Developing a Roadmap Towards the Digital Transformation of Small & Medium Companies: A Case Study Analysis in the Aerospace & Defence Sector

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Abstract. The contemporary era is pushing companies worldwide in undertaking a digital transformation path to keep high their competitive advantages acquired throughout the years thanks to their engineering competencies. Companies, especially Small & Medium ones, are getting forced to set up clear roadmaps towards an enhanced digital maturity level to address their strategic objectives. Roadmaps must support them in being both efficient and effective to keep stable their competitive advantage. Therefore, the goal of this contribution is to clarify the key elements representing the basement towards an improvement digital path and apply them to a case study. The key elements emerged to be: i) the clarification of firms' strategic objectives, ii) the awareness about firms' current internal digital maturity level to benchmark themselves in respect to competitors as well as their expected "desired TO-BE scenario", and iii) the investigation of the causes and related effects that may harm the reaching of the strategic objectives. Hence, in this contribution, these three steps are deeply investigated to design a structured and tailored roadmap leading a company to reach an increased level of digital maturity facilitating the achievement of the strategic objectives. The roadmap supports companies in evaluating the most appropriate technologies to overcome the internal inefficiencies identified hindering the achievement of the corporate results. The roadmap development process was studied from the extant literature and it has been applied in this contribution in a case study, specifically in an Italian company operating in the Aerospace & Defense (A&D) sector.

Keywords: Digital transformation · Aerospace & Defence case study · Roadmap

1 Introduction

Nowadays, companies are asked to keep high their competitive advantage optimizing their resource consumption, and digital and Industry 4.0 (I4.0) technologies may help them to move towards this direction [1]. Indeed, all the sectors are forced to improve

Published by Springer Nature Switzerland AG 2023
F. Noël et al. (Eds.): PLM 2022, IFIP AICT 667, pp. 284–293, 2023.
https://doi.org/10.1007/978-3-031-25182-5_28

their personalization performances to cover all their customers' needs and they are highly facilitated by the introduction of specific I4.0 technologies [2]. Nevertheless, they all need to find the proper balance of investments in technologies according to their strategies and the available financial resources. Different tools have been proposed in the extant literature with the goal to facilitate the Digital Transformation (DT) of manufacturing companies. For instance, [3] proposed a qualitative roadmapping tool to support Small & Medium Enterprises (SMEs) by evaluating the actions over five dimensions: business and strategy, product, customers and suppliers, production processes, factory and infrastructure. [4] proposed a Maturity Model (MM) assessing the adoption of I4.0 technologies and, [5] proposed a MM, named DREAMY4.0, aiming at evaluating the readiness of manufacturers in undertaking a DT. Although these models have been already applied in different contexts, they still lack a detailed and objective investigation over the main criticalities charactering the company to support the choice of a determined DT path. Among all, this need emerged especially in the A&D sector which is characterized, on one side by strict regulations due to the great complexity, on the other side the process digitalization lags behind the product digitalization due to the extensive product development life cycle and the limited production volumes [6]. For this reason, the research objective of this contribution is to create a robust, complete, and objective model to analyze and cover the criticalities emerged in manufacturing companies in an objective way after a maturity assessment, to provide them precise roadmaps for DT to justify the huge investments. Therefore, starting from DREAMY4.0, which emerged to be the most consolidated operative model (i.e., several citations and industrial adoptions) in the extant literature about MM towards DT, an extension has been developed in this contribution to perform an objective investigation of the major criticalities to build a structured roadmap. Moreover, considering the needs emerged in the A&D sector, the developed extended model has been applied in a manufacturing company operating in the A&D sector. The paper is structured as follows: Sect. 2 describes the theoretical background focusing on the description of the DREAMY4.0 model to highlight the key characteristics and the rooms for improvement, Sect. 3 provides the methodology employed, Sect. 4 elucidates the extended version of the model, Sect. 5 analysis the A&D case study in which the extended model has been applied and Sect. 6 concludes the papers highlighting the key contributions and the main limitations opening the way for further improvements.

2 Theoretical Background: DREAMY4.0

As just mentioned, the starting point of this contribution relies in the DREAMY4.0 digital readiness maturity model [5]. This assessment tool was developed by the Manufacturing Group of the School of Management of Politecnico di Milano and it has been already validated in multiple Italian and international-based companies (both SMEs and Large Enterprises) [5]. DREAMY4.0 aims to investigate the digital readiness of manufacturing companies by assessing six processes (i.e. design & engineering, production, quality, maintenance, logistics and supply chain) evaluating them based on four analysis dimensions namely: (i) *Execution* (i.e., how the processes are carried out within the company), (ii) *Organization* (i.e., information regarding the organizational aspects of the processes), *Control* (i.e. how a processes are monitored and controlled), *Technology* (i.e. information regarding the ICT systems, hardware and/or software, used in support of the process). The maturity is assessed along five levels of maturity [5]: from 1 (minimum level of digital readiness) to 5 (maximum level of digital readiness) in conformance to the CMMI framework [7]. DREAMY 4.0 enables to give a big picture about the current digital readiness of a manufacturing company by delineating a qualitative description of the potential rooms for improvement towards higher levels of maturity. Nevertheless, it lacks an objective quantification of the main weaknesses leading to a limited analysis of potential detailed solutions to be suggested for improvements.

3 Methodology

The present contribution aims at developing an extended version of the DREAMY4.0 especially focused on complex sectors such as the A&D. To achieve this objective, it has been relied on a workshop-based approach backed by a literature review to create the PCIM (Priority Criticality Index Mapping). Indeed, according to [8], the definition of a DT journey requires mainly a workshop-based approach. Such kind of involvement of company's employees described in the case study allows to maximize the level of commitment of all the relevant stakeholders that will implement or benefit from DT approach. Additionally, it facilitates the interviewers (i.e. the authors in this case) in the identification of the critical elements of the processes analyzed and their related solutions. Indeed, relying on an action research approach to conduct the analysis, allows to be more concrete and actively involve the case study company through constant feedbacks [9]. Figure 1 shows the 6 main steps followed to conduct the analysis to create an objective roadmap.

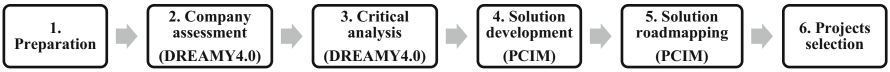

Fig. 1. Extended methodology to create an objective roadmap

4 Extended Model Development

In the first step depicted in Fig. 1, named "Preparation", there is a limited engagement of the firm, and thus, additionally to the external interviewers (here the authors) only the project champion/promoter and the CEO need to be involved. In particular, in this phase it is requested to collect all the relevant information regarding: (i) the industry in which the firm operates (e.g. trends, competitors, market approach etc.), and (ii) the records of the information about the company under analysis (e.g. balance sheets, newspapers, story of the firm, etc.). Within step 1, also the definition of the boundaries of the analysis, the signature of the NDAs and the definition of the people to be involved was carried out. Indeed, the assessment deployed is structured to cover the six processes reflecting those of the DREAMY4.0, thus the managers of the following functions were involved:

System Quality and Continuous improvement, Program, Operations, Production and Planning, Supply Chain, Quality, Logistics.

The second step, "Company assessment", requires a greater involvement of company's employees with particular regards of the functions' representatives. In this phase, the assessment method employed was the DREAMY4.0 (described in detail in the "theoretical background" section). Therefore, the authors carried out a set of interviews, both qualitative and quantitative, with the aim of collecting valuable information to understand the context in which the firm operates, to clarify its objectives, to assess the current level of digitalization by identifying its main criticalities and strengths.

The third step of the methodology, "Critical analysis", consists in the extrapolation of the key elements describing processes and technology adopted for each process, collected during the step 2, to identify the elements that might represent real barriers for the achievement of company's objectives.

Given the complexity and the needs of the sector, and more in general, the capacity and budget constraints of companies in undertaking a roadmap toward DT [10], a tool specifically designed to identify the most relevant criticalities for the case has been developed entering the fourth step "Solution Development" (see Fig. 1). Here, the extended part of the DREAMY 4.0 has been named PCIM and it aims at prioritizing criticalities and consequences in a quantitative form. Therefore, taking as input the weaknesses collected thanks to the DREAMY4.0, the PCIM methodology starts with a further sorting into: root weakness (the criticality) or weakness generated by the firsts (the effect). Afterwards, such criticalities and effects are linked through arrows which specify whether a block (criticality or effect), positioned at the tail of the arrow, has an impact on another block (effect), positioned at the head of the arrow. According to [11], graphical representation of problems facilitate the process of depicting alternatives (and scenarios) more easily and effectively. The map is then converted into a matrix which represents the occurrence of a criticality, row, in impacting a given effect, column. The translation of the map into a matrix is useful to numerically detect which criticalities generates most of the problems within the set of the six processes analyzed and consequently to propose a set of solutions able to address the most critical areas. Based on that, the fifth step of Fig. 1, "Solution roadmapping", is reflected into the prioritization of the solutions to be proposed based on the key criticalities identified and based on a further quantitative analysis of inefficiencies (e.g., waiting times, time dedicated to not value adding activities etc. extracted from database exports). More specifically, the authors identified 3 areas of intervention: 1) *Process*: including those actions of improvement which require a redesign of the processes and/or a change in the approach adopted to carry them out; 2) *Technology*: including those actions of improvement which involve the selection, implementation and integration of Information Systems and/or I4.0 technologies, 3) *Training*: including all those actions of improvement aimed at enlarging the competences of workers, at every hierarchical level, both in technological and procedural terms and/or at setting up a digital culture. This categorization was developed not only to clarify the drivers of the solutions but also to stress the importance of a multi-layered approach to DT. Indeed, the technological evolution of the system must be anticipated by reviewing processes to be digitalized to minimize the risk of digitalizing the inefficiencies [12]. On the other hand, the change in the technological configuration of the system as well as the re-engineering of the processes must be supported by a proper education of the individuals operating in the system [13]. The last step, "Projects selection", required the active involvement of both the authors and the firm's stakeholders. Indeed, it consisted in the prioritization of the solutions to be developed, the identification of the expected efforts and logical constraints and the chronological distribution of the solutions themselves. As suggested by [8], the activity needs to be conducted collectively to ensure the maximum commitment of all the managers involved and alignment with corporate objectives. In this phase, the objective was to define the actual action plan and ensure its robustness and feasibility. In particular, in terms of robustness, the authors have focused on the logical and technological priorities that might link different projects [14]. Hence, the requisite of robustness was mainly functional to the definition of the macro-phases of the roadmap developed and the positioning of solutions within each of them. In terms of feasibility, greater attention was devoted of the level of expected effort for each process and consequently on levelling them according to the actual resources available. It is worth specifying that the evaluation of effort, although shared with the managers of the case study firm, was defined in a qualitative way, and considered the following drivers [15, 16]: (i) Expected Full Time Equivalent (FTE) needed; (ii) Capital invested; (iii) Cross-functional coordination needed; (iv) Numerousness of the functions involved; (v) Numerousness of the processes modified; (vi) Coordination with external stakeholders needed.

5 Results from the Extended Model Application

In this section, the results of the application of the extended model is presented. The company subjected to the analysis is an Italian family-owned SME operating in the A&D sector. It is specialized in the design, development, production, maintenance and logistical support of defense equipment, structural components and ground support equipment of fixed-wing and rotary-wing aircraft and employs around 200 workers. Given the peculiarity of the industry, where the requisites are often fixed and rarely negotiable, the company adopts an Engineer to Order (ETO) approach. However, an element of stability in design and engineering effort is provided by the long lasting of the programs (i.e. the products) contracted. The CEO wanted to perform this assessment since within the organization some criticalities (unknown yet) were perceived as affecting processes efficiency. Hence, first it was posed the attention in formalizing and making evident those problems. For this reason, the scope of the analysis consisted in the definition and prioritization of the solutions addressing the criticalities collected to cope with the long-term corporate objectives: i) Increase in control over the processes; ii) Increase in process management efficiency; iii) Preserving the high product's quality standards; v) Supporting the expected increase in volumes. Due to the peculiarity of the industry, some information collected and analyzed, even if crucial for the prioritization of the intervention, will be omitted. The case study was conducted in four steps reflecting the structure of the next sections: **Task 1:** AS-IS critical analysis of processes; **Task 2:** Identification and prioritization of existing critical issues; **Task 3**: Identification and prioritization of improvement projects; **Task 4**: Roadmap development.

5.1 Digital Readiness and Criticalities Identification

The analysis of the AS-IS situation shows an overall maturity index equal to 3 as depicted in Fig. 2. First, it emerged that the "engineering" and the "supply chain" processes were those more ready towards a DT. This was especially driven by the commitment of the managers of these functions. On average the different processes were instead characterized by a poor control over the processes and clear difficulties in terms of coordination and collaboration among departments.

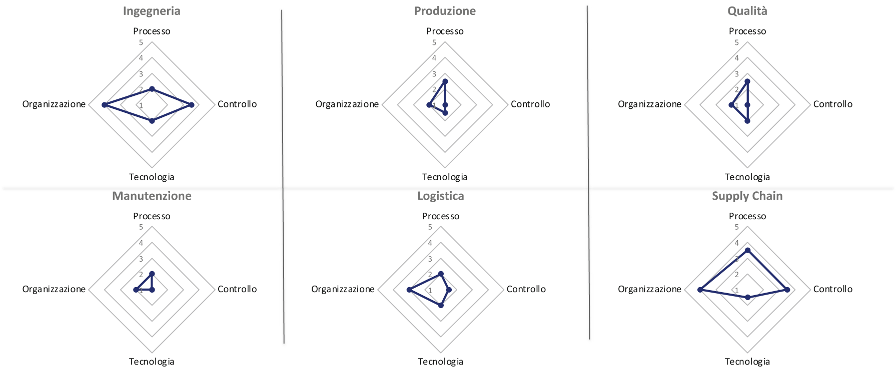

Fig. 2. Process maturity index

No processes were considered advanced from a technological perspective thus proving a pervasive inadequateness of ICT systems. Such gaps, in parallel to the low reliability on data quality, resulted in a general adoption of locally-stored files (mostly Excel documents) developed and used by individuals to manage their processes [17]. In addition, it emerged that the spread of home-made files turned out to reinforce the misgiving towards the IT systems. Overall, 38 main criticalities were detected and based on an iterative process these were clustered according to six macro categories: 1) Misalignment between purchasing and production Lead Times (LTs) and LT deemed acceptable by the market: 2 criticalities; 2) Process and product data not sufficiently disclosed among the functions and generated and managed outside the IT systems: 6 criticalities; 3) Process and product data not sufficiently reliable, manually input in the IT system and not unique: 8 criticalities; 4) Unsuitability of IT systems: 13 criticalities; 5) Lack of physical and logical Track & Trace of products and components throughout the procurement, production and delivery cycle: 3 criticalities; 6) Lack of codified and standardized procedures and methodologies: 6 criticalities. The identification of criticalities was backed by a quantitative approach which consisted in the analysis of 25 locally-stored files exploited by the departments during their activities, the ERP system and more than 40 documents ranging from procedures to follow up to performance reports. This analysis was beneficial for two main reasons:, it allowed the company to understand the real impact of the processes inefficiencies and, it supported the authors in estimating the expected benefits of the solutions proposed. To report an example, the time spent for not value adding activities (e.g., photocopying, manual delivery of documents etc.) proved to be to most critical. Design & Engineering areas, namely Research & Technology and Engineering, proved to be acutely affected by such waste which accounted, for Engineering, for up to 71% of the time spent by an FTE.

5.2 Prioritization of Criticalities

Once the criticalities were identified, the analysis of the links among criticalities and the related effects has been performed by using the PCIM model. Figure 3 shows the map in which all the linkages have been identified. All the criticalities are represented through a colored square based on the 6 macro-categories of criticalities defined while the effects are represented by pink hexagons. Overall, 32 effects coming from 50 criticalities have been collected. The links in the maps, once jointly validated with firm's managers, have been elaborated, into a matrix, through the PCIM model to quantify the occurrences of each criticality impacting on each effect.

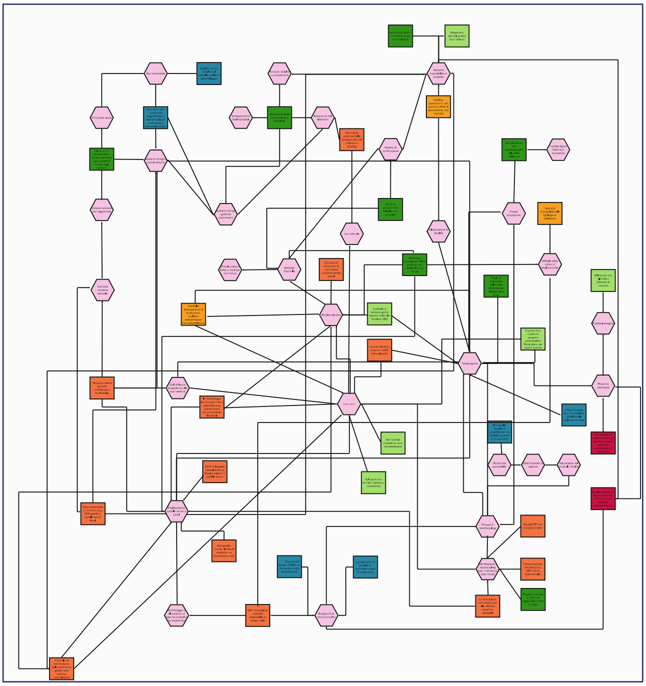

Fig. 3. PCIM graphical visualization

More specifically, each criticality has been mapped across the effects as well as each effect has been mapped across all the effects emerged to quantify the secondary effects weight. This enabled to quantitative evaluate how many times a criticality creates an effect looking also to the secondary effects. Last, to tailor the possible solutions to be proposed in accordance with the main criticalities observed, the matrix developed, linking the criticalities and the effects, has been divided into four quadrants based on the

Pareto law. With regards to the most relevant critical issues in terms of relationships with the effects found, it was noted that 50% of them account for 80% of the concatenations detected. Shifting the analysis on the most impacted effects, there is a high preponderance of those concerning the increase in times spent in not value adding activities. More specifically the main criticalities emerged are the following: Misalignment between time to market and supplier's delivery LT (C1), Data manually managed and not visible to functions (C2), Unreliable and not unique data (C3), ICT systems' inadequacy (C4), Poor materials and products track & trace (C5), Lack of standardized procedures and methodologies (C6).

5.3 Solution Development

Based on the PCIM, 50 different detailed solutions have been proposed. Afterwards, they were clustered according to 6 main areas of interventions described below:

1. PLM (**S1**): Introduction of a PLM system capable of supporting the efficiency of the process of data sharing from the technical department towards the others and of developing different Bills of Materials (BoM), like E-BoM, M-BoM etc.. This system needs also to be designed for the documentation management of the product currently managed by the various functions (e.g. Quality); (covering C2, C4)
2. ERP (**S2**): Update or replacement of ERP in use to meet the business requirements found (e.g. robust robustness, reliability of data, ability to manage different BoMs, purchasing procedures, planning, and warehouse); (covering C2, C4, C5)
3. ERP-MES (**S3**): Introduction of a system for visualizing and monitoring the production processes and assets which guarantees the product tracking. The system, identified as the MES, needs to be integrated with the ERP to enable consistent decisions based on the actual assets' performances; (covering C2, C4)
4. PROCESS REDESIGN (**S4**): Review of part of the procedures and process logics in use aiming to optimize and align them with the needs of the market. This project was designed also considering to the TO-BE information systems; (Covering C1, C6)
5. I4.0 (**S5**): Introduction of systems based on business intelligence and Machine Learning in order to make internal business processes more effective and efficient; (Covering C3, C5)
6. TRAINING (**S6**): Definition of training programme for staff at all hierarchical levels to raise awareness about the functionalities and benefits of digital technologies. (Covering C1, C2, C3, C4, C5, C6)

These proposed solutions addressing the key criticalities were also mapped along a timeline to highlight the prioritization in terms of both urgency and links. Hence, such blocks were organized as depicted in Fig. 4. The roadmap generated was composed by three transversal projects: cybersecurity, ICT systems integration and training which supported the projects on the organization, the update of the already existing systems and the implementation of the new ones. It is worth clarifying that the definition of such roadmap does not represent a standard of clustering of solution but rather was jointly defined with the management to support them to tackle the DT project into manageable and self-sustained sub-projects, defined based on an analytical and objective model.

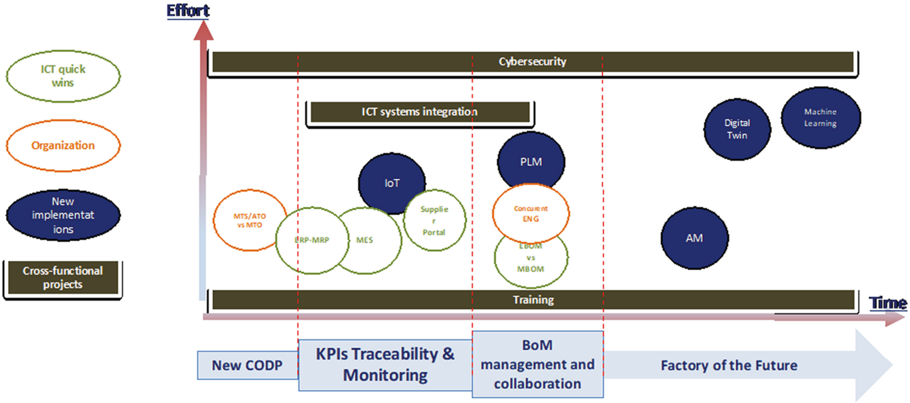

Fig. 4. Final roadmap

6 Discussion and Conclusions

This paper aimed to support manufacturers, operating in complex contexts like A&D sector, in undertaking a properly design DT. Therefore, based on literature review and workshop-based research, a new method was developed to quantify the criticalities emerged from the assessment to design a roadmap. This method, the PCIM, objectively clarifies the key criticalities to address through specific solutions. The proposed extended model, DREAMY4.0-PCIM, relies on six main phases and was applied in one A&D manufacturing company. The manuscript evidenced a successful integration of the tools which resulted into a comprehensive, cross-functional, and multi-objective roadmap for manufacturers operating in complex contexts. It enabled to first evaluate strengths and weaknesses of the different processes and quantify the criticalities. The following research presented some limitations related to the adoption of the single-case study approach and the limited focus on quantitative benefits achievable from the solutions proposed. Hence, the authors suggest to consider the following activities to expand the research: to implement a complete review of the organizational structure that may consider also the departments supporting operations with the aim of maximizing the effectiveness of the solutions, to deepen the micro-processes of the areas investigated to eliminate the macro-issues not tackled in this study, to support the firm in redesigning processes and selecting and implementing the adequate IT and I4.0-related tools suggested.

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