Navigating the Fourth Industrial Revolution: SBRI – A Comprehensive Digital Maturity Assessment Tool and Road to Industry 4.0 for Small Manufacturing Enterprises

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This article presents the development and validation of SBRI (Small Business Digital Maturity Assessment and Road to Industry 4.0), an innovative methodology for assessing digital maturity and supporting digital transformation specifically designed for small manufacturing enterprises in the context of Industry 4.0. Unlike existing models, which are often too complex or unsuitable for smaller organizations, SBRI considers the unique characteristics and constraints of small businesses. The methodology includes five key dimensions: Strategy, Technology, Process, People, and Organization, elaborated into 25 subdimensions with specific maturity criteria and indicators. The SBRI includes a structured roadmap for digital transformation through a proposed digital maturity continuous improvement cycle. An empirical study involving 23 small manufacturing enterprises in the Czech Republic has demonstrated the validity and practical applicability of the methodology. The results showed an average level of enterprise digital maturity of 0.9 on a scale of 0 − 4. These findings suggest that small businesses are just at the beginning of their digital transformation journey. Therefore, the SBRI methodology represents a valuable tool for navigating small businesses through their digital transformation journey, contributing to academic discourse and practical application of Industry 4.0 principles in the small business segment.

Keywords: Digital maturity assessment, Industry 4.0, Small manufacturing enterprises, Digital transformation, SBRI methodology

1 Introduction

The advent of the fourth industrial revolution in 2011, commonly referred to as Industry 4.0 [1], has brought unprecedented opportunities and challenges for manufacturing businesses of all sizes and has ushered in a new era of digital transformation in various sectors of the economy [2-4]. This paradigm shift is characterized by the integration of cyber-physical systems, the Internet of Things (IoT), cloud computing and cognitive computing, which are fundamentally changing the landscape of manufacturing and industrial processes [5–9]. Although large corporations often set the pace for the adoption of advanced digital technologies, small and medium-sized manufacturing enterprises (SMEs) face unique obstacles in their pursuit of digital transformation [10, 11]. These enterprises, which form the backbone of many national economies, play a key role in innovation and employment. In the European Union, in 2020, micro and small enterprises (0-49 employees), hereafter referred to as "small enterprises", accounted for 99% of all enterprises in the non-financial business environment;

contributed 35.4% to the total gross value added and employed 48.6% of the workforce [12].

The concept of digital maturity, which encompasses the level of adoption and use of digital technologies in an organization, has emerged as a critical factor in assessing a company's readiness for Industry 4.0 [11]. Current research in the area of digital transformation and Industry 4.0 has focused primarily on large enterprises [10, 11]. Existing models for assessing digital maturity, such as. [10-14], often assume a level of resources and expertise that small enterprises typically do not possess. In addition, these models often do not take into account the specific characteristics of small businesses, such as limited financial resources, less formal organizational structures, and faster decision-making processes [15-18].

Research specifically focused on the digital transformation of small manufacturing companies is still very limited. The studies [20, 21] suggest that small businesses face significant challenges in adopting Industry 4.0 technologies, including a lack of skilled workers, limited access to finance and uncertainty

about return on investment. Furthermore, as stated in [22, 23], small businesses often lack a clear digital transformation strategy and tend to implement digital technologies ad hoc, without a systematic approach.

This situation creates a significant research gap: There is a lack of a comprehensive and empirically validated methodology to assess digital maturity and support digital transformation specifically designed for the needs and constraints of small manufacturing enterprises. This gap is particularly critical given the increasing pressure on small businesses to remain competitive in a rapidly digitizing industrial environment [24–26].

Our research focuses on filling this gap by introducing SBRI (Small Business Digital Maturity Assessment and Road to Industry 4.0), a new methodology designed specifically for small manufacturing businesses. SBRI offers a comprehensive framework for assessing digital maturity across five key dimensions: Strategy, Technology, Process, People, and Organization. Additionally, it provides a structured approach to continuous improvement and progressive implementation of Industry 4.0 concepts.

The objectives of this research are threefold:

- Develop and validate a comprehensive digital maturity assessment methodology tailored to the needs of small manufacturing enterprises.

- Empirically assess the current state of digital maturity of small manufacturing enterprises.

- Provide a structured approach to support the digital transformation of small businesses toward Industry 4.0.

The next parts of the article are structured as follows: Chapter 2 describes the methodology for the development and validation of SBRI. Chapter 3 presents the results of an empirical study conducted on a sample of 23 small manufacturing enterprises. Chapter 4 discusses the implications of our findings, compares them with the existing literature, specifies the limitations of the study, and suggests directions for future research. Chapter 5 summarizes the main contributions of the research.

2 Methodology

The development of the SBRI methodology was based on a multidisciplinary approach that combined rigorous scientific methods with practical industry insights. The process of developing and validating the methodology can be divided into the following key phases.

2.1 Systematic Literature Review

The first step was to conduct a state-of-the-art review of the existing literature on digital maturity as-

sessment models for Industry 4.0. This review included a comprehensive analysis of 56 models from 22 sources [7, 8, 23-42]. The review followed the methodology proposed by Tranfield et al. [47, 48] and Kitchenham et al. [49, 50], and was assessed using the study quality assessment method according to [49], using the DARE criteria (Database of Abstracts of Reviews of Effects Reviews) [51] and PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) quality standards [52]. This systematic approach ensured a thorough and transparent analysis and evaluation of existing models and their limitations for the small business segment.

2.2 Identification of the Specificities of Small Enterprises

Based on the literature and empirical studies, the specifics of small enterprises in the engineering industry have been identified [15, 49-52]. This phase was crucial to ensure the relevance and applicability of the SBRI methodology for the target group of small manufacturing enterprises. The key specifics identified included limited financial resources, low organizational complexity, fast decision-making processes, and high flexibility.

2.3 Draft Structure of the SBRI Methodology

Based on the findings of the previous phases, the structure of the SBRI methodology was proposed. In designing the structure, the principles of the system approach and the CMMI (Capability Maturity Model Integration) framework were used [53-55]. This structure includes five key dimensions: Strategies, Technologies, Processes, People, and Organizations, which are further subdivided into 25 subdimensions. These dimensions were selected to provide a comprehensive view of the digital maturity of the enterprise (the scope and reach of digital transformation), while reflecting the specific needs and constraints of small enterprises.

The choice of dimensions was based on the following reasons:

- Strategy: Reflects the need for a clear vision and plan for digital transformation, which is often a weakness of small businesses [10, 11].

- Technology: Focuses on the adoption and use of digital technologies, a key aspect of Industry 4.0 [30–32, 41, 60].

- Processes: assesses the degree of digitization and optimization of processes, which is critical to increasing the efficiency of small businesses [43, 38].

- People: Takes into account the importance of human capital and digital competencies of employees [44, 45].

- Organization: Assesses the ability of the business to adapt to digital transformation and use data for innovation [10, 43].

2.4 Design of Digital Maturity Levels in the SBRI Methodology

Based on the findings of the previous phases and discussions with small business representatives, five levels of digital maturity of the enterprise were proposed: 0 (Digital Unaware), 1 (Digital Beginner), 2 (Digital Adopter), 3 (Digital Advancer), and 4 (Digital Transformed). These levels were designed to provide a clear path to incremental improvement while still being granular enough to capture the nuances of small business digital maturity.

2.5 Development of a Data Tool

For the practical application of the SBRI methodology, a data collection and processing tool in the form of an interactive data file in .xslx format (Microsoft Excel) was developed. This format was chosen because of its accessibility and ease of use for small enterprises without the need to invest in specialized software. In the offline .xlsx solution, the authors also considered companies' concerns about data misuse, especially in terms of security and privacy.

2.6 Empirical Validation

The SBRI methodology was validated through an empirical study involving 23 small manufacturing enterprises in the Czech Republic, during June and July of 2024. The companies were selected based on the following criteria:

- Company size: up to 65 employees.

- Activities in the engineering manufacturing sector according to CZ-NACE, Section C - Manufacturing [61].

- Different levels of progress in digital transformation.

2.7 Data Analysis and Iterative Improvement

Data obtained from the empirical study were analyzed using a combination of quantitative and qualitative methods. The quantitative analysis involved calculating the average levels of digital maturity for each dimension and subdimension. The qualitative analysis focused on the feedback from businesses on the applicability and relevance of the SBRI methodology. Based on this analysis and feedback, the SBRI methodology was iteratively refined to ensure its robustness, relevance, and practicality for small manufacturing enterprises.

3 Results

This chapter presents the key results of the empirical validation of the SBRI methodology, which was carried out on a sample of 23 small manufacturing enterprises in the Czech Republic.

3.1 Profile of the Enterprises Surveyed

The enterprises surveyed represented various sectors of the manufacturing industry, with a predominance in the sectors of metal structure manufacture and fabricated metal products (35%) and plastic products manufacture (35%), see in Fig. 1. The average number of employees in the enterprises surveyed was 32, with a range of 3 to 65 employees.
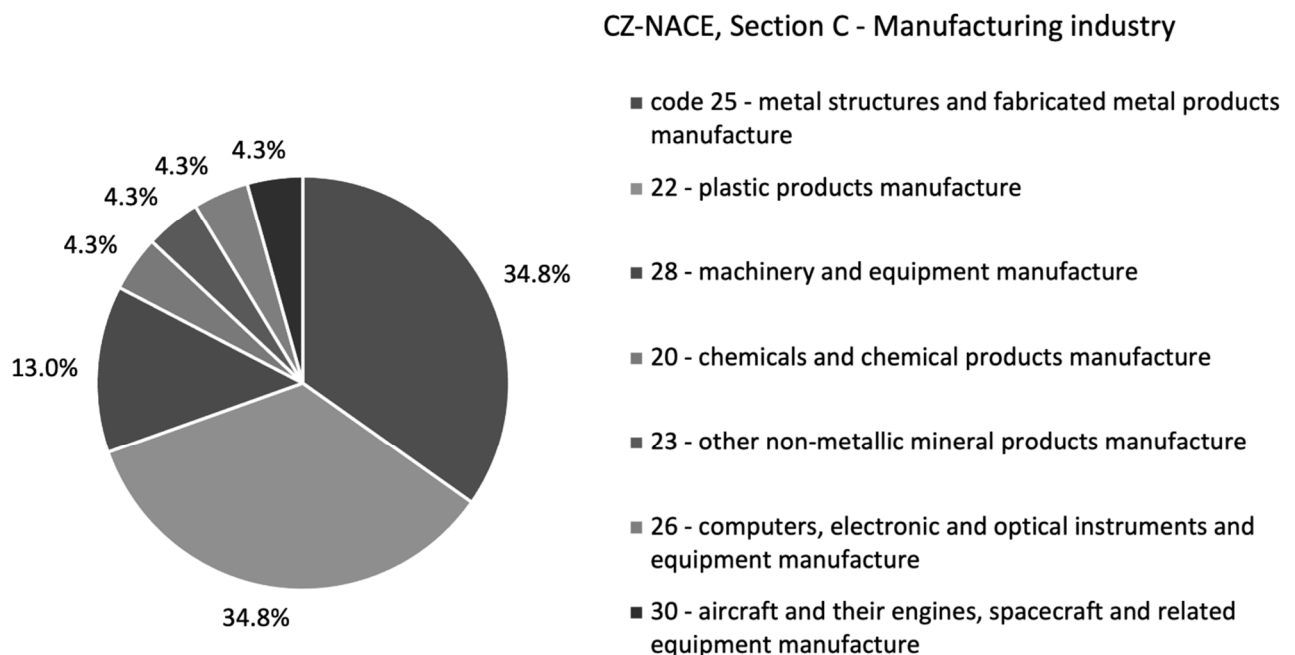

CZ-NACE, Section C - Manufacturing industry

- code 25 - metal structures and fabricated metal products manufacture
- 22 - plastic products manufacture
- 28 - machinery and equipment manufacture
- 20 - chemicals and chemical products manufacture
- 23 - other non-metallic mineral products manufacture
- 26 - computers, electronic and optical instruments and equipment manufacture
- 30 - aircraft and their engines, spacecraft and related equipment manufacture

***Fig. 1** Sectoral distribution of the respondents*

3.2 Overall Level of Digital Maturity

Data analysis revealed that the average level of digital maturity of the surveyed enterprises was 0.9 on a scale of 0 − 4. This finding suggests that most small manufacturing enterprises are in the early stages of digital transformation. The frequency of occurrence of the level of digital maturity achieved by the company is shown in the following figure.
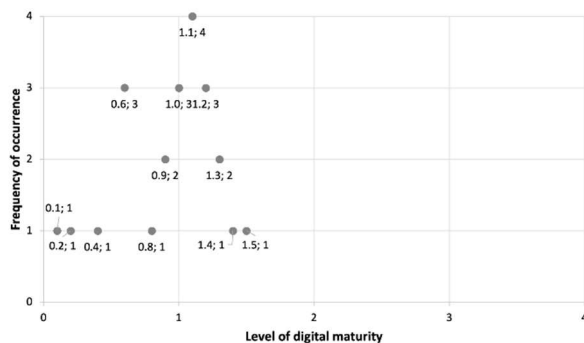

Fig. 2 *Frequency of occurrence of the achieved level of digital maturity of the enterprise*

3.3 Levels of Digital Maturity by Dimension

Analysis of the different dimensions of the SBRI methodology revealed significant differences in levels of digital maturity:

- D1: Strategy - average level 1.0;
- D2: Technology - average level 0.7;
- D3: Processes - average level 0.9;
- D4: People - average level 1.2;

- D5: Organization - average level 0.9.

These results suggest that small businesses have a relatively strong position in human resources and strategy, while the biggest challenges they face are in technology.
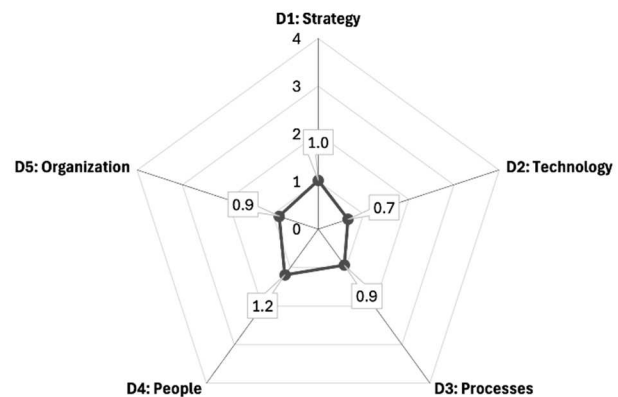

Fig. 3 *Radar chart visualizing the average values of the dimensions of the digital maturity profile of all respondents*

The following figure shows a real example of the visualization of the result of the self-assessment of the company, i.e. the values of all 5 dimensions and 25 subdimensions. The red square points indicate the subdimension level achieved. The green circle shows the level of digital maturity achieved by the entire company (1.2). The red dotted circle shows the average level of digital maturity of all enterprises assessed (0.9) in the validation study. The blue dotted circle shows the average level of digital maturity of the top 10% of enterprises (1.4).
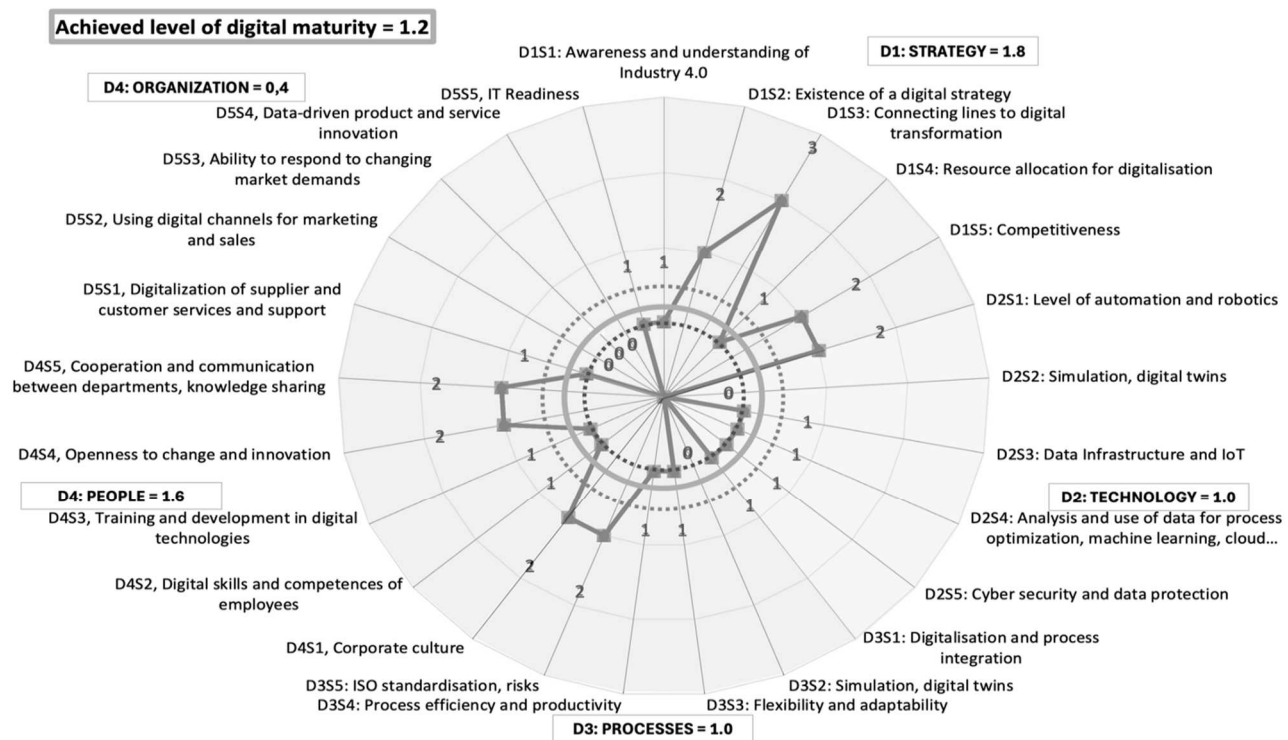

Fig. 4 *Radar chart visualizing a respondent's assessment of the digital maturity*

3.4 Detailed Analysis of Subdimensions

Analysis at the subdimension level has provided deeper insight into specific areas where small businesses excel or fall short.

The lowest average maturity level (0.3) was recorded in the subdimensions:

- D2S2: Simulation, digital twins;
- D2S4: Analysis and use of data for process optimization, machine learning, cloud computing.

In contrast, the highest average maturity level (1.5) was achieved in the subdimensions:

- D4S1: Company culture;
- D4S4: Openness to change and innovation.

3.5 Variation in Digital Maturity Levels

An analysis of the variance in digital maturity across businesses revealed considerable variability, illustrating the diversity of approaches to digital transformation in the small business segment. In the box plot in Fig. 5. the symbol "✕" with a bold number indicates the average value of the dataset (dimension level). The lower, or upper, part of the graphical "box" (rectangle) denotes the value of the lower, or upper, quartile. The lower or upper line on the vertical indicates the recorded minimum or maximum value of the data set.
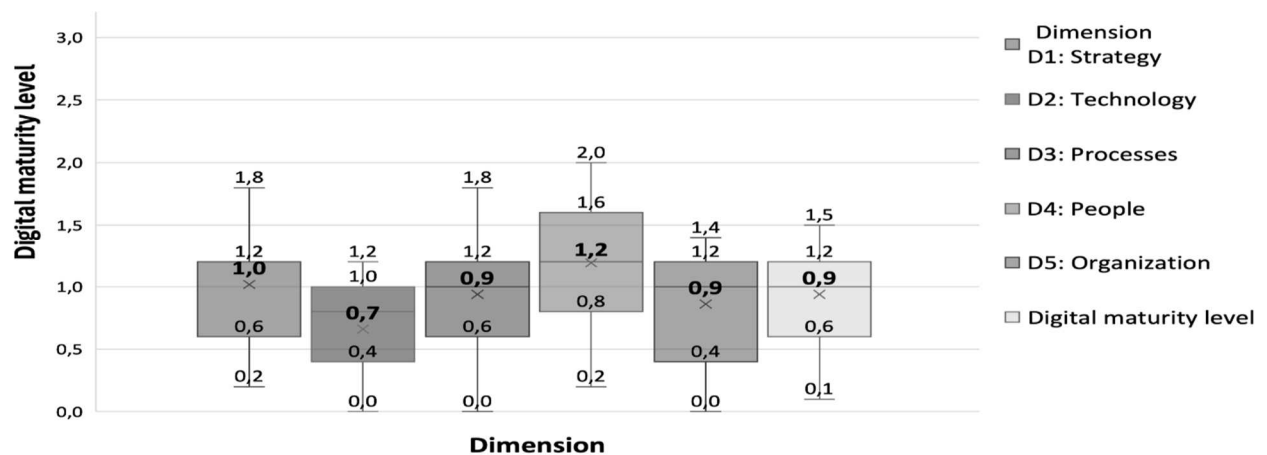

Fig. 5 *Characteristics of a set of digital maturity level values using quartiles*

3.6 Feedback from businesses

The qualitative analysis of the feedback from the study participants provided valuable information on the practical applicability of the SBRI methodology, captured in Tab. 1.

Tab. 1 *Feedback from respondents on the SBRI methodology*

	Area	Findings
1)	Time-consuming self-assessment questionnaire and evaluation process.	100 % compliant.
2)	Balance and completeness of dimensions and subdimensions.	96 % satisfactory, structured content, easy to navigate.
3)	Clarity and unambiguity of the description of levels.	96 % compliant.
4)	Practical applicability and clarity of the methodology and its ability to identify priority areas for improvement and guide the digital transformation of the business.	74 % yes, helped identify priorities.
5)	Relevance and meaningfulness of the results for the type of business, possible barriers to the implementation of the recommendations resulting from the methodology.	83 % relevant; The ability to simulate priorities is important; Barriers: workers' motivation and attitude towards innovation.
6)	Intention and motivation to reuse the methodology in the future.	39 % of the respondents confirmed their interest in actively using the methodology.
7)	Preference of the form of off-line file methodology vs. the cloud solution.	96 % prefer off-line.
8)	Need for an initial workshop and/or the services of an external consultant.	100 % not needed.
9)	Possible weaknesses and limitations, areas for improvement of the methodology before its widespread deployment.	Capabilities of the internal/external methodology holder and the changes he/she brings to the company with the methodology; Lack of competent human resources.

3.7 Cycle of continuous improvement of digital maturity

In the process of digital transformation of the enterprise and adoption of the Industry 4.0 concept, the main goal is to achieve and maintain the maximum value of maturity level (i.e. 4) in each dimension and subdimension. A general recommendation would be to strengthen weaknesses and continue to develop strengths. However, given the limited capabilities of small enterprises, improvement needs to be systematic, structured and consistent to effectively achieve the desired results. Based on the results of the empirical study and feedback from businesses, a "Digital Maturity Continuous Improvement Cycle" was developed. This cycle provides a structured approach to the implementation of Industry 4.0 concepts, and to the gradual and continuous (never ending) improvement of digital maturity. It will be implemented by the five steps in Fig. 6.
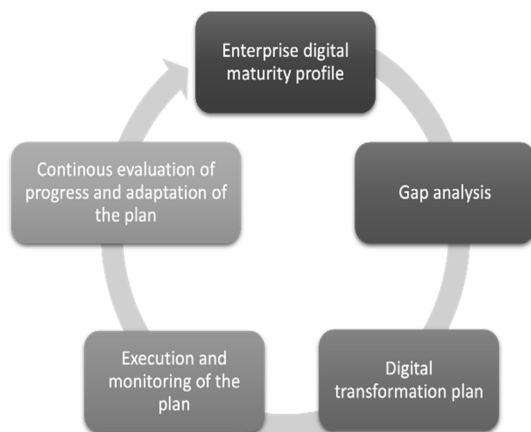

Fig. 6 *Cycle of continuous improvement of the digital maturity of the enterprise*

The above key results of the empirical validation of the SBRI methodology provide a comprehensive picture of the state of digital maturity of small manufacturing enterprises and demonstrate the practical applicability and relevance of the SBRI methodology. In the following section, these results will be discussed in the context of the existing literature and their implications for theory and practice.

4 Discussion

This chapter provides an in-depth analysis of the results of the SBRI methodology validation study, their interpretation in a broader context, and a discussion of the implications of these findings. Focuses on the validity and reliability of the methodology, comparisons with the existing literature, identification of study limitations, and suggestions for future research and development.

4.1 Interpretation of validation results and their implications for the validity and reliability of the SBRI methodology

The average level of enterprise digital maturity of 0.9 on a scale of 0 (digitally unaware) to 4 (digitally transformed) in the sample of 23 small businesses surveyed suggests that the majority of businesses surveyed are at the beginning of their digital transformation journey. This result is consistent with general expectations about the state of digitalization in the small business segment [10, 11, 18] and supports the validity of the methodology.

The validity of the methodology content is supported by positive feedback from respondents on the balance and completeness of dimensions and subdimensions. All respondents identified the content structure as satisfactory and easy to navigate, indicating that the SBRI methodology adequately covers relevant aspects of small business digital maturity.

The construct validity is demonstrated by the consistency of the results with the theoretical assumptions about digital maturity. For example, the lower score on dimension D2: Technology (0.7) compared to dimension D4: People (1.2) is consistent with the expectation that small businesses often face greater challenges in acquiring and adopting new technologies than in developing human resources [10, 31, 37, 45].

The practical applicability of the methodology is supported by positive feedback from respondents on its clarity and its ability to identify priority areas for improvement. The average time required to complete the questionnaire of 24 minutes is acceptable for small enterprises with limited time resources.

We conclude with an interesting note. Three enterprises (130, 220 and 620 employees) were excluded from the validation study due to exceeding the number of employees parameter. Their exclusion was methodologically correct, as it ensures the consistency of the sample for the analysis of small enterprises. However, they were evaluated using the SBRI methodology outside the study, and their results may provide additional interesting information. General insights from the evaluation of the excluded enterprises:

- The size of the enterprise can have a positive impact on digital maturity, but it is not the rule. Other factors such as industry, company culture, or strategy can play a significant role.

- Larger enterprises may tend to be more mature in the areas of strategy and human resources, perhaps due to greater capacity for strategic planning and employee development.

- Even larger enterprises can face significant challenges in certain dimensions of digital

transformation, particularly in the area of organizational adaptability.

- The feedback rated the SBRI as fully compliant in the areas of: balance and completeness of dimensions and subdimensions, clarity and explicitness of level descriptions, practical applicability, and ability to identify priority areas for improvement and direction of the digital transformation of the enterprise.

Therefore, the SBRI methodology appears to be applicable to medium and large enterprises, suggesting its potential for a wider applicability. These findings could be valuable for future research aimed at comparing digital maturity between different sizes of enterprises and for the potential adaptation of the SBRI methodology for a wider range of organizations.

4.2 Comparison of Results with the Existing Literature and other Digital Maturity Models

A direct comparison of the results of the SBRI methodology with the literature is difficult, as most studies do not provide specific data on the level of digital maturity of the individual enterprises assessed or categories of enterprises or deal only with large enterprises; see the literature search of the authors in Chapter 2.1 and [18, 21, 40, 62]. The resulting claim of our validation study, i.e. that most enterprises are at the beginning of their digital transformation journey, is in line with the findings of studies that provide qualitative assessments that SMEs generally lag behind large enterprises in the areas of digital transformation and implementation of Industry 4.0 technologies, which are still a major challenge for them and for which they are not sufficiently prepared [37, 40, 42, 45].

It is interesting to compare our results with the recent survey by the Czech Statistical Office on enterprise innovation activities in 2020-2022 [63] and the 2016-2018 survey [64]. For example, only 22% of enterprises stored their data in the cloud, 8% used industrial or service robots, 6% used 3D printing in production, and 3% used elements of artificial intelligence. This low rate of adoption of advanced technologies is consistent with our findings of low levels of maturity in dimension D2: Technology (0.7).

Comparison with the 56 digital maturity models studied shows that the SBRI provides a more comprehensive and detailed view of small business digital maturity, especially due to its structure of 5 dimensions and 25 subdimensions, adaptability, and the possibility of self-assessment without the need for external consultants.

4.3 Implications for Digital Transformation Theory

Our findings have several important implications for the theory of small business digital transformation:

- The multidimensional nature of digital maturity: The results support the view that digital maturity is a multidimensional construct that encompasses not only technological, but also organizational and human aspects [38, 43].

- The importance of strategy: The strong correlation between the dimensions of Strategy and People suggests that a successful digital transformation requires a clear strategy and investment in human resource development [10, 11].

- Nonlinear transformation process: The variation in maturity levels across dimensions suggests that digital transformation is not a linear process but can occur at different rates in different areas of the enterprise [42].

- Specificities of small businesses: The study confirms that small businesses face unique challenges in digital transformation, supporting the need for specific tools and approaches for this segment [11, 18].

4.4 Study Limitations and Directions for Future Research

Although this study provides valuable insights, it has several limitations that must be considered:

- Sample size: The sample of 23 small businesses, while providing important findings, is relatively small to generalize conclusions to the entire population of small businesses.

- Geographical limitation: The study was conducted only in the Czech Republic, which limits the possibility of generalizing the results to other countries or regions.

- Self-assessment: The self-assessment method can lead to a degree of subjectivity and potential over- or underestimation of the level of digital maturity.

- Lack of longitudinal data: The study provides only a cross-sectional view, lacking data on the evolution of digital maturity over time.

These limitations open several directions for future research:

- Conduct a larger study with a larger sample of enterprises to increase the statistical power and representativeness of the results.

- Extend the study to other countries or regions for international comparison and to

identify cultural or economic factors that affect digital maturity.

- A deeper analysis of the relationships between the different dimensions of digital maturity and their impact on overall business performance.

- Conduct a longitudinal study tracking the evolution of the digital maturity of enterprises over time and the factors influencing this evolution.

In conclusion, the SBRI methodology represents a significant step forward in our understanding of the digital maturity of small manufacturing enterprises. It provides a robust tool to assess and support digital transformation that takes into account the specific needs and constraints of this important segment of the economy. Future research should build on this foundation and further deepen our understanding of the digital transformation process in small companies.

5 Conclusions

This article introduces SBRI (Small Business Digital Maturity Assessment and Road to Industry 4.0), an innovative comprehensive methodology for assessing the digital maturity and supporting the digital transformation of small manufacturing enterprises in the context of Industry 4.0. The main contributions and conclusions of the research can be summarized in two areas:

5.1 Benefits to Science

- Extending theoretical knowledge: The research contributes significantly to the extension of theoretical knowledge in the field of digital transformation and Industry 4.0, with a specific focus on small enterprises. A comprehensive analysis of 56 existing models to assess digital maturity and their limitations for the small business segment provides valuable insights on the current state of knowledge and identifies key gaps in the literature.

- Identification of key dimensions: The research identifies and empirically validates five key dimensions of digital maturity relevant to small businesses: Strategy, Technology, Processes, People, Organization. This finding provides a valuable framework for future research on the digital transformation of small businesses.

- Developing a new methodology: The creation of the SBRI methodology represents an innovative approach to assessing the digital maturity of small businesses. This methodology combines insights from the existing literature with the practical needs, constraints, and specificities of small businesses to create a unique tool that bridges the gap between theory and practice.

- Empirical validation: A thorough validation of the SBRI methodology on a sample of 23 small enterprises provides empirical evidence of its validity and practical applicability. This validation process contributes to the robustness of scientific knowledge in the field of digital maturity assessment.

- Methodological benefit: The use of a combination of quantitative and qualitative methods in the development and validation of the SBRI methodology demonstrates an effective approach to digital transformation research that can be replicated in future studies.

- Identification of directions for future research: The article identifies several directions for future research, including the need for longitudinal studies, a deeper analysis of the relationships between different dimensions of digital maturity and their impact on company performance, and the need for international comparative studies.

5.2 Benefits to Industrial Practice

- A practical tool for small businesses: The SBRI methodology provides small businesses with an easy-to-use and time-efficient tool to self-assess their digital maturity. This allows businesses to better understand their current state and identify key areas for improvement.

- Strategic decision support: The results of the SBRI methodology help small business managers make informed decisions about investments in digital technologies and processes. This contributes to a more efficient allocation of scarce resources.

- Continuous Improvement: The proposed "Enterprise Digital Maturity Continuous Im

provement Cycle" provides a structured approach to the long-term development of a company's digital capabilities.

- Benchmarking: the SBRI methodology allows businesses to compare their digital maturity with other businesses in the sector, which can stimulate competitiveness and innovation.

- Supporting digital transformation: The use of the SBRI methodology can accelerate the digital transformation process in small businesses, which can lead to increased competitiveness in the context of Industry 4.0.

- Identification of specific challenges: The research identifies specific challenges faced by small businesses in the digital transformation process, which can help technology providers, consulting firms, policy makers and supporting private and public organizations to better tailor their services to the needs of this segment.

The SBRI methodology represents a significant step forward in understanding and supporting the digital transformation of small manufacturing businesses. It provides a robust tool for assessing digital maturity and offers a structured approach to implementing Industry 4.0 principles in this critical segment of the economy.

The results of our study highlight the need for further research and development in the area of digital transformation of small businesses, especially with regard to long-term impacts, international comparisons, and the relationship between digital maturity and company performance. They also point to the need to develop adaptive digital transformation strategies that take into account the specific needs and constraints of small businesses.

As the global economy becomes more digital, the role of small businesses in the adoption of Industry 4.0 technologies will become increasingly important. The SBRI methodology and the findings of this study can serve as a starting point for policy makers, technology providers, and businesses themselves in their efforts to successfully navigate the digital transformation era.

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