Article

Maturity Model for the Manufacturing Industry with Case Experiences

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Received: 28 May 2024; Revised: 11 July 2024; Accepted: 14 August 2024; Available online: 19 August 2024

ABSTRACT: This manuscript describes the research path when extending a maturity model. The initial model—ManuMaturity—was for manufacturing companies aiming beyond Industry 4.0. The extended OSME model covers data sharing within a supply chain, an open innovation ecosystem and sustainable manufacturing. The OSME maturity model has five maturity levels: traditional factory, modern factory, agile factory, agile cognitive factory and agile cognitive industry and seven dimensions (such as infrastructure, data, customer, business model, employee, sustainability and processes). The tool was experimented with in manufacturing companies on two occasions: with a set of manufacturing companies and a group of companies. In both cases, feedback was gathered from the respondents. The article follows the maturity assessment development phases such as scope, design, populate, test, deploy and maintain, and reports the software implementation of the maturity tool. With the help of the developed maturity model and the tool, it was possible to make assessments in case companies, where the tool and its results were commented mostly positively. The tool can be applied in various ways. For example, a group of people can jointly submit their common understanding and have a thorough discussion or a group of company representatives submit their responses and the variation is discussed afterwards.

Keywords: Manufacturing industry; Maturity model; Sustainable manufacturing; Data sharing; Ecosystem; Supply chain

1. Introduction

In addition to potential new business possibilities, digital transformation (DT) also generates challenges for manufacturing companies. Aside from manufacturing skills, these companies must learn new capabilities while integrating physical objects, human actors, intelligent machines, production lines and processes across the organisation [1] and simultaneously considering product servitisation, business model innovations and supply chains [2]. Even without the challenges of the external world and the phenomenon that appears at an accelerating pace, the transformation is challenging. Manufacturing SMEs struggle with resource constraints and knowledge gaps that slow down their digitalisation efforts and investments. The main challenges and barriers to overcome are limited understanding, insufficient resources and gaps in deploying digital solutions in practice [3,4].

Although sustainability has three pillars (economic, environmental and social), the majority of the activities considered in the manufacturing industry still pay attention purely to the economic goals [5]. The ongoing climate change has put the environmental aspects and circular economy (CE) in focus. Companies are pursuing a CE by implementing new R-cycles such as reuse, repair and remanufacture, aiming for even zero defects [6]. Companies have also discovered that collaboration is a new way of working. To enable this, data management rules and platforms for securing private data and sharing federated data with trusted partners are required [7–9]. Data sharing between business-to-business partners is a key enabler for sustainable manufacturing [10].

The twin transition combines digitalisation and green transition and creates a green, digital and resilient economy as digital technologies enable the circular strategies of the manufacturing industry [11]. The positive impacts on the sustainability of manufacturing can be achieved by (i) increasing data sharing and the use of artificial intelligence (AI), (ii) using digital products and services, instead of physical products, as much as possible (digital twins, simulations, etc.), (iii) exploiting information and communication technology (ICT) solutions for energy and material consumption

https://doi.org/10.35534/ism.2024.10010

optimisation, and (iv) developing (and applying) sustainability tools and methods [5,12]. The key elements of sustainable manufacturing are non-polluting processes, closed loops for energy and resources, and safety for employees, communities, and consumers on top of the profitability goals [13,14]. Occupational safety and human well-being bring in the concept of Operator 4.0 [15].

In recent years, several maturity models (MM) have been published by both consultancies and academies for various topics, such as digitalisation and Industry 4.0. Even the EU created a digital maturity assessment tool to evaluate the progress of digitalisation before and after interaction with European Digital Innovation Hubs [16]. Manufacturing companies need three skills to proceed with DT: awareness, informed decision-making and rapid implementation [17]. A good MM (with a tool) can support building awareness.

Our ManuMaturity tool [18] was developed to accelerate the Finnish manufacturing industry towards Industry 4.0 [2] or even beyond [19] in 2019. In 2020, Industry 4.0 was not the major goal for the manufacturing industry. It must consider openness and data sharing within the supply chain, employees and sustainability. This manuscript reports on how the tool was extended and experimented together with a Finnish manufacturing ecosystem. The extended MM tool was nominated as the OSME maturity tool, according to the project (Open Smart Manufacturing Ecosystem [1]) where the extension took place.

2. Related Research

2.1. Maturity Models

MMs have a long history, with academies, alliances, and consultancies regularly publishing their work. These institutions have also developed and published many models that have been applied to various topics [20]. For DT only, dozens of MMs are available from both practitioners and academies [21,22]. There are also MMs for business processes [23,24] and information security [25]. MMs dedicated to manufacturing companies or Industry 4.0 [2] and beyond [19] are discussed in the next chapter.

2.2. Maturity Models for Manufacturing Companies

Wendler systematically studied the maturity of MM research with more than 200 articles and found that 46% of the articles focused on model development, 35% presented a model application, and only 14% focused on model validation. Thus, there seems to be a gap in evaluating and validating the developed MMs [26]. According to another study, when 15 published MMs of the smart manufacturing or journey towards Industry 4.0 were analysed, three research gaps were identified: (i) differences in the starting conditions between SMEs and original equipment manufacturers (OEMs) regarding Industry 4.0 or smart manufacturing, (ii) disconnection between the MM and the self-assessment tools and (iii) support (especially tailored for SMEs) to propose the next steps after maturity assessment is missing [27].

Another systematic literature review on MMs against Industry 4.0 elements (human-centred design, resiliency and sustainability) also evaluated dimensions: technology, employees, data, organisation and processes, strategy and management, products and services, corporate environment, customer, and corporate culture [28]. In another study, 15 dimensions—organisational strategy, smart factory, smart operation, smart product, vertical integration, horizontal integration, employees, leadership, customers, culture, governance, technology, data-driven governance, IT infrastructure and information systems—were identified from 16 MMs [29].

Sustainability is an emerging topic, and the manufacturing industry shall proceed with the twin transition, i.e., enhance their environmental and economic sustainability via implementing new digital solutions and R-cycles, such as reuse, repair and recycle [30]. An MM for CE proposes maturity levels, such as (i) linearity, (ii) industrial CE piloting, (iii) systemic materials management, (iv) CE thinking and (v) circularity, and maps them to the manufacturing value chain [31,32]. A systematic literature review [33] explored 16 CE MM, among which only one focused on manufacturing companies [34], another was dedicated to remanufacturing [35], and a third was on the material flow in the supply chain. In addition to CE MMs, several tools are available. For example, the Ellen MacArthur Foundation introduced a CE measurement tool, Circulytics, in 2020. It supports a company's transition towards the CE, regardless of industry, complexity and size [36].

Further, innovation management needs to be considered. Companies are gradually ready to work together when they realise that the industry's challenges require a wide range of skills and technologies that a small company alone cannot provide. Collaboration and co-creation are easier to start with trusted partners who have already worked with a project, community, or ecosystem. There are also MMs for ecosystems, innovation ecosystems [37,38], innovation ecosystem strategies [39], software ecosystems [40] and software start-up ecosystems [41], to mention a few. The continuous flow of new MMs for manufacturing or Industry 4.0 seems not to diminish, although new viewpoints, such as green suppliers [42], appear. MM can even be exploited for proactive skill development in the context of DT [43] and data value management capabilities [44]. In addition, industry-specific models are needed, as a systematic literature review found 19 Industry 4.0 MMs that did not fit into the oil and gas upstream industry [45].

To boost the development and digitalisation of the manufacturing industry, academies, industrial alliances and consultancies have provided various tools and models. In 2019, researchers reported on 10 academic Industry 4.0 MMs and 10 consultancies [46]. Several other maturity tools have been developed for Industry 4.0 and the manufacturing industry [47,48]. Before creating an MM for digital twins in the battery cell industry, Schabany et al. [49] analysed 767 papers and found four features relevant to any MM. Table 1 carries several examples of academic MMs having either clear dimensions and maturity levels or other highlighted features suitable for manufacturing companies. Alliances (e.g., ADMA, BDO, EDB Singapore and VDMA) and consultancies (e.g., Deloitte Consulting, Frost & Sullivan, IXON and PWC) have also created MMs for the manufacturing industry or Industry 4.0. [18].

Table 1. Academic MMs related to manufacturing industry or Industry x.0 (in alphabetic order) updated from [18].

Title and Source	Dimensions	Maturity Levels	Notes on Tool or Results
The ECO Maturity Model—A human-centred Industry 4.0 maturity model [50]	Environment, competence, operability	Not implemented, partially implemented, fully implemented	Excel-based tool
A review of Industry 4.0 maturity models: adoption of SMEs in the manufacturing and logistics sectors [51]	Smart manufacturing, product development, technological infrastructure, performance evaluation, employee participation, smart supply chain and logistics, digitisation	In 2024, they propose five levels: absence, beginner, existence, survival and maturity [29]	
A maturity assessment approach for conceiving context-specific roadmaps in the Industry 4.0 era [52]	Governance, technology, connectivity, value creation, competence	None, basic, transparent, aware, anonymous and integrated	Piloted within a large Danish manufacturing company [53]. Three industrial cases [52]
A multicriteria model for assessing maturity in Industry 4.0 context [54]	Strategy and innovation, technology and processes, sustainability, people, leadership	Non-existent, basic, intermediate, experienced, specialist and convergent	
Industry 4.0 technologies: Implementation patterns in manufacturing companies [55].	Four digitalisation domains in manufacturing companies: smart manufacturing, smart products, smart working, and smart supply chain	Adaptation levels of technologies: low adapters, moderate adopters and advanced adopters	
Three-stage maturity model in SMEs towards Industry 4.0 [1]	Three Industry 4.0 development stages are exploited as dimensions: envision, enable and enact	Initial, managed, defined, transformed, and detailed BM	Developed for Basque SMEs
A maturity model for assessing the digital readiness of manufacturing companies [56]	Key processes such as design and engineering, production management, quality management, maintenance management and logistics management	Initial, managed, defined, integrated and interoperable, digital-oriented	Evolutionary phases of maturity models are descriptive (as-is), prescriptive (aiming for improvements) and comparative (benchmarking).
A framework for Industry 4.0 readiness and maturity of smart manufacturing enterprises: a case study [57]	Four dimensions: Factory 4.0., Logistics 4.0, Operator 4.0 and Management 4.0, having 60 second-level dimensions and 246 subdimensions	Outsider, beginner, intermediate, experienced, top performed	The weighting factor included gaps calculated between the current and desired state. Case study with a large automobile parts manufacturing enterprise in Turkey
Industrie 4.0 roadmap: a framework for digital transformation based on the concepts of capability maturity and alignment [58]	Technology, organisation and process	No Industrie 4.0 or only "ad-hoc", departmental level (isolated silos), organisational level (cross-departmental) and inter-organisational level (cross value chain/supply chain partners)	Describes the roadmap process
Investigation on the acceptance of an Industry 4.0 maturity model and improvement possibilities [59]	Data, intelligence, and digital transformation	Ten levels (even 11, if zero is counted)	Web-based application
Toward the development of a maturity model for digitalisation within the manufacturing industry's supply chain [60]	Strategy development, offering to the customer, a "smart" product, complementary IT system, cooperation, structural organisation, process organisation, competencies and innovation culture	Digitalisation awareness, smart networked products, service-oriented enterprise, thinking in service systems and data-driven enterprise	In addition to the dimensions and maturity levels, the model has two domains: smart product realisation and application

Model to evaluate Industry 4.0 readiness level in industrial companies [61]	52 statements from the SAE J4000 standard associated with one Industry 4.0–enabling technology, such as collaborative robots, additive manufacturing, augmented reality, simulation, system integration, internet of things, cloud computing, cyber security or big data	Not present, present, fully present and implemented, and effectively implemented	
Developing a green supplier maturity model: concepts, application and limits [42]	Organisational structure, processes, technology, control, collaboration, human resources, and planning	They list the maturity levels of five separate models but do not declare their levels	Focus on green supply
Energy and utility management maturity model for sustainable manufacturing process [62]	Energy and utility management	Common maturity levels, such as initial, managed, defined, quantitatively managed, and optimised, are mapped with maturation process stages: energy and utility management practice establishment, standardisation, performance management and continuous improvement	It may be the first MM considering the sustainability of manufacturing. Applied to a Chinese textile manufacturing company. Eleven executives from separate companies were interviewed
Industry 4.0 readiness in manufacturing: Company Compass 2.0, a renewed framework and solution for Industry 4.0 maturity assessment [63]	Physical world, virtual world, human, strategy and culture, products and services, value chain, and environment	Each dimension has five unique intervention points	
Comprehensive lean manufacturing maturity model [64]	Leadership, people, process and results	Informal implementation, standardisation of implementation, system implementation, continuous improvement, and best-in-class implementation	Claims to have case studies, but company cases are not described
Assessing the maturity and benefits of the digital extended enterprise. Modelling of digital extended enterprises [65]	Three key performance areas (KPA) with open questions. Domains include strategy, business model, and processes; performance indicators, interfaces and information flow	Non-existent individuals, teams, and company extended enterprise	UI for the questionnaire has been implemented and the results can be visualised. The MM comprises five levels of maturity, defined by 69 statements in the KPAs. Four industrial cases were repeated twice
An Industry 4.0 maturity model for machine tool companies [66]	Smart products, smart operations, data driven, smart factory, strategy and organisation, employee	Outsider, beginner, intermediate, experienced, expert and top performer	Both the current level and target
DigiMove analysis for manufacturing SMEs to identify their current status and next digitalisation steps [67]	Manufacturing, products and services, digital skills of production staff, foresight, customer interface, and administrative functions	General, improved, advanced, forerunner and future opportunity	Applied with 43 manufacturing SMEs in Finland. Digitalisation has a positive correlation with business results
Development of a maturity assessment model for digital twins in the battery cell industry [49]	Data quality, data preprocessing, data acquisition and aggregation, autonomy, hardware connection and connectivity, external communication, IT security, digital twin models, operational analysis	Not reported	Maturity model tailored to digital twins in the battery cell manufacturing industry

	capabilities, IT integration and implementation, operational business level, and metalevel		
Industrie 4.0 Maturity Index—Managing the digital transformation of companies [68]	Resources, information systems, organisational structure, and culture	Stages in the Industrie 4.0 development path: computerisation, connectivity, visibility, transparency, predictive capacity, and adaptability	
Development of a digital maturity model for Industry 4.0 based on the technology–organisation–environment framework [69]	50 interview questions for 12 axes in the three dimensions: technology, organisation and environment	Digitisation, communication, visibility, transparency, predictability, and flexibility/adaptability	
A maturity model for evaluating the impact of Industry 4.0 technologies and principles in SMEs [70]	Service orientation, interoperability, modularity, decentralisation, virtualisation, and real-time capability	Internet of things, internet of services, cloud computing, big data analytics, augmented and virtual reality, autonomous robots, cybersecurity, additive manufacturing, digital twin	Maturity tool for digital technologies enabling Industry 4.0. Both as-is and to-be assessments
Roadmapping towards industrial digitalisation based on an Industry 4.0 maturity model for manufacturing enterprises [71]	Technology, products, customers and partners, value creation process, data & information, corporate standards, employees, and strategy and leadership	Four maturity levels	Tool for questions with Likert scale and weighting factor was piloted with an Australian manufacturing enterprise. A radar chart for result visualisation
A pilot study: an assessment of manufacturing SMEs using a new Industry 4.0 maturity model for manufacturing small- and middle-sized Enterprises [72]	Strategy, value chain, organisation, human resources, technology	Five, not identified	Subdimensions have weights that are summarised on the dimension level. Pilot with nine manufacturing companies
A maturity model to assess digital employee competencies in industrial enterprises [73]	Digital content, human-machine, human-human and personal	Four levels, where 1st is lack and 4th is completed development. The numeric zero stands for no need	Both maturity level and relevance are assessed. Radar graphs are drawn
M2DDM—A maturity model for data-driven manufacturing [74]	Data storage and computing, service-oriented architecture, information integration, digital twin, advanced analytics, and real-time capabilities	Non-existent IT integration, data and system integration (between three levels: manufacturing, manufacturing control and enterprise control level), integration of cross-life cycle data, service orientation, digital twin and self-optimising factory	Maps three reference architectures, including Reference Architecture Model Industrie 4.0 (RAMI)

3. Research Design

Many MMs have been developed and are widely applied in various industrial contexts. However, their construction and testing must be rigorous and result in practical solutions for industrial use. To support this, approaches have been reported to support model development [75–77]. In our research, we have followed the maturity model development approach defined by de Bruin et al. [75]. This model was already selected for use in the first phase of the research [18]. The widely used model offers easy-to-understand steps while enabling systematic maturity model development. It also allows incremental improvements to be made over time to the model and tool (Figure 1).

Figure 1. Maturity model development phases.

The development and testing of the extended MM and tool were done in two iterations. The first iteration covered the definition, implementation and testing of our original model and tool (called ManuMaturity). The model and tool were intended to help manufacturing companies proceed in digitalisation, reach Industry 4.0 or even go beyond it [78]. The ManuMaturity model and tool were tested in an industrial setting [18]. The study revealed the concepts of sustainability [13,14], employee [15] and data sharing [7–10]. They eed to be included in the model and tool. This triggered the development of the next iteration of the model and tool.

This article reports the research carried out in the 2nd iteration. Table 2 illustrates the actions performed, techniques used and output for each development phase, extending the ManuMaturity model and tool to cover sustainability, innovation ecosystem and data-sharing components identified as important additional components of the model. In the development of the extended MM and the tool (nominated as OSME maturity tool), we applied the maturity model development approach defined by de Bruin et al. [62], which led to the following research question:

How can the maturity model development process be followed when extending a maturity model with features like data sharing, open innovation ecosystem and sustainability?

The purpose of the model and tool is to support "as-is analysis" to provide a diagnostics tool to describe the company's current state (descriptive) and, later on, enable a comparative analysis with different sizes or domains of manufacturing companies when sufficient data has been collected. Indeed, it has been indicated that MMs are in their first phase, which is descriptive, then prescriptive and finally evolve towards a comparative purpose [56].

The model development process was assisted by both practitioners and academia. Practitioners comprise the manufacturing and IT companies in the Open Smart Manufacturing Ecosystem (OSME) project [1]. Academics are represented by the selected research scientists of one research institute. The new scope of the model and tool affected meant that there was a need to include experts in data sharing, innovation ecosystems, sustainability and employee viewpoints in model development.

The model and tool are primarily intended for company executives and management to understand the company's current state and to identify possible paths to improvement in the future (targeted audience). The model and tool should enable self-assessment and third-party–supported analysis (method of application). The respondents of the model application are representatives of different employee groups related to the company's manufacturing process covering the model's new scope such as manufacturing managers, procurement, quality, information management, and sustainability. The model architecture was the same as in the first iteration [18], including sectors, dimensions, question areas and five maturity levels. The logic of how the assessment happens was similar to the ManuMaturity model and tool, i.e., question areas were formulated as questions with response alternatives reflecting each maturity level. The respondent chooses the most descriptive response from the set of five alternatives.

Table 2. Research approach as the matrix of MM development method model [75] as columns and procedures [79] as rows.

	Scope	Design	Populate	Test	Deploy	Maintain
Performed activities	Defining the focus and purpose of the model Identifying stakeholders who can contribute to model development	Identification of targeted audience and method of application The driver of the application, respondent groups and the structure of the model were defined.	Defining what to measure and how to measure it	Testing the model and instrumenting the tool Make the model and tool available to other companies.	Create a lifecycle plan to define maintenance responsibilities and resources. Communicate and market the model/tool for feeding the tool to new respondents.	Maintaining the model and tool
Used techniques	Literature review: updating MMs related to (i) manufacturing industry or Industry x.0, (ii) sustainability, (iii) innovation ecosystem, and (iv) data sharing ManuMaturity analysis for five manufacturing companies [18]	The results of the literature review were utilised in the design phase.	The literature review results were utilised to define question areas and questions. Expert interviews (academia five and practitioners two) were utilised to modify and validate question areas and questions.	Case studies with five manufacturing companies: responding to maturity tool, follow-up results meeting with four companies (results and experiences). Expert interviews (two IT houses) The same researchers (two) are used in every industrial case, i.e., result and feedback discussions.	Case study in one manufacturing company group: response to maturity tool, follow-up results meeting for results and experiences.	Operation according to the lifecycle plan
Output	Focus: manufacturing domain, beyond Industry 4.0, towards data sharing within a supply chain, to an open innovation ecosystem and towards sustainable manufacturing Purpose: as-is analysis, to-be support and enables comparative analysis Development stakeholders: academia and practitioners	Audience: Executives and management Method: self-assessment or 3rd party–supported assessment Driver: The model and tool are intended for companies to recognise the current state and identify potential improvement paths. Respondents: different employee groups related to manufacturing (with wide scope) in the company Structure: same as in ManuMaturity but the content changes (question areas)	What and How: Renewed model with updated dimensions and question areas New questions and their response options to measure question areas Response options are mapped with maturity levels having numeric values from 0 to 4. Each question and response option can be traced to its source (literature or expert) Implementation of the tool (dimensions, questions of question areas, reporting), including registration with meta-data to allow comparative analysis	Testing the model and instrument: The model was reviewed by domain experts. 12 maturity assessments were received from four companies. In the follow-up meetings, the respondents commented on tool structure, functionality and ease of use in addition to the perceived completeness of the model and questions. The discussions were recorded.	Lifecycle plan Public web page 24 maturity assessments were received from the case company group. In the follow-up meetings, the respondents commented on tool structure, functionality and ease of use in addition to the perceived completeness of the model and questions.	
Relation to paper	Introduction (Section 1) Related research (Section 2) Research design (section 3)	Related research (Section 2) Research design (Section 3) Results (Section 4.2)	Related research (Section 2) Research design (Section 3) Results (Section 4.2)	Research design (Section 3.1) Results (Section 4.3)	Research design (Section 3.2) Results (Section 4.4) Discussion and future research (Section 5)	Discussion and future research (Section 5)

The new scope heavily impacted the model details; therefore, the population phase required much work and calendar time. The scope and design phase of the maturity model process was more straightforward since the second iteration was based on the ManuMaturity model and tool, and there were just a few changes in the overall design. The population phase focuses on the questions of what to measure and how. The literature review results were utilised to iteratively generate an updated model [75] considering sustainability, innovation ecosystem and data sharing–related maturity model literature. The OSME MM contained dimensions, question areas (questions) and response alternatives organised according to the MM principles. The updated model with dimensions, questions and response alternatives was presented and discussed thoroughly in expert interviews with both research scientists (academia) and practitioners. Five senior scientists–high-level experts with wide industrial experience representing manufacturing (1 person), data sharing (2 persons), innovation ecosystems (1 person) and sustainability (1 person)–were interviewed and workshopped with. All experts could also comment on the whole model from the manufacturing industry's point of view, not just on their expert areas. Furthermore, two IT companies were interviewed about the model. They represented especially human/employee and data sharing aspects. Interviews were semi-structured; new or modified questions and response alternatives were presented in the interview and feedback and improvement proposals were gathered during the interviews. This process resulted in an extended version of the original model, the OSME MM.

The model's development reported that each question of the question area and response alternative can be traced back to its source, either literature or interviews. While formulating the response alternatives, the development steps of the manufacturing industry [3] were kept in mind. The practical measurement was implemented as a web-based tool guiding the respondent through background and actual maturity model questions. As a result, the respondent gets a report that indicates the respondent company's maturity level (dimensions and question areas) compared to the dimension averages of all respondents in the tool. Therefore, the respondent can compare their situation with the average of the other companies on a large scale.

After the model was populated with questions and their response alternatives, the model and tool were tested. The OSME MM and tool were tested in case studies in four manufacturing companies (see Section 3.1 for details). Companies were invited to respond to the OSME maturity tool. Follow-up meetings were arranged for each company. Two researchers facilitated all meetings. Meetings were recorded for research purposes. In these follow-up meetings, the company's results were presented and discussed. Furthermore, the respondents commented on tool structure, functionality and ease of use, as well as the perceived completeness of the model, with dimensions, questions and response alternatives.

In the deployment phase, the lifecycle plan for maintaining the tool was developed and the OSME maturity tool was integrated into the web portal, which introduces several tools for twin transition (in Finnish at TwinTransition.fi). This contributes to the tool's availability and continuous maintenance of the tool and the model. Bruin et al. [75] stated that it is likely that the initial application of the model will be with the stakeholders with whom the model has been developed and tested. Therefore, the tool was applied on a larger scale with one participating manufacturing corporation (5 subsidiaries) (see Section 3.2 for details). The research followed the same protocol as in the previous case. In this way, we gained insight into a larger group of respondents (24 respondents). This is the first and critical step when building acceptance. Until the model and tool have been deployed to entities independent of development and testing activities, generalisability will remain an open issue [75]. This further testing and feedback collection will be one of the future research activities.

3.1. Testing the OSME Maturity Model with Heterogeneous Companies

The OSME maturity model was piloted with five Finnish manufacturing companies from the OSME [1] project (Table 3). The responses were gathered from February to March 2023. A total of 12 responses were received from 5 companies. Four were original equipment manufacturers (OEM) and one was a small and medium-sized company (SME). The results and feedback sessions with four out of five companies took place from March to May 2023. Table 4 indicates the level of interest in the companies.

Table 3. Twelve responses were received from five Finnish manufacturing companies.

Company ID	Size	Responses	Industry Domain
A	OEM	2	27 Manufacture of electrical equipment
B	OEM	3	28 Manufacture of machinery and equipment
C	SME	5	25 Manufacture of fabricated metal products, except machinery and equipment
D	OEM	1	28 Manufacture of machinery and equipment
E	OEM	1	28 Manufacture of machinery and equipment
5		12	

Table 4. The results and feedback session took place between March and May 2023.

Company ID	Senior Manager	Middle Manager	Expert	Total	Date
A		1	1	2	31 March 2023
B	1	2		3	30 March 2023
C	2	1		3	5 May 2023
D	1	2		3	29 March 2023
4 companies	4	6	1	11	4 sessions

3.2. Deployment with a Group of More Homogeneous Companies

Company C—a corporation with 5 subsidiaries—expressed their willingness to repeat the maturity analysis within their group of companies on a larger scale. During the second round, we received 24 responses from Company C (5 subsidiaries) in June 2023 (Table 5). The results were delivered in August, but the feedback session was delayed until 17 October. Four managers attended the feedback session, all representing senior manager roles. It was agreed that a similar analysis and session would be arranged in autumn 2024 to see how the situation has improved in companies. Company C is an SME in the industry domain, which is "Manufacture of fabricated metal products, except machinery and equipment," as indicated in Table 3.

Table 5. Twenty-four responses were received from the case company group (corporation) having four subsidiaries.

Company ID	Responses
C company group	2
CS1 Subsidiary 1	2
CS2 Subsidiary 2	4
CS3 Subsidiary 3	10
CS4 Subsidiary 4	6
5	24

4. Results

The results are expressed in the maturity tool development phases: model development, tool implementation or instrumentation, test and deployment [75]. Thus, the next subtitles carry the model development phase in brackets.

4.1. Extension of ManuMaturity (Model Development)

The maturity model presented in this paper was built on the ManuMaturity tool [18,78]. The ManuMaturity model was designed with seven dimensions in three sectors (Figure 2). The (grey) dimensions of sustainability and employee contributed to the responsibility sector. Further, the dimensions of infrastructure and data together discovered the viewpoints of the (blue) technology sector. Finally, the (red) business sector had two dimensions: business model and customer. The process dimension interacted with all three sectors and was drawn around the other six dimensions [18].

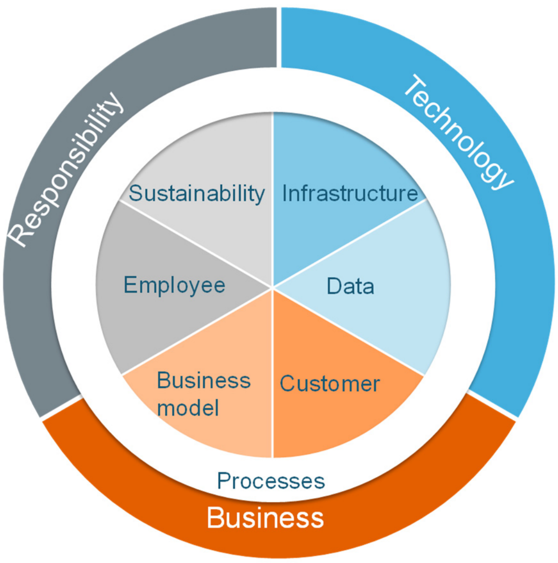

Figure 2. The sectors and dimensions of ManuMaturity.

The ManuMaturity model had five maturity levels: (i) traditional factory, (ii) modern factory, (iii) agile factory, (iv) agile cognitive factory and (v) agile cognitive industry [18]. Our initial hypothesis was to add new dimensions covering the "ecosystemic way of working" and federated data sharing. When looking into the existing maturity model, we found that the ecosystemic way of working was already embedded into the maturity levels. The federated data shading was implemented with one additional question (supply chain data management) in the data dimension and another (openness for collaboration) in the business model dimension. In addition to openness to collaboration, the business model dimension was enhanced with new questions, such as resiliency and foresight. The old dimension of the employee was enriched with several relevant question areas that contributed to the human-centric Industry 5.0 approach and renamed as employee and culture. The new questions relate to monitoring work(ing hours), teamwork, attitude to global challenges, well-being and learning and development programmes. One employee-related question (occupational safety) was replaced in the processes dimension, together with quality. Figure 3 displays the additions and modifications made for the OSME MM and Table 6 the actual questions for each dimension.

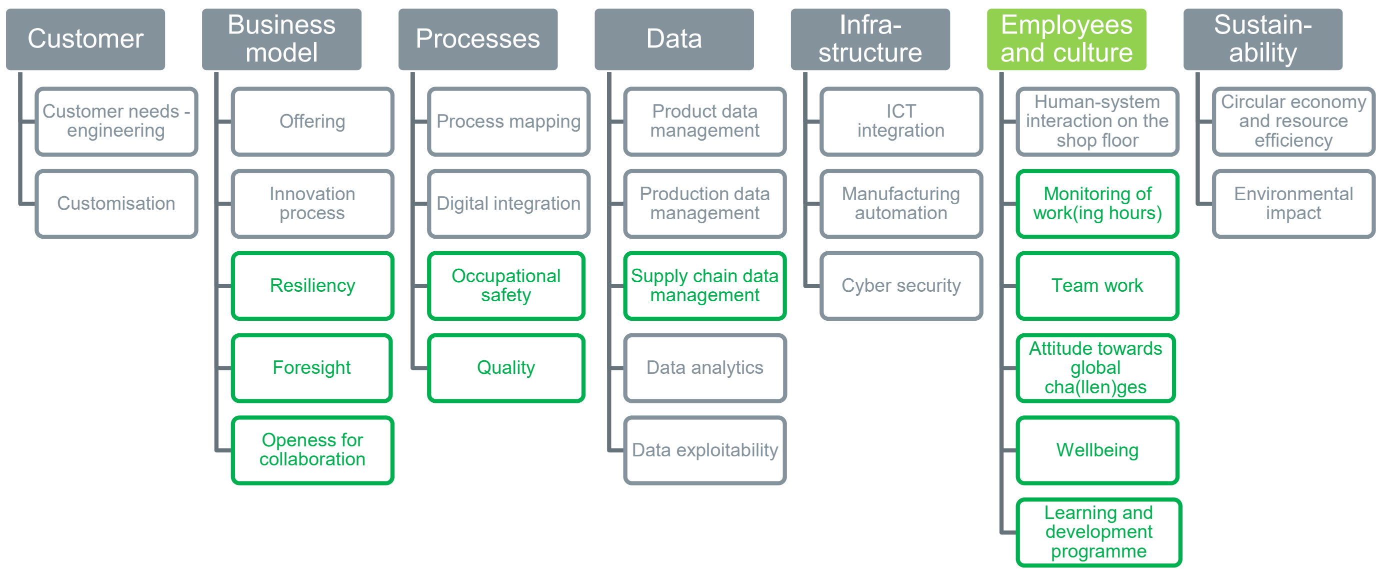

Figure 3. The dimensions and question areas of the OSME maturity model.

Table 6. Dimensions and questions of the OSME MM.

Dimension	Question
Customer interface	How are customer needs and requirements gathered and exploited? How can products be customised?
Business model	What is your company selling? How are innovations mastered? How is resiliency considered? How are the potential external signals treated (scanned, interpreted or prospected)? What is the level of collaboration in the supply chain?
Processes	What is your organisation's status, definition, and implementation of processes? How is digitalisation exploited in the integration of processes? How is occupational safety guaranteed? How is product quality assured?
Data	How is product data collected and shared? How are production data collected and shared? How are supply chain data collected and shared? How is the data analysed? How is the exploitability of data ensured?
Infrastructure	How are order, product and production data handled? How is agile production enabled? How are systems, networks and programs protected from digital attacks?
Employee and culture	How do machines/systems interact with employees? How are work (ing hours) monitored? What is the role of teams on the factory floor? How do employees respond to global challenges or changes, e.g., digitalisation or sustainability? How is well-being supported? How is the continuous learning and development of employees supported?
Sustainability	How are resources used? How are environmental impacts considered?

4.2. Implementation of the OSME Maturity Model (Tool Implementation)

The OSME MM was deployed as a web application, i.e., full-stack software implementation. Figure 4. Maturity tool architecture shows the web architecture with the backend and frontend. The frontend was implemented as a web browser user interface (UI) with React JavaScript library [2], Material UI component library [3], i18next internationalisation framework [4] and Apollo Client [5]. The backend was implemented with Spring Framework [6] modules and the Netflix DGS Framework [7]. The backend utilises PostgreSQL [8] as a database. Communication between the frontend and the backend was deployed with GraphQL [9]. While localisation was done for Finnish and English languages, the maturity tool supports internationalisation, i.e., enabling adding more regions or languages. For identity and access management, including registration with customised maturity tool themes (i.e., background figure and stylesheet) and properties (i.e., additional registration input), Keycloak was utilised.

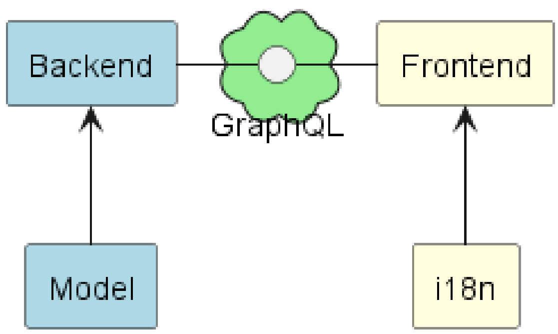

Figure 4. Maturity tool architecture.

When conducting the assessment, the respondent goes through several phases. Background information is asked to enable the use of the maturity tool. This is needed for data gathering and publishing the results after analysing the data so that the respondent cannot be identified. In the user registration phase, identification information is asked, i.e., username, password, first and last names, email address, telephone number, organisation, postal code and country. After logging in, in the background phase, additional information not required for the registration is asked for, i.e.,the respondent's position and represented function, headcount, turnover and domain of respondent's company. The 'statistical classification of economic activities' in the European Community, abbreviated as NACE rev. 2, [10] is utilised for the drop-down selection of the domain.

The maturity model is presented internally as JavaScript Object Notation (JSON), but to enable feasible editing of the model, the maturity model JSON can be generated from the document with a fixed structure produced with a word processor so that different parts required for forming the views of the UI can be identified. A separate document with the same structure but a different language is utilised for each desired localisation. Figure 5 shows a view of the questionnaire phase, i.e., the questions and response options (to choose from) of the customer interface dimension. The response options indicate a numeric value to enable the calculation of averages. The view consists of (i) a stepper that displays progress through a sequence, (ii) buttons for backward and forward navigation between views of the sequence, (iii) snack bars (also known as toasts) for brief notifications about unlocking the next view of the sequence, (iv) the name of the model, (v) dimension of the model as a list with questions as radio buttons and (vi) counter for required responses.

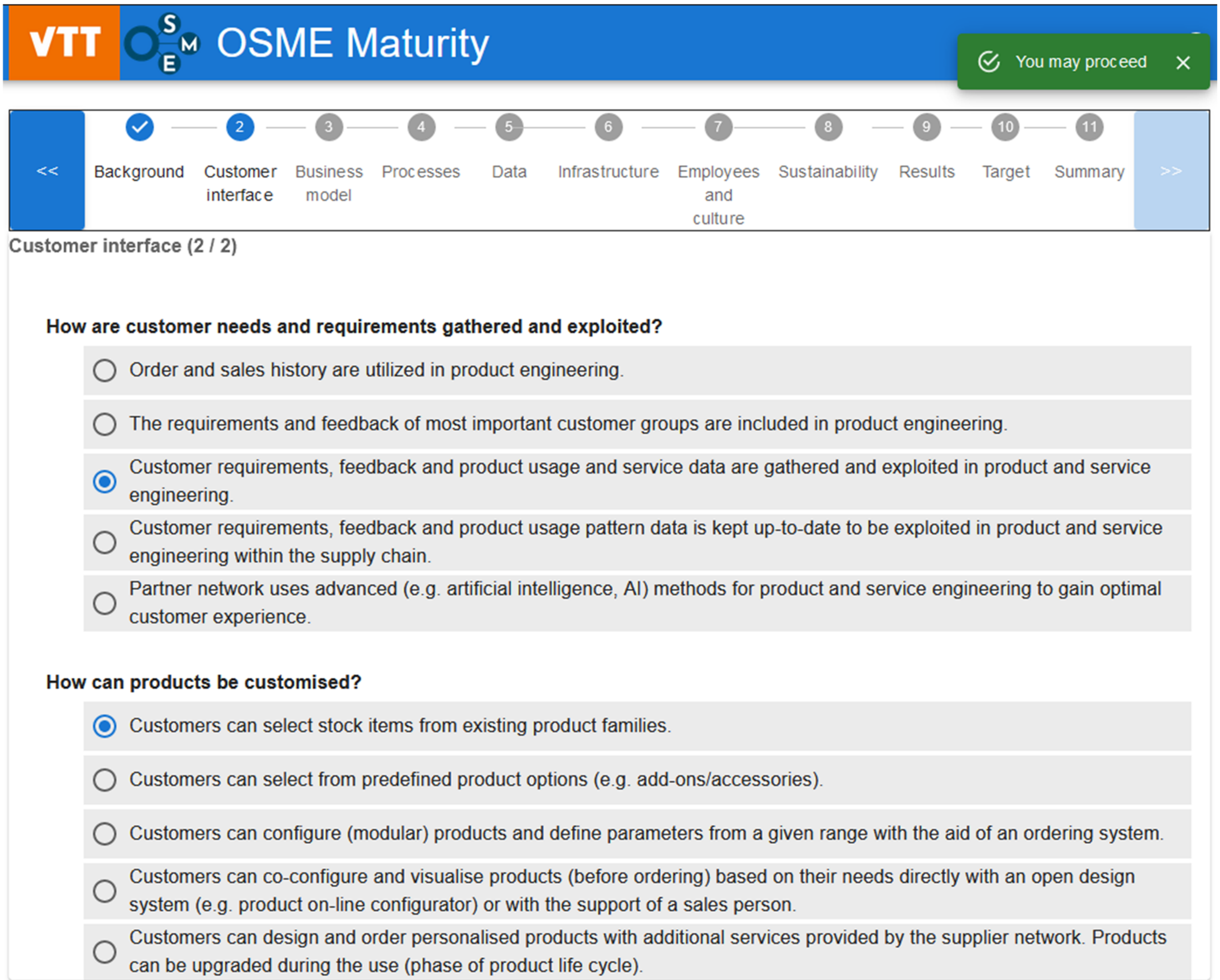

Figure 5. Questions and prewritten response options for the customer interface dimension.

In the results phase, the result levels of maturity dimension or questions are visualised in three ways. The radar chart in Figure 6, displays dimension averages calculated from the fresh responses (my current state, orange) and all given responses (all, blue). The bar chart for each question in Figure 7 and the textual report for each question in Figure 8 enable detailed analysis. In case the respondent has completed the target setting phase addition, the results are visualised with the response of the respondent (smiley) compared to the average level with the value of all responses (numeric value) as well as the desired target level (cup) Figure 9. The respondent can also export the visualisations.

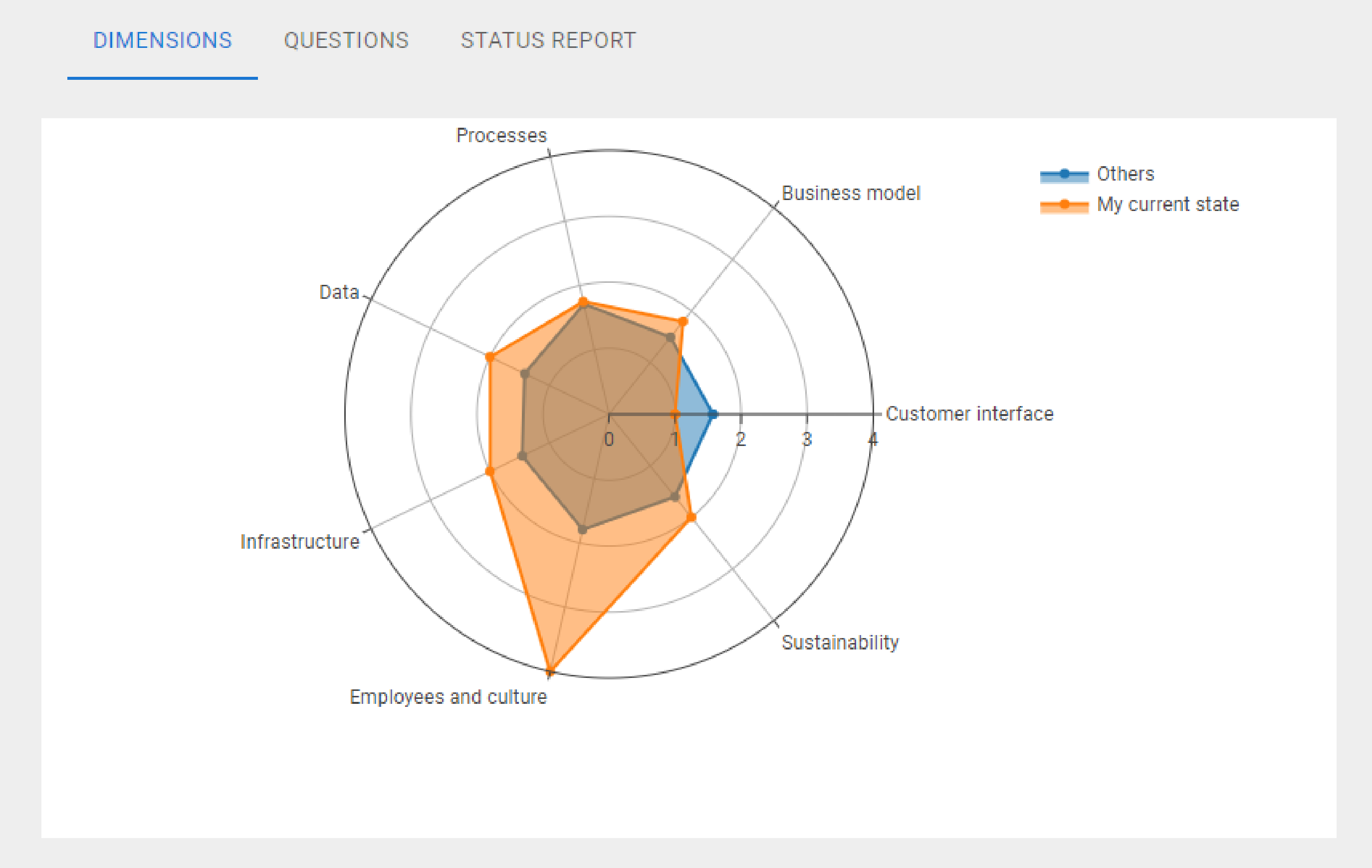

Figure 6. Sample radar chart on the dimensions tab in the results phase.

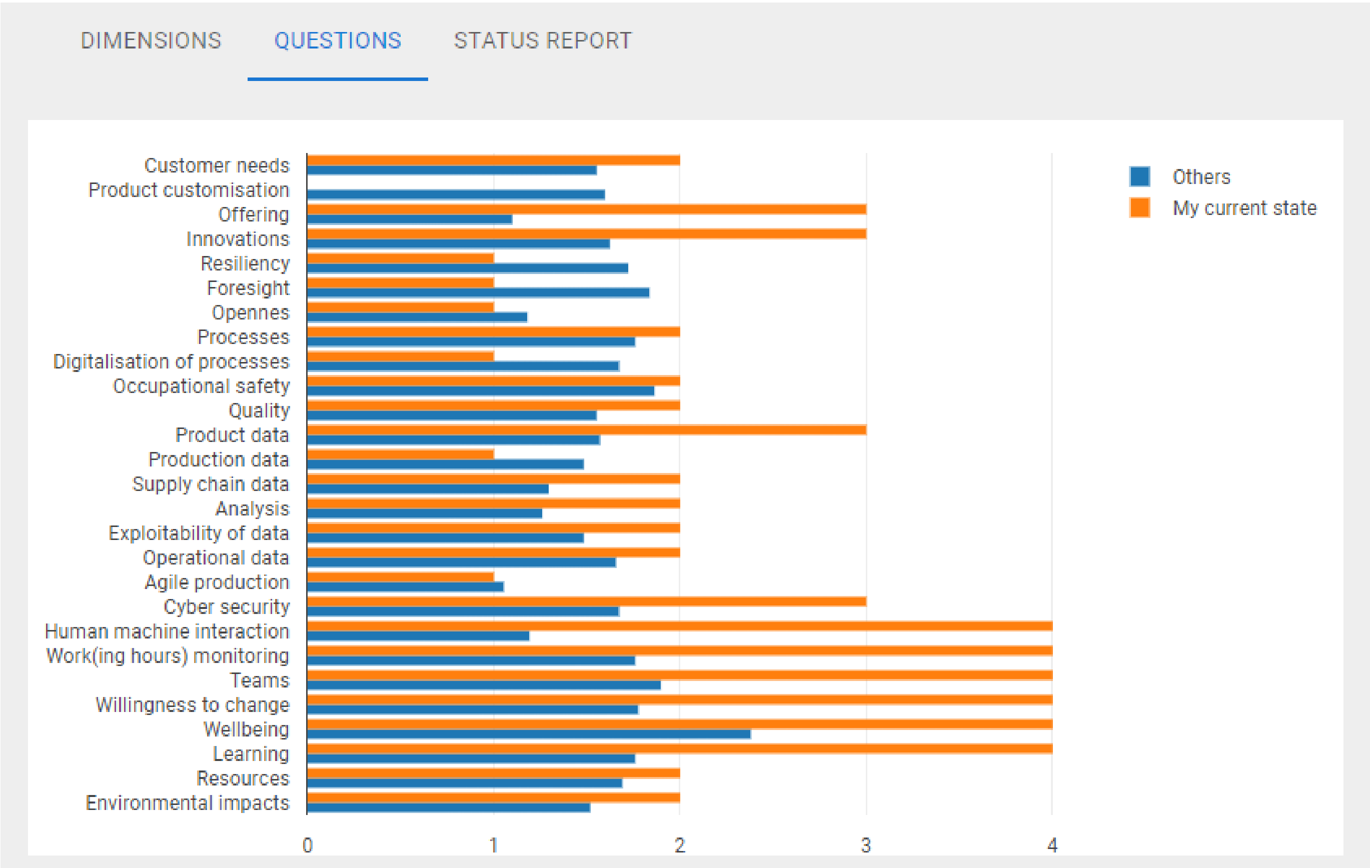

Figure 7. Sample bar graph on each question in the questions tab of the results phase.

Your response to the question: **How are customer needs and requirements gathered and exploited?** is: **Customer requirements, feedback, product usage, and service data are gathered and exploited in product and service engineering.** Your response is **above** the average of all responses. The next level you could reach is: **Customer requirements, feedback and product usage pattern data are kept up-to-date to be exploited in product and service engineering within the supply chain**.

Your response to the question: **How can products be customised?** is: **Customers can select stock items from existing product families.** Your response is **below** the average of all responses. The next level you could reach is: **Customers can select from predefined product options (e.g. add-ons/accessories)**.

Figure 8. Screenshot from the customer interface in the textual status report of the results phase.

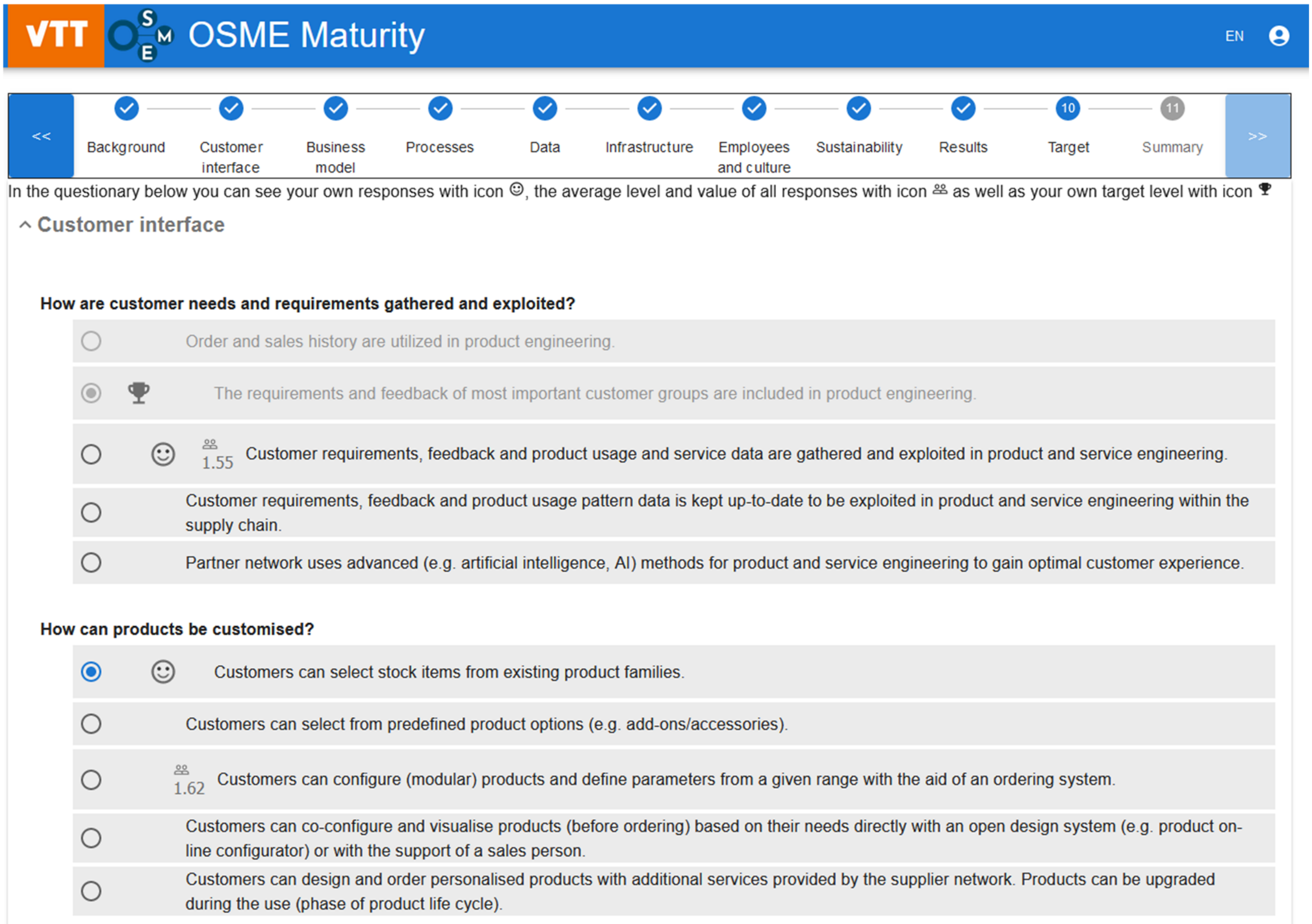

Figure 9. Visualisation of target setting phase of the maturity tool.

4.3. Heterogeneous Company Results and Feedback Discussions (Testing)

Testing of the maturity tool took place from February to March 2023, with a total of 12 responses from five companies, four of which were OEMs (see Figure 10 for further details). Each company received its results on a radar graph displaying its dimension averages and the dimension averages of all respondents. The average of a dimension is the average of responses given for a question related to that dimension. In addition, the bar graphs for each question were shared with the companies. Figure 11 displays the overall results presented to the companies, counted and drawn in Excel. All OSME companies (twelve responses, N = 12) are represented in the blue line and OEMs (N = 7) with red. The customer dimension is the only one that exceeds level 2, agile factory [3], within the average of OEMs. Generally, OEMs are slightly above all respondents. The patterns are quite similar, as OEMs represent 7/12 of all responses. The biggest gap lies in the data where the responses of SMEs pull down the average of all respondents. The bar graph in Figure 12 displays the averages and average deviations for each question in the data and infrastructure dimensions. The average deviation is lowest in the question, "How are systems, networks and programs protected from digital attacks?". This means that the variation in the responses was minor. The highest average deviation is in the question "How is production data collected and shared?", all OSME responses 0.75 and OEMs 0.57. The production data reaches level 2 for OEMs and the deviation is low, while the level is lower for all responses and the deviation is higher.

The lowest maturity levels in the data dimension are in questions related to (i) supply chain data, (ii) data analytics, (iii) exploitation of data and (iv) agile production. The average response (OSME average) for these questions remains below 1.5. The even maturity result between OEMs and all responses of the infrastructure dimension (three rightmost questions in the radar graph, Figure 11) is also visible on the bar chart (Figure 12).

Some companies requested the target-setting option, but only two persons finally completed the target-setting. Further, the registration phase was considered complex. Another way to block unwanted (robot) responses is to find them before the verified registration can be skipped.

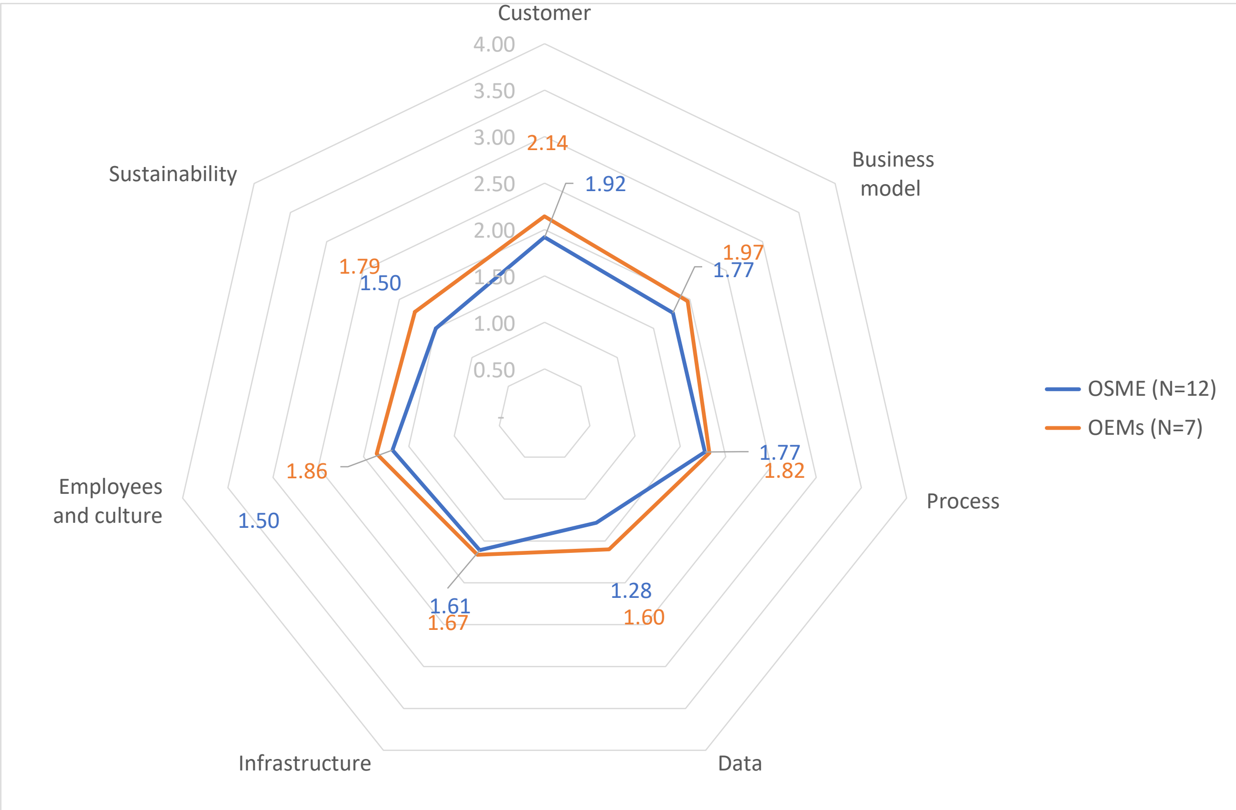

Figure 10. Results as a radar graph visualise the averages of the dimensions in heterogeneous test case.

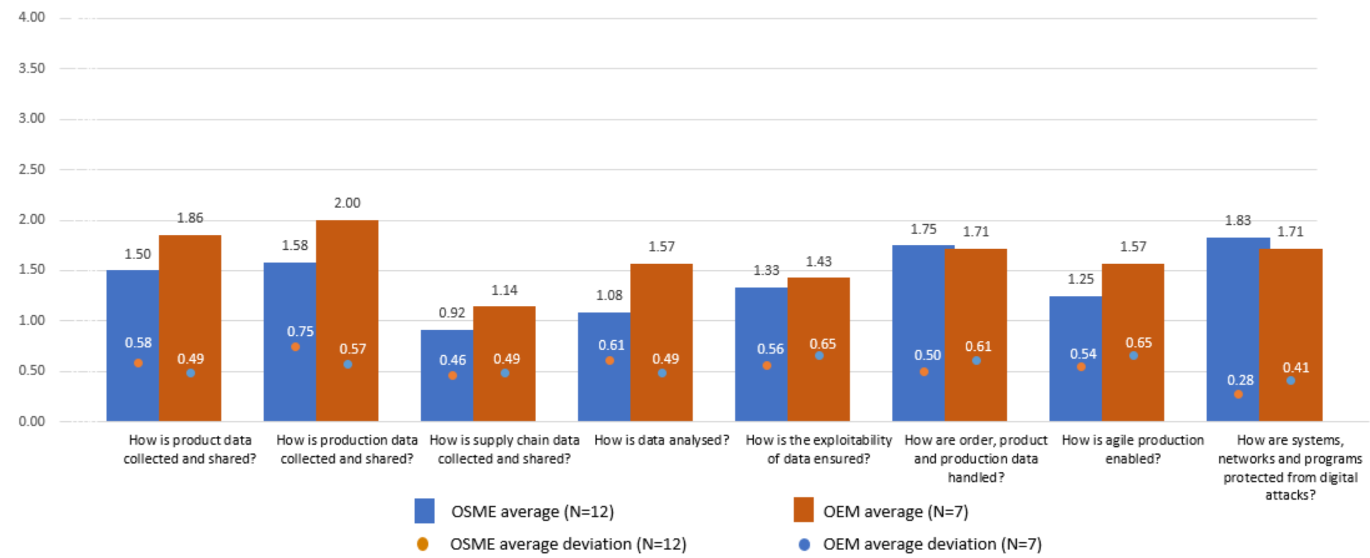

Figure 11. Results as a bar graph over the questions of data and infrastructure dimensions with the average deviation.

Semi-structured interviews were organized during the feedback sessions with the companies, where the functionality of the model and the tool in the pilots were discussed. The semi-structured interview questions were divided into two perspectives. One focused on the maturity model and questions and the other on the use and usability of the tool.

The general comment was that the model seemed to be comprehensive. However, regarding the structure of the model, there was a reflection that some of the themes of the questions intersected in the dimensions, meaning that some questions could also fall under another dimension. Furthermore, some dimensions have many questions and some have a few. The levels of the response options sparked a discussion. It was suggested that the lowest level should be marked as "1". This was because it is more difficult for a person to think of the lowest level as "0". According to companies, transitions between different levels are not always evenly spaced. Thus, for example, the step from levels 1 to 2 can be bigger than from levels 2 to 3. It was also commented that finding your own level among the different options was sometimes challenging. On the other hand, it was observed that there was no ambiguity in most of the questions. There were some comments on the contents of the individual questions, for example, regarding their clarity which will be considered when maintaining the model and tool. In addition, it was stated, for example, related to hybrid work, that well-being and tools for teamwork are important when there is not so much F2F interaction anymore; therefore, it was good that the employees and culture dimension had many questions. It was mentioned that many questions about the employee and culture dimension can be quite subjective in how they are interpreted. Company D especially considered the modifications and additions compared to the previous version of the model and tool, i.e., ManuMaturity:

"I believe that this (model) is quite good in terms of coverage. Discussion and iteration in the OSME project have now brought additions to this model. When I look at it now, safety and quality are extremely important to us, so they are good additions. In the bigger picture, cooperation at the ecosystem level to make it open is important and must be measured. Resilience has also been an important issue during the last couple of years. Examining the entire supply chain is a good and logical addition when supply chains compete with each other. There is now much emphasis on the employee and culture dimension and they are of course good things, but they can also be subjective things, how the current state of these things is interpreted." [Vice President of Company D]

In all the interviews, it was stated that the tool was fairly easy to use but that it is good to remember that the responses reflect the respondent's understanding of the situation in their companies.

"No problems in responding, we have experienced much more difficult tools." [Production director of Company B]

"The answering was straightforward, but of course, this is my subjective assessment of the situation." [Continuous Improvement Manager & Lean Leader of Company A]

After getting responses, navigation between questions of different dimensions and results pages sparked debate and criticism. This functionality was not seen as flexible as it should be.

"... when you have responded once, moving between questions and responses was difficult. Maybe you could add a shortcut menu from which you can access results, goals or questions." [Production director of Company B]

The response time varied from 1/2 h to 1 h. Goal setting was a new feature of the tool requested in the previous round (Saari et al., 2022) [18]. However, only two persons (out of 2 companies) completed the goal setting. For example, it was commented that the goal-setting section of the tool was not noticed after looking at the results. In addition, it was commented that the target setting was not sufficiently specified. Goal setting is a different kind of activity from identifying the current state. You should see the current state and the defined target state, and based on that, you should think about practical actions and what should be done. Thus, the tool could be more of a support tool for the company's development projects.

"First you get the results in the tool and after that—maybe the next time you use the tool—you start making a goal setting. The goal setting is a different kind of mental process for a person than the evaluation of the current state. When the goal setting comes directly after the results tab (sequence), the user will not necessarily click any Next-button there ... the goal setting is also not sufficiently specified. It would perhaps be easier to see the current and target states, and based on that you could think about (and describe) practical actions. The tool could be a support tool for development projects ... such as what development projects there should be and how to prioritize these projects." [Production director of Company B]

Related to the reports, it was noticed that not all users found all reports. They were difficult to find. This is a shortcoming in the usability of the tool. On the other hand, one respondent had gone through all the graphs and even noticed a mistake in his responses based on them and changed his response.

Regarding the usability of the results, it was stated that they could be used for different purposes. The result of this tool can be used as a basis for discussion and development in the company because it gives a reference point where the company is, identifies gaps, concretises different issues and thus helps to find development targets. It was also stated that companies had a broader understanding of the use of digitalisation, especially if a team responded and discussed the results together. Therefore, the company's internal discussion and getting a big picture was emphasised. This was already noticed when piloting the ManuMaturity tool as one good way to apply it [18].

"It would be good to implement this assessment within our whole team." [Business Data Analyst of Company A]

"It is better that this kind of [assessment] is done with a group, because it brings discussion, iteration and different points of view, which brings added value to the assessment when there is also an open atmosphere of trust in the team." [Vice president of Company D]

One respondent had experience with MMs and their utilisation (e.g., EFQM [11]). He considered them a good approach when applied correctly.

"Maturity-type assessment solutions are good ... we can discuss where we are and where we should be and adjust activities accordingly." [Chief Operations and Supply Chain Officer of Company B]

"Very good tool to concretise issues and situation in a company." [Production director of Company B]

Company C proposed they could use the tool more intensively in their company (group type of company). This meant they wanted to have a broader application of the tool to cover the stakeholders of different subsidiaries and then discuss the results together. This was done in the deployment phase of the model and tool and is explained in the next paragraph.

4.4. Homogeneous Company Group Results and Feedback (Deployment Phase)

The deployment phase was experienced with a group of more homogenous companies, i.e., within one group of companies during the summer 2023 (more details in Section 3.2). The group contained four subsidiaries. Figure 12 displays the averages of each dimension for the four subsidiaries, the group as a whole (N = 24) and the reference group, i.e., OSME companies (N = 32).

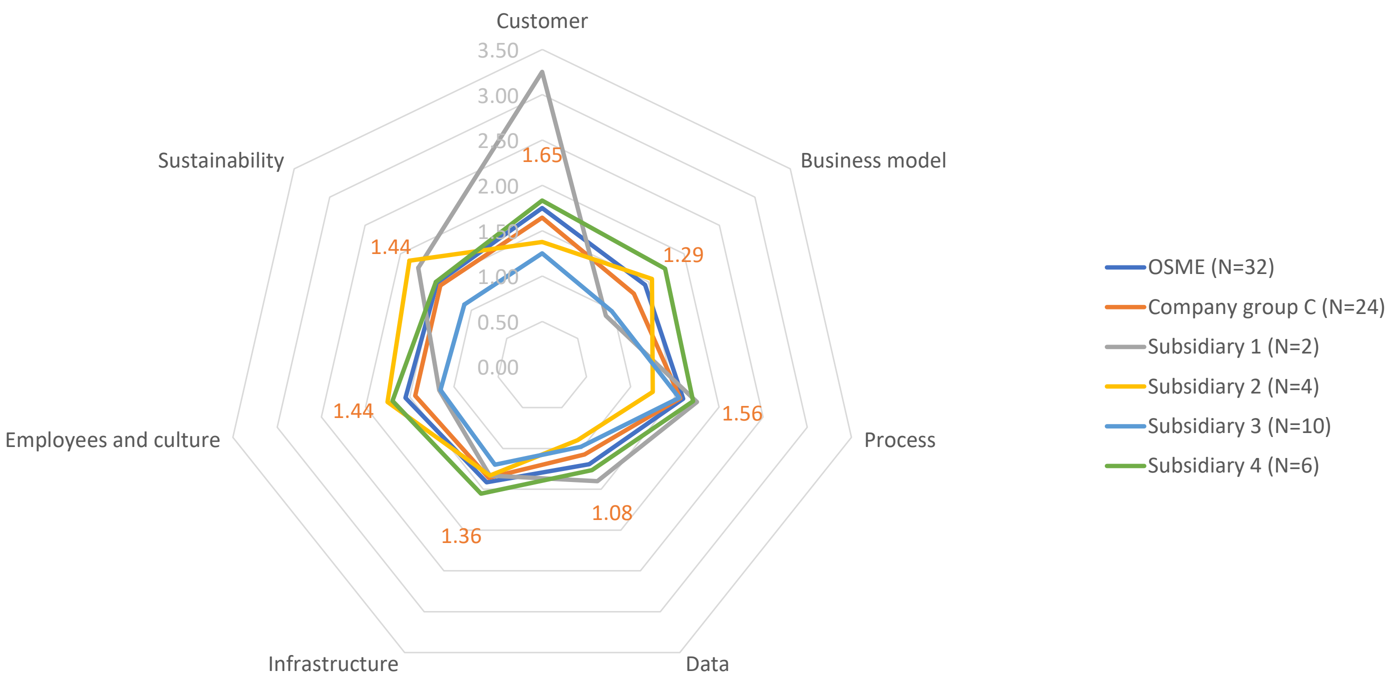

Figure 12. Radar chart of the averages for the company group experiment.

This time, the radar chart is quite busy, so the averages for each dimension are presented in Table 7. The number of new responses also decreased the averages of all OSME responses in every dimension. Subsidiary 1's peak in customer dimension and drop in business model dimension were discussed in the feedback session.

Table 7. Dimension averages of the company group experiment.

	Customer	Business Model	Process	Data	Infrastructure	Employees and Culture	Sustainability
OSME (N = 32)	1.75	1.45	1.59	1.19	1.42	1.55	1.48
Company group C (N = 24)	1.65	1.29	1.56	1.08	1.36	1.44	1.44
Subsidiary 1 (N = 2)	3.25	0.9	1.75	1.4	1.33	1.17	1.75
Subsidiary 2 (N = 4)	1.38	1.55	1.25	0.9	1.33	1.75	1.88
Subsidiary 3 (N = 10)	1.25	0.98	1.55	0.98	1.2	1.15	1.1
Subsidiary 4 (N = 6)	1.83	1.73	1.71	1.27	1.56	1.69	1.5

In autumn 2023, subsidiaries of Company C responded to the tool. They gathered into a joint session where the results of the OSME maturity analysis and feedback for the model and tool were discussed. Regarding the model and tool, it was stated that the model brings out areas where the company could improve its operations. When applied in the context of a group of subsidiaries, this tool also enables you to discuss, find, and share "best practices" between different subsidiaries.

At the end of the session, the method by which the results will be utilised in practice was discussed. Company C (with 4 subsidiaries) agreed that each subsidiary first considers the development targets (e.g., in the steering group) and identifies 1–2 development targets. Then, they bring these ideas to the group-wide discussion to agree on what to focus on at the group level. It was also discussed that this same analysis could be repeated after about a year, testing again with the tool to see where the whole group was heading and how to steer the improvement actions. This allows us to utilise the model and tool for "before-after" scenarios within a set of subsidiaries.

5. Discussion

Research on MMs and tools began in 2016, when a generic—suitable for all industries—digitalisation maturity tool was published [80]. The tool in question was used in various case studies, mainly to support the digitalisation development of SME companies [4,81]. The ManuMaturity tool supported the digitalisation needs of the manufacturing industry [18,78]. The tool in question was piloted in the spring 2022 when the need arose to expand this tool also to cover the perspectives of information sharing, ecosystem way of working, human perspective, and sustainability [18].

Some development model support the development of MMs and tools [75–77]. In our research, we used the model presented by Bruin et al. [75], because of good experiences in the first iteration [18]. Further, the same model has been utilised in other studies, for example [40,82]. The discussion hereafter is structured based on the model development phases: (i) model development, (ii) testing and piloting, (iii) deployment and (iv) maintenance [70]. Therefore, we start with the development phase.

Schabany et al. [49] identified four features relevant to any MM. The first one is goal congruence or consistency, i.e., the dimensions shall reflect the goal of the MM. Our OSME MM fully fulfills this objective, as the model's foundation and prewritten response options lie on the stair model developed for the manufacturing industry aiming for Industry 4.0 or even beyond (Figure 13) [3].

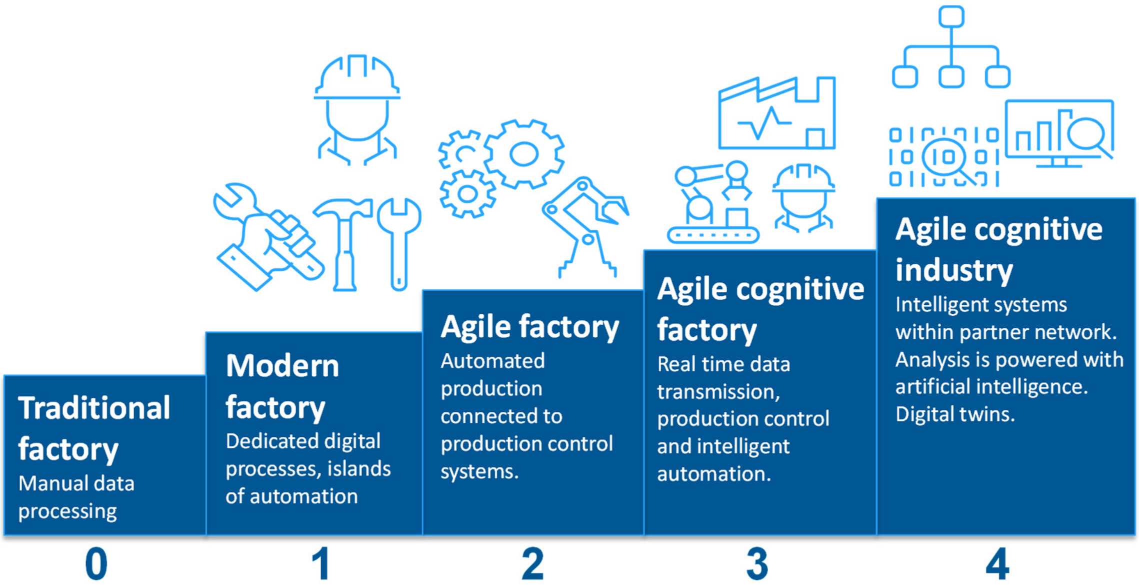

Figure 13. The development steps of the manufacturing industry [3].

The second principle, uniqueness, is also followed, as a topic is represented by only one dimension. Thus, the ecosystemic operation did not reserve a new dimension in the OSME MM, as it is embedded in the response options at the highest level (agile cognitive industry). Further, the third one—definiteness—is reached, as all seven dimensions are uniquely defined. Also, the fifth one—suggestiveness—is reached, as the highest level is beyond. In our OSME MM, the response options at the highest level are beyond the obvious. Being suggestive also caused feelings of inadequacy and frustration in the respondents, as the highest levels seemed so far away. Further, the linear scale between the levels was considered unfair, as the leap between higher steps is huge. An exponential scale was even proposed. The scale with exponent two could be feasible, starting with $2^0 = 1$ and ending with $2^4 = 16$. The problem with the linear scale raises the question of averages: can the averages be counted if the numeric values are not solid enough? As in several MMs, the averages are counted for dimensions; this is a common problem. Instead of averages, perhaps the distribution of responses at each level could be discussed.

In Table 1, several academic MMs are described. Nick et al. [63] did not follow the suggestiveness request, as each dimension has five unique intervention points. This is quite a practical outcome, as it was quite challenging to follow the stair model when formulating the response options for dimensions such as sustainability and employee and culture. A few MMs included the weighting of dimensions [57] or the selection of irrelevant questions.

The model with new elements, such as 11 new questions and one modified dimension (employees and culture) (Figure 3), was tested with a heterogeneous group of manufacturing companies, six of which were OEMs. The results for OEMs were slightly higher than those for other companies, but due to the insufficient number of responses, patterns for OEMs or SMEs could not be established.A new feature in our tool was the option of setting the target level after the assessment had been done. The target-setting (as-is and to-be) option was mentioned in a few MMs [56,66,70].

No MMs in Table 1 described the software implementation of their model or tool; thus, our manuscript is a more complete description of the development process. A few models apply the radar graph [71,73] and count averages for the dimensions. Two MMs applied digital methods as a web tool [59] or an Excel solution [50]. The OSME MM was implemented as an open and free web application [12], where registration with a functional email address is needed to avoid irrelevant input to the response database. The deployed software architecture is described, and a few screenshots of the UIs are displayed in this manuscript. Our tool immediately provides three views (radar over dimensions in Figure 6, question bars in Figure 7 and textual status report in Figure 8) for the respondent, but the analysis over a group of responses has to be conducted manually, exploiting Excel functionalities. The tool is easily reconfigurable with a new language if the dimensions, questions, response options and UI texts are translated into a new language. The tool can provide a new language instance from the translated document.

Further, the deployed tool was experimented with within one group of companies and 24 responses were gathered. In the MMs listed in Table 1, only a few reported experiments with companies [52,53,57,62,67,72]. Indeed, careful development of models and tools is needed, as well as their testing in industrial environments, to ensure their applicability in practice. This is important so that the content of the model and the operation of the tool can be modified based on the user experience gathered.This would require more research and concurrent development together with industrial representatives.

The maintenance phase is not fully managed, although technical support is agreed upon by the end of 2024. Unfortunately, the certificates and potential software version updates cannot be managed within a limited project. However, maintenance (both model and tool) is a crucial activity [75]. Therefore, a new way (funding) has to be found to enable this tool's full and continuous functionality. For this reason, the development of the business model for the tool is also relevant. Although VTT is a non-profit organisation, no unprojected work is allowed. Without promoting the tool, the response database will not have enough data. Sufficient data would enable reports and articles on the findings. VTT has created a landing page for various methods and tools to support the twin transition of the manufacturing industry [13]. Only one MM reported support after the assessment by providing a roadmap [58]. Also Mittal et al. [27] recognised this gap. Consultancies and associations naturally provide more support, e.g., workshops, but not without a fee or membership. An academic MM's business model and life cycle management remains an issue.

According to the feedback sessions, the experimentation of the OSME maturity tool was interesting and eye-opening for the companies. They planned to bring the results to internal discussions in their company.

Since the maturity model is quite extensive, in some cases, it is useful for the company to gather several people together to respond to the tool as a team. In this case, the personnel can discuss different options and come up with ideas for development needs. This identification and piloting of different usage scenarios of the maturity tool has been found useful [18,83]. One group of companies also aimed to repeat the assessment next year. This means the possibility for a before-after comparison.

Because of the low number of responses, general patterns for manufacturing OEMs or SMEs could not be created. These patterns could have been applied when accepting or rejecting new ecosystem member candidates.

6. Conclusions and Further Work

This study presents the research path of the ManuMaturity model and the tool was extended to cover rising topics such as sustainability [5], data sharing and employees in addition to the Industry 4.0 [2] goals. The extended OSME model and tool were developed and tested with a Finnish manufacturing ecosystem. This research is part of a longer research path, which aims to promote the digitalisation of manufacturing companies and towards data sharing within the supply chain, open innovation ecosystem and sustainable manufacturing. With the help of the developed maturity model and the tool, it was possible to make assessments in case companies, where the tool and its results were commented mostly positively. However, for instance, the tool considered the registration phase complicated. According to our experience, the tool can be applied in various ways and individual people can respond to the tool and receive immediate comparisons to other respondents. Also, a group of people respond to the tool together and identify the topics for further development simultaneously.

In this article, we present the development of the maturity model and tool and their testing in an industrial environment. The development and testing of the maturity model and the tool have been done following the process model to develop maturity models [75]. The process model helped structure the development and testing of the maturity model.In addition, it covered important considerations for model maintenance and further development, which are crucial for applying the tool in the industry. However, the definition of the maintenance phase is still under construction, as the business model of the tool remains open. The latest version of the tool is available on the landing page created for the twin transition tools [13]. The validation was done twice, first with a group of companies representing both OEMs and their suppliers. The second experiment was conducted within a group of companies, i.e., the validation was unusually comprehensive [26]. The limitation of the research is that the testing of the model and tool has been limited to a few companies. Thus, in the future, they should be tested more widely in other companies. In addition, it would be interesting to conduct longitudinal research on the benefits of using the model and tool. This is an interesting research topic for the future, although it requires well-planned long-term cooperation with companies. All these functions also increase the number of responses in the tool's database, which opens up the possibility to analyse the collected data, for example, concerning a certain demographic factor such as company size, turnover or subdomain.

Acknowledgments

We wish to thank the companies of the Open Smart Manufacturing Ecosystem [1] (OSME) project funded by Business Finland for contributing to this research and providing valuable feedback when developing the OSME maturity tool. Thanks also to VTT Technical Research Centre of Finland Ltd. for allowing us to perform this study.

Author Contributions

Individual contributions of the authors are following: Conceptualization, L.M.S. and J.K.; Methodology, J.K.; Software, M.Y., L.M.S. and J.K.; Formal Analysis, L.M.S. and J.K.; Investigation, L.M.S.; Resources, J.K.; Data Curation, L.M.S. and J.K.; Writing—Original Draft Preparation, L.M.S. and J.K.; Writing—Review & Editing, L.M.S. and J.K.; Visualization, L.M.S. and M.Y.; Supervision, J.K.; Project Administration, J.K.; Funding Acquisition, J.K.

Ethics Statement

Not applicable.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Funding

This research was funded by Business Finland within the project Open Smart Manufacturing Ecosystem.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

The minutes of the feedback discussions and the audio recordings are confidential. Due to its proprietary nature, supporting data cannot be made openly available. The maturity tool responses cannot be shared openly to maintain the privacy of companies.

Footnotes

1. https://cris.vtt.fi/en/projects/open-smart-manufacturing-ecosystem; https://www.mexfinland.org/osme/.
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