept of maturity and consequently of maturity model is not unique. However, commons aspects among the definition of maturity exist. Overall, maturity could be defined as the status of

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completeness, perfection or of being ready for something [1]. Academia has also defined the process of achieving a certain degree of maturity as the achievement of a full growth [3]. Moreover, the concept of maturity was also identified as an evolutionary progress from a current stage to a desired one [1]. This last description points out a key element, MMs are meant to be exploited within a broader transformation process aimed at making something grow from an initial stage toward a final one (full growth) through a set of intermediate stages. According to these characteristics, literature has proposed many MMs focused on different fields. However, the authors have focused their studies on the discrete manufacturing industry in the Small and Medium Enterprises (SMEs) context. This topic, indeed, turns out to be extremely crucial in EU area as many European Commission's funded projects in the Horizon 2020 (H2020) programme have been focused on the topic [4]. Among the projects, MIDIH (Manufacturing Industry Digital Innovation Hubs) has specifically also addressed a key element for the enhancement of digital transformation of manufacturing SMEs which is the development of a MM and a subsequent Digital Transformation Methodology aimed at defining a roadmap and quantitatively tracking the progress of Digital Transformation initiatives, the 6Ps Migration Methodology.

2. Research Context

Several studies aimed at developing a Digital MMs have been conducted so far and accordingly to the definition of general MM, the objective is evaluate the DM level of a give entity and consequently develop a roadmap aimed at increasing this level [5]. Hence, according to this, another key characteristic of a Digital MM is that an increase in DM is the outcome of a digital transformation journey that must be planned in detailed and that include a set of consecutive steps to reach that represent a new, more advanced level of digitalization.

2.1. Target of the MM

Due to variety of context in which a MM might be applied, a first variable to set even before proceeding with the development of a new one consists in the identification of the target. In fact, MMs are used in many heterogeneous fields each of them characterised by specific peculiarities that the models must be capable to address, describe and eventually evaluate in a quantitative way. As mentioned above, the tool that will be presented in the following paragraphs was developed in a EU funded H2020 project, namely MIDIH, which was specifically focused on manufacturing SMEs in the context of Smart Manufacturing, or rather Industry 4.0. Accordingly, the related MM developed and presented in this work is specifically designed to target manufacturing SMEs that are willing to undertake a Digital transformation process by relying on support external experts for the definition of a structured roadmap.

2.2. Purposes of MMs

As already anticipated in the previous paragraphs, MMs aims at first at representing in the most quantitative way the current level of maturity of an entity (either an organisation, a process, a function and so on)[6]. On the other hand, it is a useful, and sometimes fundamental, tool to ensure a proper support in the definition of actions to be undertaken in order to increase the overall level of maturity.
According to current literature, there are three main areas of applicability in which MMs could be adopted [3, 7, 8].
Such purposes identified are reported below:

- Descriptive purpose: assessing the AS-IS situation of the organization/process.
- Prescriptive purpose: indicating how to approach maturity improvement in order to positively affect business value (i.e. enabling the development of a roadmap for maturity improvement).
- Comparative purpose: enabling to cross-benchmark. A model of this nature would be able to compare similar practices across organizations in order to benchmark maturity within different industries.

It is worth highlighting that despite the distinction among the different purposes that a MM may have, these could be also used with the aim of fulfilling also two or three of the purposes presented. Many MMs, like some of those presented in chapter 3, have the first objective of assessing the current status of an entity, namely AS-IS, (Descriptive purpose) and subsequently evolve into a second phase in which the aim becomes the identification of a set of actions to be implemented in order to reach a higher level of maturity (Prescriptive purpose). Again, once identified a roadmap for maturity improvement, a MM could be also exploited to collect data from many fields (different business, industries or functions) and perform valuable benchmark to validate the steps before [9]. Such comparison may be also done internally or rather being aimed at benchmarking the Desired TO-BE level of maturity identified in the definition of the roadmap with the Actual TO-BE level of maturity achieved in the end of the maturity improvement process.

3. Gap Analysis

As mentioned in chapter 2, the objective of a MM is to assess the level of maturity of a firm in a specific area of reference. In parallel, the fast technological advancement brought by the advent of Industry 4.0 has opened for manufacturing companies a new set of opportunities [10]. However, such opportunities of transformation have not been extensively exploited for many reasons, including the size of the firm [11]. As a matter of fact, manufacturing SMEs proved to be less inclined to adopt I4.0 technologies (either OT or IT related) compared to large enterprises especially due to financial constraints [11]. Hence, a critical issue that MMs are required to tackle is the definition of a system able to assess a company by excluding from the variables of assessment factors, like size or sector, that are not modifiable at least in the short-medium term. In light of this, 8 Digital MMs have been identified within MIDIH project that satisfy the need mentioned above and are also currently used in real business context. The Digital MMs have been proposed by scholars and professionals. In particular, this chapter proposes an analysis of selected digital MMs. The selection of the digital MMs analysed in the following chapters is based on the fact that they are the most recent and/or mostly used in EU area for SMEs, whose

construction took into account the previous literature in the field [12].
Fig. 1 summarises the models and the related areas investigated.

Model	Dimensions of analysis	Reference
DREAMY 4.0	• 6 processes; design&engineering, production, maintenance, quality, logistics and supply chain • 4 dimensions: Execution, Monitoring & Control, Technology, Organization	[13]
Test I4.0	• 8 processes + products + strategy; • 4 dimensions: Plan, Monitoring & Control, Technology, Organization	[14]
Industry 4.0 readiness check	• 6 dimensions: Strategy and Organization, Smart factory, Smart operations, Smart products, Data- driven services, Employees	[15]
Industry 4.0 maturity index	• 4 structural areas: Resources, Information systems, Culture, Organizational structure; • 5 Functional areas: development, Production, Logistics, Services, Marketing & Sales	[16]
Industry 4.0 Readiness self-assessment	• 5 dimensions: Technology, Manufacturing, Economy & Market, Organization, Society & Culture	[17]
BEinCPPS Industry 4.0 Maturity Method	• 6 dimensions: General, Strategy, People, Processes, Technologies, Integration	[18]
FAR-EDGE Maturity Model	• 3 dimensions: Technological, Operational, Human	[19, 20]
Dreamy4Skills	• 1 dimension: people • 3 analysis dimensions: soft skills, hard skills, ICT literacy	[21]

Fig. 1. The already existing Digital MMs

From the analysis of current MMs that are mainly adopted within the manufacturing context, 31 areas have been identifies as the most assessed even though it is still missing a model covering all the main areas. Actually, such areas can be clustered into 6 macro-categories of reference which are: Product, Process, Platform, People, Partnership and Performance. However, some differences apply among each MMs identified. In fact, even if some of them are designed to analyse the same areas, a different perspective or a different purpose may influence the level of detail devoted to them thus leading to slightly different results.

4. The 6Ps Migration Methodology

4.1. The dimensions

The 6Ps Migration Model is named after the six dimensions that is meant to impact on. In particular, they are: Product, Process, Platform, People, Partnership and Performance.
These are clustered into Technical pillars (Product, Process and Platform) and Socio-Business pillars (People, Partnership and Performance).
Image below shows the 6 dimensions.

Fig. 2. The 6Ps dimensions, of the migration model, clustered by category

Each dimension is then further divided into 6 areas, except for People that has an additional fragmentation based on the profiles within the firm. Each area is evaluated according to a 5-level scale of DM in which level 1 (INITIAL) represents no or minimum adoption of digital solutions and level 5 (EXPLOITED) describes an area in which digital solutions represents the state-of-the-art for the industry. Concerning the 6 dimensions individually, Fig. 3 shows an overview of the areas that compose them.

Product	Process	Platform	People	Partnership	Performance
[1.1] Integration of Sensors/Actuators	[2.1] Design & Engineering	[3.1] CPS and Embedded Systems	[4.M1] Industry 4.0 Strategy	[5.1] Digital Innovation Hubs	[6.1] Operational / Technical
[1.2] Communication / Connectivity	[2.2] Production Management	[3.2] Industrial Internet of Things	[4.M2-4.P1-4.O1] Smart Operations	[5.2] Research & Innovation	[6.2] Economic
[1.3] Storage and Exchange of Information	[2.3] Quality Management	[3.3] Industrial Internet	[4.M3-4.P2-4.O2] Smart Supply Chain	[5.3] Training & Education	[6.3] Environmental
[1.4] Monitoring	[2.4] Maintenance Management	[3.4] Industrial Analytics	[4.M4-4.P3-4.O3] Smart Product-Service Engineering	[5.4] IT Solutions Providers	[6.4] Social
[1.5] Product-related IT Services	[2.5] Logistics Management	[3.5] Vertical interoperability of data and events	[4.P4] Industry 4.0 Infrastructure	[5.5] Suppliers	[6.5] Product-Service Lifecycle
[1.6] Business Models enabled by the Product	[2.6] Supply Chain Management	[3.6] Horizontal interoperability of data and services	[4.P5] Big Data	[5.6] Customers	[6.6] Supply Chain

Fig. 3. Summary of the 6P MM's areas addressed

Product dimension has the objective of evaluating how and to which extent the Product or Product-Service System offered by the manufacturer is digitally mature and how the company can exploit such level of maturity. 6 areas compose this dimension, namely: Integration of Sensors/Actuators to understand how the product is able to analyse itself and the external environment; Communication/Connectivity to measure how the product is able to communicate with external devices; Storage and Exchange of Information to measure how the product is able to collect and store data internally; Monitoring to assess how the product is able to self-monitor its status; Product-related Information Technology (IT) Services to measure how the functionalities offered are dependent on the physical product; Business Models enabled by the Product to measures how the product allows the firm to reshape its business model.

Process dimension has the objective of assessing the level of DM of the main processes that manufacturers must manage. The 6 areas a directly derived from the DREAMY4.0 Assessment tool [13]. The six analysis fields are related to: Design & Engineering to evaluate how these two processes are enabled by digital technologies; Production Management to evaluate the level of DM of production processes; Quality Management to assess how much digital technologies are integrated in quality check processes; Maintenance Management to measure how digital technologies influence processes related to the maintenance of machineries and PPE; Logistics Management to assess the DM level of the logistics processes (inbound/outbound and internal/external logistics); Supply Chain Management to measure how digital technologies are used to monitor the overall supply chain manufacturing SMEs interact with.

The Platform dimension has the aim of assessing the level of DM of manufacturing firms' digital platform as already proposed by [22]. Again, six areas characterize this dimension which are: Cyber Physical Systems and Embedded Systems to measure how data are collected from the shopfloor and used to make the machines mutually interact; Industrial Internet of Things (IIoT) to measure the ability of the factory in using and integrate IoT devices; Industrial Internet (to measure how factory assets are linked to the common internet platform a vice versa; Industrial Analytics to evaluate the capability of the company in exploiting analytics; Vertical interoperability of data and events and Horizontal interoperability of data and services to measure the capabilities of manufacturing companies in collecting, manipulating and managing data that are necessarily heterogenous in an integrated way.

People dimension aims at assessing the skills owned or to be owned among manufacturing SMEs' human capital. This dimension is not directly divided into 6 areas, due to the high variance in the roles operating in the sector, this pillar has been divided into 3 macro-profiles extending the view of [21]: Operators & Technicians, Professional & Engineers and Managers & C-Levels. While, the 6 areas are: Industry 4.0 Strategy to measure the level of awareness about Industry 4.0 and involvement into Industry 4.0-related projects; Smart Operations to evaluate how digital technologies are exploited in favour to traditional tools in running operations; Smart Supply Chain to assess the level of digitalization of tools and skills exploited in this field, Smart Product-Service Engineering to evaluate the skills and tools utilized in the product development phase, Industry 4.0 Infrastructure to assess the level of skills in the field of Industry 4.0 Technologies available within the firm and Big Data to assess the level of skills in the field of big data.

Partnership dimension aims at assessing to which extent the manufacturing firm is able to exploit digital technologies to manage relationships with its stakeholders and to which extent the relationship built are relevant in the definition of the digital technologies adopted. This dimension is divided into six areas (stakeholders) which are: Digital Innovation Hubs to evaluate the level of engagement the company has established or is willing to establish with Digital Innovation Hubs; Research and Innovation institutions to measure the level of engagement that the firm has with these typologies of institutions); Education and Training institutions to measure the level of collaborations between partners and institutions such as universities are quantified; IT Solution Providers to assess the level of collaboration with this typology of companies, Suppliers and Customers to measure the level of collaboration that the firm has developed with its peer supply chain actors.

Performance dimension aims at investigating what the role that Industry 4.0 technologies have in the definition, monitoring and interpretation of key performance indicators (KPI)s of the manufacturing enterprises. The dimension is divided into 6 areas, namely: Operational/Technical to assess the approach in monitoring the performances of machines and production activities such as OEE, or accuracies of plans and procedures such as MAPE; Economic to evaluate the approach in monitoring economic and financial results such as ROI; Environmental and Social (to measure the approach adopted in measuring these performances thus covering all the aspects of the triple bottom line; Product-Service Systems (PSS) Lifecycle to measure to which extent and what areas of the PSS delivered are taken into consideration for the analysis of its lifecycle and Supply Chain (to assess the modalities through which manufacturing firms are able to measure the overall performances of their entire Supply Chain.

4.2. The methodology

The 6Ps Migration Methodology is a tool developed by POLIMI within the H2020's MIDIH Project. The aim of the tool is to support manufacturing enterprises to identify and assess the impact of a Digital Transformation (DT) project and is the second step of a broader process that consists in:

- Assessment of the current level of DM of the firm
- Definition of a Digital Migration Roadmap
- Transition toward a higher level of DM

For each of the three steps, specific tools have been designed. In particular, the evaluation of the current level of DM of manufacturing companies is performed through the DREAMY4.0 that is carried out via a set of face-to-face and on-site interviews with managers and expert of the company itself [23]. In this first phase, the scope of the analysis is mainly focused on the processes, either internal or external, and the interactions that manufacturing firms have been able to develop to run their reference core business. Afterwards, the 6Ps Migration Methodology has the double role/objective of enlarging the boundaries of analysis of the DM of the firm (AS-IS), identifying which are its future expectations (TO-BE), matching AS-IS and TO-BE to find the digital gaps and finally drawing a Digital transformation roadmap based on the gaps identified. To achieve such results, two modalities are adopted. At first, a guided self-assessment phase is required to be performed by the company and subsequently an interview phase (ideally face-to-face) is conjectured to validate both the current perception of DM (AS-IS) and finalise the desired level of DM to be reached in the end of the whole process mentioned above (TO-BE).

Finally, once defined a structured digital transformation

roadmap and the related action plan to be deployed by the manufacturing company, the macro-process starts it last phase that consists in the supply of tools and solutions aimed at achieving the planned transition toward the desired (TO-BE) level of DM and so reach a new AS-IS.
Fig.4 summarises the macro-process described above.

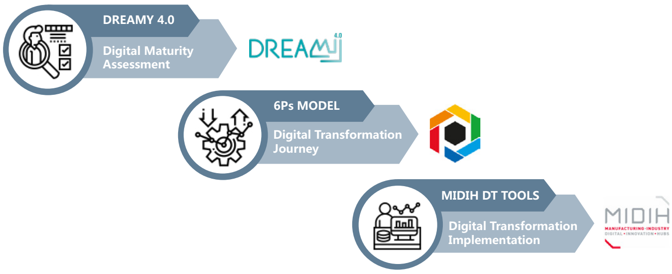

Fig. 4. The 3 processes characterising Digital Transformation

Looking at the phases of the 6Ps MM in detail, the process is defined by 5 consecutive steps which are:

- **Set-up of a team bringing together different organizational area**s: collection of all the needed human resources available inside the company that are aware of its digital status and need and/or are involved in the decision-making process for the selection of digital solutions
- **Identification of the AS-IS profile of the manufacturing SME**: the firm and the 6Ps external consultants/experts jointly identify the current level of DM of the company.
- **Definition of the target TO-BE profile of the manufacturing SME**: the company and the 6Ps experts jointly identify the future level of DM to be reached.
- **Identification of actions, feasibility and prioritization**: the gaps among the AS-IS level of DM and the TO-BE level designed in the previous steps are defined. Then the feasibility of the goals is evaluated according to time horizon and resources that the company is willing consider. Then, the goals are prioritized and a set of actions to be undertaken to achieve the goals are developed.
- **Development of the Migration Plan towards Industry 4.0**: the actions identified in the previous steps are linked one to each other and distributed among the desired time horizon of the company. The objective is then to generate a homogeneous action plan aimed at reaching the goals defined in the previous steps. A good approach in this phase is to balance long-term results with some "quick wins" and mid-term milestones and validations.

Fig. 5 shows the 5 steps of the 6Ps Migration Methodology.

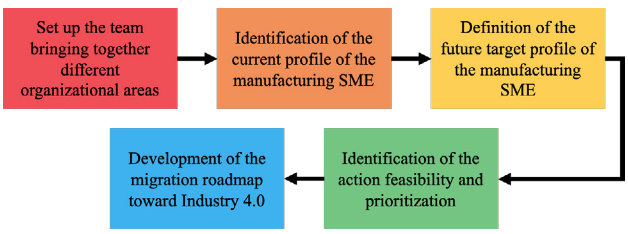

Fig. 5. The 5 steps of the 6Ps Migration methodology

4.3. Expected outcomes

The results of the analysis can be summarised in a report containing the analysis of the AS-IS (blue line) and TO-BE (orange line) level of DM, the analysis of the gaps and the description of the action plan (roadmap) to fill the gaps.
To visualize the results, some radar charts have been designed as reported below. In particular, each element represented refers to the different areas whose number is reported in Fig. 3.

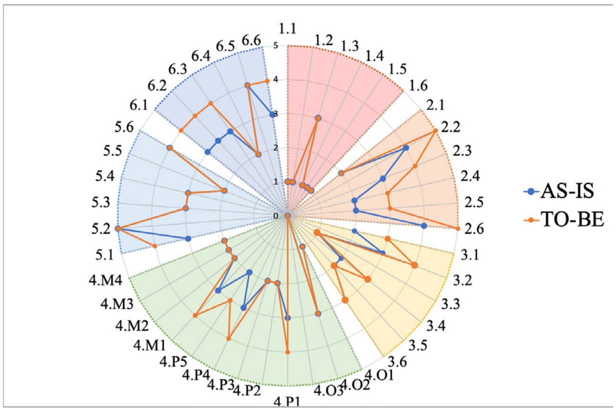

Fig. 6. Integration with the DT process

4.4. Integration with the DT process

Once identified and reported the gaps as shown in Fig 11, the last step of the 6Ps Migration Methodology consists in the definition of priorities and the development of a DT roadmap aimed at supporting the manufacturing SMEs in reaching the desired results. To do so, a GANTT chart is collecting all the actions defined for each area (sub-dimension) is prepared jointly with the company. The roadmap developed has so the goals of visualising how the services, in particular MIDIH's, should be distributed along the whole time horizon established by the firm.

5. Validation

The methodology presented in chapter 4 has been applied and validated via 9 manufacturing SMEs. Such firms were involved in MIDIH project and the focus of the 6Ps was on the increase in DM due to the impact of the project itself. Other sources of impact have not been considered. Each company has been tested according to the 5 steps of the 6Ps. The identification of the teams resulted the least critical step since the people required for the assessment were already identified in the previous phases of MIDIH. For what concerns the assessment phase, not all the areas have been tackled in each single company. This because, as mentioned above, not all the areas or dimensions have been tackled by each firm since the improvement areas planned were quite focused on specific goals. However, all the areas have been validated, assessed and the results measured (e.g. packaging process efficiency improving by 16,7%; Time for in line dimensional control reduced even up to 75%). Moreover, due to COVID-19 restrictions, the interview phase has been conducted virtually. Finally, for each company, the action plan has been identified together with the partner company. It is worth highlighting that some TO-BE levels of DM have not been reached yet by the firms but only planned and in the making. In fact, due to the potential high impact of some solutions, the related effects could be observable only in the mid-term or after MIDIH's conclusion.

6. Conclusions

This research has focused on the presentation of a new methodology for the definition of the DM of manufacturing SMEs and the subsequent development of a digital transformation roadmap based on the results collected and the desired level of DM of these latter. In particular, the methodology has been perceived as particularly fruitful under many aspects. At first, to benchmark the results and compare the expected TO-BE with the actual results of the project and secondly, to structure an action plan able to specifically impact the detailed improvement areas for the company in an effective and efficient way. However, from the validation done with manufacturing SMEs, it emerged that the minimum level of DM initially designed was deemed by some practitioners as too advanced compared to their current status. In future works, the methodology could be further enriched by a "level 0" able to better describe the initial level of DM of such realities (e.g. craftmanship-based companies). Moreover, the focus of the 6Ps is devoted to manufacturing SMEs. A possible hint for future researches could be oriented to the enlargement of the target of reference and so including other relevant sectors like process industry or large firms. In this sense, the model will be applied in other EU projects (e.g. AI REGIO).

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