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Reconciling Strategy, Maturity, and Performance Measurement in Industry 4.0

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Abstract

Maturity models are essential tools to evaluate Industry 4.0 readiness. However, they have limitations in supporting organizational strategies over time and are insufficient to create company-specific Industry 4.0 roadmaps. This paper presents a research project to steer Industry 4.0 transformation in a leading paper pulp company listed on the Euronext Lisbon stock exchange. The contribution to the body of knowledge is a novel approach for Industry 4.0 adoption that extends the Balanced Scorecard with a fifth perspective and exposes the value of maturity model fragments: fractions of maturity models pertinent to a custom strategy. The proposed solution can support continuous improvement in long-term digital transformation strategies. Moreover, the lifecycle of maturity model fragments, namely, (1) dimensions and criteria elicitation, (2) personalization, and (3) strategic alignment, opens innovative prospects for maturity model design, tailorability, and practical relevance.

Keywords

Industry 4.0, maturity model, balanced scorecard, strategy development.

Introduction

Digital transformation in the industry (Industry 4.0 or I4.0) requires a strategy of transition enabled by disruptive technologies that include cloud, artificial intelligence, Internet-of-Things (IoT), robotics, or augmented reality. To keep the momentum of change, it is crucial to balance the strategic goals with the creation of capabilities for I4.0 (Huber, Oberländer, Faisst and Röglinger, 2022). On the one hand, modern strategies require a shared organizational view of business and technologies; on the other hand, "maturity" stages enable companies to evaluate their present situation and continuously improve down the desired path (Becker, Knackstedt and Pöppelbuß, 2009; Elibal and Özceylan, 2022).

A strategy map is essential to launch, monitor, and boost disruptive transformations (Matthies and Coners, 2021). One of the most popular tools to assist companies in creating strategy maps is the Balanced Scorecard (BSC), proposed by Kaplan and Norton (2005). The BSC guides companies in identifying interrelated goals across four perspectives: financial, customer, internal processes, and learning and growth. The central importance of the BSC for strategic development and its potential to be combined with other frameworks and approaches is patented in recent IS publications. However, according to Matthies and Coners (2021), "*IS research to date has paid rather little attention to the supporting concept of the strategy map*." Additionally, the BSC was not built for an era of profound

digitalization that requires tackling the challenges of end-to-end digital integration proposed by I4.0 (Matthies and Coners, 2021).

Maturity models have proven helpful in adopting I4.0 (Mittal, Khan, Romero and Wuest, 2018; Elibal and Özceylan, 2022). Additionally, authors such as Leyh et al. (2016) proposed comprehensive dimensions (e.g., areas of analysis such as "Digital Product Development") for transformations in the industry. However, these instruments are sometimes adopted as templates for improvement without clear ties to the overarching business strategy. Challenges persist in this alignment, sometimes causing reduced adoption by practitioners (Mittal et al., 2018). Notwithstanding the numerous enterprise maturity models available (Santos-Neto and Costa, 2019), they need (1) more adoption by the industry, (2) a deeper exploration of their prescriptive (*vs.* descriptive) value, and (3) the capacity to be integrated into business strategies, because "*few procedures for defining maturity exist, and sometimes these procedures become complex to apply, which makes it difficult to propagate them in other organisations*" (Santos-Neto and Costa, 2019). Recent studies reveal that I4.0 maturity models often fail to adapt to changing conditions and particularities of each organization (Kieroth et al., 2022).

Therefore, we agree with Mullaly (2014) that "*a contingent and contextual approach to assessment is required*." The recent comparison by Elibal and Özceylan (2022) explains the unbalanced perspectives of maturity models for I4.0, suggesting that each one has particular strong points. The deployment of I4.0 strategy maps and goals does not allow measuring the evolution of enterprise maturity to improve the consistency of desired performance. Conversely, while interesting for assessing and guiding specific areas (e.g., leadership, smart products), maturity models are hard to tailor to each organizational context. Our research question is thus: *How to combine maturity models and a strategy-oriented instrument, like the balanced scorecard, to manage tailored strategies for Industry 4.0 (I4.0)?*

We investigated this question using design science research (Hevner, March, Park and Ram, 2004) in a leading European paper pulp company adopting I4.0. Their CIO was struggling to clarify the digital transformation strategy to the board of administrators and ensure the continuous assessment of I4.0. To support him in that task, we extended the BSC with an additional dimension and explored the utility of *maturity model fragments*, defined as fractions of maturity models pertinent to a custom strategy.

The remainder of this paper starts with a revision of the literature about maturity models in I4.0 and strategy maps. Subsequently, the research approach is explained, including the description of the case company and problem formulation. Afterward, we detail the design of our proposed artifacts and the intervention. The discussion follows, presenting the lessons learned and their implications. Finally, the conclusions summarize the results, limitations, and future work avenues.

Background

The relevance of I4.0 is unquestionable, but managers need to identify their organizations' readiness and maturity level to create change roadmaps and steer the necessary investments (Mittal et al., 2018).

Models for Managing Maturity in Industry 4.0

Maturity models define areas of operation and maturity stages, offering guidance for improvement (Becker et al., 2009). Maturity is organized as a progression of stages for a specific class of objects, intending to reach a designed target from a starting point (Becker et al., 2009). Hundreds of maturity models have been developed over the years for multiple purposes and areas of application (Becker et al., 2009), including I4.0 (Elibal and Özceylan, 2022). Each model embodies a vision, so one of the main difficulties of decision-makers is selecting which to use. From the vast offer available, they must identify which ones align with the organizational strategy. Some models focus on technologies, while others include social and organizational aspects (Leyh et al., 2016). The quality of available models also varies (Elibal and Özceylan, 2022), making the selection even more difficult.

Despite their popularity, there are limitations in current maturity models in establishing roadmaps tailored to the context of each company (Barata and Cunha, 2017). For example, some maturity models are a poor fit for SMEs or too simple to be helpful in large enterprises (Mittal et al., 2018). Additional problems include shortcomings when dealing with environmental changes (the model is static regarding its dimensions and maturity levels), scant guidance on how to address identified issues, insufficient detail

to measure progress over time (e.g., lack of studies showing how an organization can use the maturity model for multiple assessments), deficient theoretical grounding (Röglinger, Pöppelbuß and Becker, 2012), and poor support for social and organizational issues (Kieroth et al., 2022).

The work of Mittal et al. (2018) presents critical gaps in maturity models for I4.0 and offers a solid starting point for further research. First, the authors highlight the distinct starting conditions of digitalization, which are difficult to capture with maturity models. Second, they note the "*disconnect between maturity models and self-assessment readiness tools*" that separately evaluate the organization's current state and the support for improvement actions. Third, they mention the lack of support "*for next step after maturity and readiness are assessed*." Moreover, the study presented by Kane et al. (2016) shows that the I4.0 concept is understood differently across industry sectors, thus demanding specific know-how when tailoring existing approaches. Exploring synergies between maturity and performance measurement may contribute to some of the maturity model challenges, namely in the adaptation to the organizational starting point and particular strategy.

Strategy in Turbulent Environments

Strategic management demands continuous assessment and effective initiatives. The increasing changes in the technology portfolio of I4.0 open new opportunities to compete and raise new risks to identify the best investments. It is crucial to create maps tailored to each organization, agreed upon by the stakeholders "*and not just copied from the generic BSC books*" (Lueg, 2015). Performance measurement is part of the management control process. It consists of three main steps: (1) setting performance indicators, (2) measuring the performance indicators, and (3) taking corrective action if necessary (Jennings and Beaver, 1997). Some approaches have been proposed for I4.0, like the work of Kamble et al. (2020) for intelligent manufacturing, requiring a goal alignment with the overall organizational strategy.

The BSC proposed by Kaplan and Norton (1996) is one of the most popular tools for envisioning strategic goals while planning the operational activity, objectives, and control over their achievement. The BSC draws on a strategy to establish goals requiring that people take the actions necessary to reach those goals. By design, the measures pull people toward the overall vision (Kaplan and Norton, 1992) and not merely represent the strategy. To minimize information overload, the BSC focuses on the most critical measures across four perspectives: "*Customer Perspective: How Do Customers See Us?*" which prioritizes time, quality, performance and service, and cost; "*Internal Business Perspective: What Must We Excel at*" which addresses cycle time, condition, employee know-how, and productivity; "*Innovation and Learning Perspective: Can We Continue to Improve and Create Value?*" which measures the ability to develop and introduce new products that will eventually form the bulk of future revenue; and "*Financial Perspective: How Do We Look to Shareholders?*" which indicates whether the company's strategy, implementation, and execution are contributing to bottom-line improvement (Kaplan and Norton, 1992).

Several studies adopted the BSC to set I4.0 priorities. For example, Szóka (2018) uses its original form to describe the main factors to address in the I4.0 strategy (e.g., automation, motivation of employees). Other authors, such as Frank et al. (2002) or Hegazy, Hegazy, and Eldeeb (2022), extended the BSC with an additional perspective (for sustainability and corporate ethics, respectively), while Aldea et al. (2018) combined the BSC and the ArchiMate language to develop a more detailed strategy map. Additionally, Frederico et al. (2021) adopted the BSC for I4.0 performance measurement. These authors also suggest longitudinal studies to understand performance evaluation over time.

Research Approach

Our inquiry used the design science research (DSR) approach (Hevner et al., 2004). We selected DSR because of its fit with our dual goal of developing artifacts to guide I4.0 strategies and evaluating the organizational challenges in a real-world situation. It consists of two complementary phases to ensure relevance and rigor, iteratively searching for better artifacts that solve an organizational problem (Hevner et al., 2004). Our DSR is inspired in practice, taking place in one of the major European paper pulp industry players, established in 1962, also operating in renewable energy. It produces over 680 tons/year of eucalyptus pulp. The company integrates the Portuguese Stock Index (PSI) and is recognized worldwide for the high quality of its product and excellent customer service.

This research started when we contacted the company's CIO to understand the importance of I4.0 to a top stock market index company with demanding technology investments and strategy disclosure requirements. It is a priority for this company to create a comprehensive I4.0 strategy that aligns with its main stakeholders' vision. Initial discussions with the company's CIO confirmed the misfit between generic tools to assess I4.0 maturity and their business setting. According to the CIO: "*we have lots of ideas and potential pilot projects* (...) *that is important and making experiments can generate valuable knowledge about* [I4.0...] *but the piece that is missing is the creation of our own vision for Industry 4.0*".

It was evident to researchers and practitioners that a better artifact for crafting I4.0 strategies was needed. In our design process, we examined the maturity models and strategic management bodies of knowledge to ensure that solid theoretical foundations guided the artifact. We conducted the research project for nearly a year. It involved several meetings with company experts to collect data and refine an artifact that integrates BSC and maturity models. Finally, we instantiated and evaluated the artifacts in the participating company.

Steering Industry 4.0 in the Case Company

Designing and Evolving the Artifact

The case company was already familiar with the BSC, so we explored how to adapt it to better support I4.0 strategies. We started by experimenting with incorporating I4.0-specific goals and measures in the standard perspectives. For example: including "*Implement IoT in approx. 5000 engines to reduce plant maintenance cost*", in the process perspective, with links to "*Control variable costs*" in the financial perspective. We assumed that I4.0 results would appear in the traditional perspectives of the BSC. This approach, however, made it difficult to extricate the aspects related to I4.0 investments. Moreover, it was not possible to understand how the I4.0 strategy was related to each perspective, hindering the proposal of improvement initiatives by the IT department and lacking the capacity to communicate the I4.0 strategy to organizational stakeholders.

In our next experiment, we investigated adding a dedicated I4.0 perspective to the BSC. Several documents were analyzed (e.g., strategy plans, IT investment portfolio), and meetings were held between researchers and practitioners to understand the particularities of I4.0 investments and how they were linked to the company strategy. In contrast to the previous approach, connections to other standard perspectives enabled an understanding of how I4.0 contributed to more general organizational goals and better integration of CIO and top management views. For example, the I4.0 perspective concentrates on all the goals supported by technology systems (e.g., robotics and sensing technologies). Therefore, the strategy map can be linked with other goals from the four traditional perspectives. However, the project participants found the new I4.0 perspective insufficient. The CIO claimed that it enabled the I4.0 goals to be elevated to a shared organizational concern, leading to a better understanding of their impact on other goals. Nevertheless, this modified BSC lacked a maturity assessment and guidance for concrete initiatives.

The initial attempt to extend the BSC adopted a new perspective for I4.0. We considered using maturity models to evaluate existing goals and define new ones, including maturity assessment in each perspective (on a five-level scale). However, since the BSC perspectives address significantly different issues, that would mean adopting a maturity model broad enough to encompass all of them (which we could not find) or adopting various maturity models aligned with the various perspectives, which imposes a significant overhead while also potentially introducing redundancies and extraneous aspects. Moreover, it was not our purpose to add more maturity models to the already extensive list but make them more useful for industry practice, using relevant parts for the organizational strategy.

In our final iteration, we thus experimented with adopting only "parts" of different maturity models (which we call fragments) that were deemed relevant to the company goals. The idea of selecting "parts" of existing maturity models could (1) avoid duplication of redundant dimensions, (2) promote a debate about existing maturity models by the industry practitioners, increasing their awareness and identifying relevant candidate dimensions, (3) avoid discarding an entire maturity model just because some of its dimensions were not relevant for the company. Table 1 offers the foundations for their integration.

Comparison	BSC	Maturity Model (MM)	Industry 4.0 Particularities
Artifact structure	Prescriptive perspectives with flexible goal setting	Prescriptive dimensions with fixed criteria	Requires adjustments for each company. Best practice guidance (typical in MMs but absent in the BSC) is necessary
Artifact adoption	Continuous reflection. More popular for self-use in organizations	Specific evaluation episode. More popular among consultants	Implements a long-term vision and continuous monitoring. The multiplicity of tools may hinder the adoption
Artifact outcomes	Strategy map and quantitative measures to understand the evolution	Clarify the current state and recommendations for improvement – next-level criteria	It is highly dependent on technological advances and the industry sector. KPIs are necessary but do not provide maturity insights
Assessment	Dependent on the suitability of goals and indicators	Dependent on the suitability of model selection	Can differentiate the company if a tailored strategy is used
Artifact advantages	Decision-making; Goal Assessment; Inside-out evaluation	Suggestions; Capability Improvement; Outside-in evaluation	It should be a result of internal reflection and best practice recommendations
Artifact disadvantages	Prevalent in organizations; Digital advances depend on the goal selection	Popular among I4.0 consultants; Low adoption in companies. Digital advances incorporated into the model	It is increasingly popular in the industry, but companies struggle to identify supporting tools and need experts assistance

Table 1. BSC and Maturity Models in Industry 4.0: Looking for Synergies

The BSC precedes maturity analysis and provides the map, priorities, goals, and performance measurement. Complementarily, the maturity models offer the criteria and guidance for maturity improvement (that can assist in goal formulation). Relevant parts of maturity models can be selected to keep the momentum of change. Figure 1 presents the final version of our artifact that integrates the BSC and maturity models to manage tailored strategies for I4.0.

Figure 1. BSC-MM for Industry 4.0

The BSC-MM contains five perspectives for navigating I4.0 strategies; the original four: financial, customer, processes, learning and growth, represented vertically on the right of Figure 1. We can find one or more maturity model fragments linked to each strategic goal that evaluate a particular maturity

dimension. It is possible to integrate maturity model fragments in the five BSC perspectives. For example, vertical integration (Leyh et al., 2016) is an example of a dimension in the I4.0 maturity models literature selected by the case company. The following elements characterize each maturity model fragment: (1) identification; (2) related goals (which goals in the BSC-MM can be improved with a higher maturity); (3) questions/items (how the measurement is done); (4) maturity level identification (the result of maturity assessment in a specific period) with the actual value and the target.

The sequence of steps to apply the proposed artifact is the following: 1- Identify the company goals for the five strategic perspectives (or for the additional I4.0-related goals if a BSC is already in use in the organization); 2- Identify the most relevant maturity models for the organizational strategy and, for each one, which fragments to adopt (we present three examples extracted from 24 maturity models evaluated during this research); 3-Create the strategy map and link each goal with the maturity model fragments that can contribute to its sustained performance; 4-Define the (a) indicators, (b) metrics, and (c) an action plan. For the latter (c), consider the recommendations of the selected maturity model fragments on how to achieve a higher maturity level for the topics at hand; 5- Continuously evaluate the results of strategy implementation. Refine the association of goals and maturity model fragments. Fragments can be replaced if the desired maturity has been achieved or results are unsatisfactory.

Field Intervention and Evaluation

Figure 2 shows our case company's main dashboard using the proposed BSC-MM.

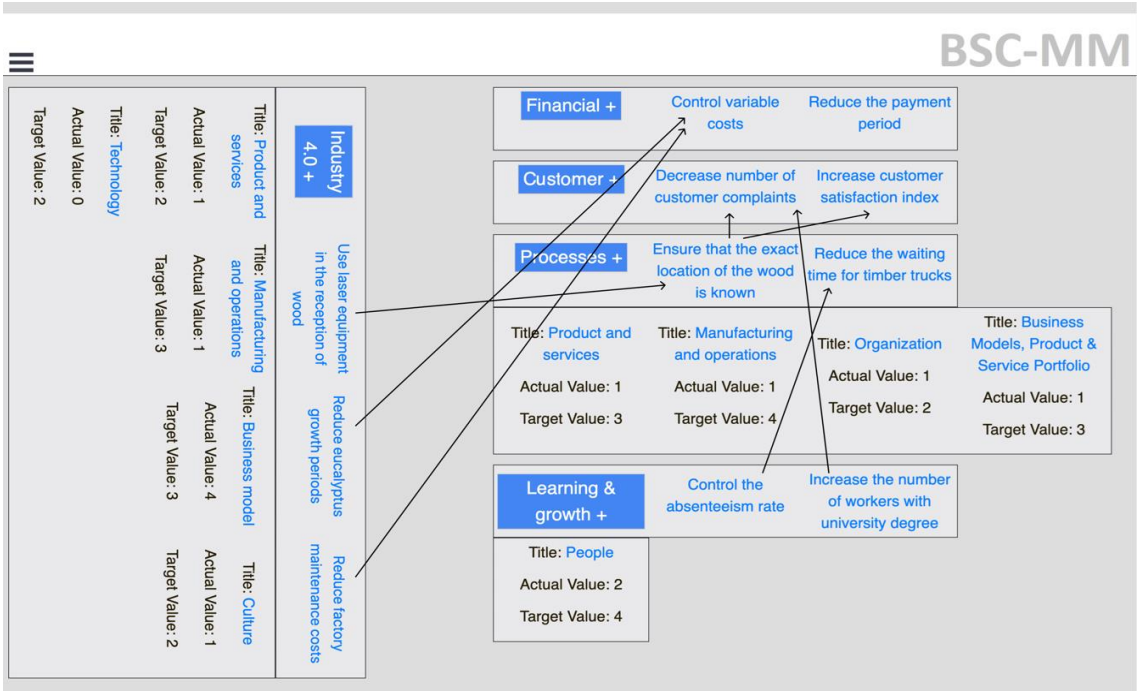

Figure 2. BSC-MM Instantiation in the Paper Pulp Company (Dashboard)

The main menus of the software tool implementing the BSC-MM are the administration (e.g., configure the maturity models dimensions and questions), dashboard (presenting the most recent actual/target values for each strategic goal), assessment update, and management of initiatives. For example, the "Learning & Growth" perspective in Figure 2 (on the bottom) includes two strategic goals related to absenteeism and qualifications. Each goal has indicators and targets – as usual in the traditional BSC – and a maturity model fragment (in this case, People) to provide an additional assessment based on acknowledged good practices.

The arrows in Figure 2 connect I4.0 strategy goals to other types of goals (e.g., "Reduce factory maintenance cost" associated with I4.0 investments is linked to "Control variable costs" in the financial perspective), in parallel with the traditional links between the four original perspectives (on the right). A

drill-down of the goals in each perspective enables one to see the actions needed to achieve the goal and reach the target maturity level that may contribute to sustaining its performance over time.

The summary of each maturity model fragment assessment (including the actual and target stages) is part of the dashboard. Examples of selected fragments are "*Product and services*" and "*Manufacturing and operations,*" (used in the Industry 4.0 and Processes perspective) extracted from the University of Warwick (2018), "*Business Models, Product & Service Portfolio,*" extracted from PwC (2017), and "*Culture", "Organization", and "Technology,*" extracted from Forrester research (2016). The BSC-MM suggests the creation of a portfolio of maturity model fragments for I4.0, to fit various situations and strategies. Table 2 presents an example of the maturity model fragment used for "Product and services" on the left – Industry 4.0 perspective.

Fragment	Dimension	Measurement Item (5-point Likert scale)
Product and services-oriented technology	AR, VR, and MR	The company uses technological devices for 'design process enhancement by visualizing issues in product development life cycle'; 'productivity improvement by providing *tablets* to the workers that assist them to improve turnaround time in supply chain and manufacturing processes.'
	Mobile Devices and Wearables	The company uses *tablets* and Wearables (e.g., smart watches, glasses, and gloves) to access the information and communicate with *SAP* on a real-time basis; *smartwatches to monitor health and safety parameters used for quality audit*
	Blockchain Technology (BT)	The company uses BT for effective and efficient e-value chains: 1) transparent supply chain involving tracking and tracing *wood* from supplier to their origin; tracking *inventory*; and enhancing procurement data accuracy. 2) Smart contracts that include automatically verifying *wood delivery in the park* and *origin from certified suppliers*
	Smart Product	The company develops smart products by embedding intelligent sensors into the *paper pulp packs* that enable sensing the environment around them *and creating the product biography*

Table 2. Maturity Model Fragment for People – Industry 4.0 Awareness (adapted from Wagire, Joshi, Rathore, and Jain, 2021: text in italic represent company-specific changes made to the original version of the maturity model)

Table 2 demonstrates a maturity model's influence on the BSC. First, the strategy assessment is based on best practices included in the maturity model, providing insights for actions – in this case, the selected fragment suggests the use of specific technologies. Second, elements of the maturity model are only used as necessary. In fact, Wagire et al. (2021)'s "*Product and services oriented technology*" dimension states that "*The company employs 3DP* [3D printing] *technique at various stages of production, i.e., from product conceptualization - manufacturing to after-sales. For example: in the design phase of the new product, rapid prototyping* (…). However, 3D Printing is not relevant to the business of our case company (as they produce paper pulp), so it would not make sense to adopt this maturity dimension in its entirety. The selected fragment is customized to use only the parts aligned with their strategy. We found evidence that the BSC-MM approach can contribute to increasing the practical relevance of maturity models and revealed a novel adaptation, probably unexpected to maturity model authors.

Interestingly, while the practitioners were selecting which criteria would suit their strategic purposes, they also reflected on what I4.0 means to their company and which parts of best practices could influence their strategy. For example, the analysis of "*Smart Product … intelligent sensors into the products that enable products to sense the environment around them*" (Wagire et al., 2021), which, at first, would seem irrelevant for paper pulp, originated one of their most innovative initiatives for product quality monitoring: adopting IoT to monitor humidity and storage conditions during sea transport and in intermediate warehouses at specific ports.

The association between "company goals" and "mature practices" offers a robust strategy evaluation for I4.0. For example, the metrics related to the goals may comply with what is expected (e.g., absenteeism below 1.5% or the average waiting time below 30 minutes). However, the maturity evaluation may provide a complementary result, for example, evaluating the feasibility of sustaining the indicators over time at the desirable stage, while the traditional BSC indicators address the present moment.

The perspective for I4.0 (on the left of Figure 2) identifies three priorities for I4.0 investments in the case company. The representation of maturity is continuous in our proposal (actual – target), not in a single moment in time. Moreover, the identification of BSC-MM improvement initiatives uses only valuable fragments. By "valuable," we mean the part of the original maturity model tailored to the company strategy, obtaining a commitment from the managers in their I4.0 adoption.

Discussion

We will frame this discussion of the outcomes of our research project using the seven guidelines proposed by Hevner et al. (2004). The first guideline (G1-design as artifact) emphasizes the need for viable artifacts designed to address a relevant organizational problem (G2), as we confirmed in the paper pulp organization. The evaluation was jointly performed by researchers and practitioners with actual data (G3), contributing (G4) to a BSC extension that incorporates maturity models. The artifact must be informed by theories (G5) and aligned with the needs of the context, evolving iteratively (G6): we have departed from the original BSC (Kaplan and Norton, 1996) and proposed an extension to address I4.0-related strategy aspects that are not well served by the four traditional perspectives. We sought inspiration from the structure proposed by Frank et al. (2002) and Hegazy, Hegazy, and Eldeeb (2022), including a new dimension. As previously discussed, a team of academics and practitioners worked together to iterate on extending the original BSC and evaluate how the resulting artifact would fit the organizational problem and the results adequately communicated (G7). The proposed BSC-MM and supporting software tool are now being experimented with actual company data.

According to the company managers, the extension proposed in this research equips them to better deal with a class of problems associated with creating and managing I4.0 strategies without unduly overhead. The new separate perspective enhances the awareness of I4.0 and its implications across the organization and enables the involvement of the CIO in strategy discussions. Complementing the BSC with fragments of maturity models proved valuable, seeking guidance for suitable initiatives to support the established goals. By associating goals with a maturity level, managers get a more grounded understanding of their critical success factors. Maturity models that focus specifically on I4.0 technologies (e.g., cyber-physical systems) can be contrasted with the strategic goals to help evaluate the impact of investments. Interest synergies exist in the joint use of the BSC and maturity models. The BSC delivers simple monitoring of a reduced set of customized key indicators, while maturity models offer a more foundational view of the company and capabilities supporting those existing results. Higher maturity levels assure that some results are sustainable rather than circumstantial. Specific initiatives indicated in the maturity models can be launched to increase maturity in critical areas for the company. Used independently, maturity models can be an excellent starting point to evaluate readiness and decide on initial steps. However, they require additional work to establish a strategy specific to each sector and company context.

We espouse the vision of Chen et al. (2010) when they call for a third shared view where the business strategy not only guides but is also profoundly transformed by the IS strategy, providing "*a basis to form the organizational perspective of how to invest in and utilize IS for strategic goals*." Nevertheless, strategic tools like the balanced scorecard were not made to assess maturity or improve resilience to change, which can be addressed with maturity models. Strengthening the business with the conditions to deal with change is one of the essential advantages of maturity models (Santos-Neto and Costa, 2019).

Continuous improvement and learning are intertwined (Zangwill and Kantor, 1998). The balanced scorecard is a pivotal instrument to support continuous improvement initiatives, evaluate performance, provide valuable strategic feedback, and serve as a communication tool. Moreover, as stated by Kaplan and Norton, organizational learning and the capacity to revise the strategy are among the most valuable characteristics of the BSC. However, it is not sufficient to compare the value obtained in two moments in time to conclude about improvement, and "*what drives continuous improvement is some sort of underlying learning*" (Zangwill and Kantor, 1998). Our work may contribute to incorporating learning cycles in continuous improvement of what Kaplan and Norton (1996) coined as strategic learning.

Conclusion

We presented the results of a research project to determine how a strategy-oriented instrument, like the balanced scorecard, could be combined with maturity models to create and manage tailored strategies for

I4.0. The final version of our artifact introduces the concept of *maturity model fragments* to support the organizational goals and initiatives. A vital advantage of the proposed approach is the capacity to incorporate long-term learning cycles for continuous improvement in more immediate performance evaluation tools and short-term action deployment. Digital transformation is pervasive in organizational strategies. However, digital transformation goals are usually buried in strategy maps, making communication more complex and the role of learning less relevant for continuous improvement decisions. The proposed BSC-MM approach may contribute to these purposes in a long-term time frame.

Although our objective to achieve a better artifact was considered successful by the case company, we must point out some limitations. First, despite the various iterations in refining the artifact, only a longitudinal study can provide a complete evaluation of its effectiveness in helping craft an I4.0 strategy. Second, a broader generalization of our results requires testing the approach and the artifact in companies of different sizes and industries. The IT department of our case company has the skills and the motivation to adopt the BSC-MM. However, smaller organizations or other sectors of the economy may face different challenges, including finding suitable maturity models. Third, maturity models have internal consistency, so mixing and matching fragments from different ones must be made with extreme care. When selecting a fragment from a given maturity level, ensuring that the company meets any preconditions is critical. In addition, maturity levels from different models may not be aligned, so a joint characterization is required. Finally, our selection of maturity models started with a review of options available for Industry 4.0, but it will be necessary to create guidelines for model selection. For example, selecting models with sufficient documentation and not exclusively descriptive can be a good starting point.

We identified several opportunities for future research. Authors of maturity models can consider the possibility of creating fragments – parts that can be separated to assess particular strategic goals of organizations. We have faced difficulties testing some maturity models in the literature because they lacked a detailed list of questions and stage identifications. The tailorability of maturity models is a promising line of research and can contribute significantly to their practical use. In this case, the unconventional use of existing maturity models allows a high degree of freedom in maturity model manipulation: extracting only relevant dimensions, combining parts of different models, not following the initially determined weighting, or even adapting the criteria descriptions to the organizational setting. This approach can improve maturity model relevance for long-term strategy formulation, continuous assessment, and decision support. It opens an opportunity to compare different sectors with variants of a single maturity model or a combination of fragments from different maturity models. Nevertheless, it reduces the prospects of using maturity models to compare organizations in the same sector. More studies are necessary to understand how to overcome the comparability shortcoming of our proposal and extensions for model selections. Finally, templates of sector-specific BSC-MM can be created.

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