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ScienceDirect

Procedia CIRP 136 (2025) 91–98

www.elsevier.com/locate/procedia

35th CIRP Design 2025

Towards a future-proof holistic production system

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Abstract

Manufacturing companies face growing challenges from skills shortages and energy crises to increasing product complexity and variance. Three approaches have emerged to remain competitive: lean, digital, and sustainable production. Despite the relevance and the awareness of these approaches, they have yet to be widely implemented, which causes difficulties. One reason for this, besides the lack of tangibility of the paradigms, is the missing transparency regarding an objective assessment of the current and the target state, considering the interdependencies of the paradigms and the companys' objectives. A holistic maturity model for future-prof production systems is a tool that can address this issue. This article presents a detailed analysis of the need for such a model and the related, pertinent requirements.

Keywords: Lean; Digital; Sustainable; Production; Future; Maturity; Requirement; Survey; User story

1. Introduction

Market volatility and uncertainty, geopolitical shifts, technological innovations and disruptions, the climate crisis, and the limits of the natural environment pose a variety of challenges to production [1–3]. Through this situation, manufacturing companies are confronted with a constant cost pressure and a rapidly changing customer behavior. Consequently, companies must cope with increasing product variety and complexity, creating a greater need to innovate quickly and to develop intelligent products and processes. This goes along with the increased demand for qualified employees, which conflicts with the skilled labor shortage. In addition, greater challenges such as the global climate crisis and the German energy crisis, as well as political issues such as raw material scarcity, are threatening established business concepts and they are posing further challenges for companies. [4–7]

In terms of production, companies can address these challenges through three paradigms: lean, digital, and sustainable production. Lean production reduces waste and costs while enabling a quick and flexible response to changing customer needs and behavior [8, 9]. Digital production supports production workers based on digital technologies. For example, assistant systems and artificial intelligence provide them with technical and linguistic assistance. However, it also enables companies to partially replace highly qualified employees with less qualified ones. In addition, digital production can increase the ability to innovate through data mining, providing opportunities for improvement. [10, 11] Sustainable production supports companies in establishing a circular economy and minimizing ecological damage. In addition, reducing waste in production and using recycled materials can help counteract raw material scarcity. [12, 13]

Despite the relevance and familiarity of these production approaches, they have not yet been widely implemented [14–16] or considered holistically [17–19]. Consequently, companies are missing opportunities for improvement, including the potential for cost savings and quality enhancements, as well as the possibility of achieving synergies, which collectively contribute to the overall

10.1016/j.procir.2025.08.018

implementation progress of the paradigms [20, 21]. In addition to the lack of tangibility due to the high complexity of the transformation caused by the paradigms [22, 23], there is a lack of transparency regarding an objective assessment of the current state and the possibility of an objective assessment of the desired state, considering the individual company's goals [20, 24].

The objective of this paper is twofold: Firstly, to provide a rationale for the necessity of a comprehensive maturity model that is aligned with the current landscape of manufacturing challenges, and secondly, to delineate the essential requirements for such a maturity model. Therefore, the first part of the paper (Chapter 2) aims to identify the production approaches that will enable manufacturing companies to remain competitive in the future by presenting the results of an international survey with manufacturing experts. Furthermore, the first part investigates the extent to which companies have already established the necessary production paradigms, their willingness to further develop them, and the existence of an objective tool for evaluating these paradigms. The findings are then subjected to a comprehensive analysis of the state of knowledge on holistic maturity models for future-proof production systems through a systematic literature review in Chapter 3. Finally, in the second part of the contribution (Chapter 4), based on the derived need for research, the requirements for a maturity model for future-proof production systems are identified and defined. For this, the results of expert interviews with the industry will be presented.

2. The importance of lean, digitalization, and sustainability in production systems

Figure 1 presents a three-step procedure to examine the relevance of a holistic maturity model for future-proof production systems, comprising lean, digital, and sustainable production.

Step	1 Future viability of production systems	2 Current and target state of paradigms	3 Availability of assessment approaches
Result	Identification of the relevant paradigms to ensure the future viability of production systems	Identification of the performance of companies regarding the paradigms relevant for future-proof production systems	Identification of the availability of a tool/procedure to assess the performance of the paradigms in companies

Figure 1: Procedure to identify the importance of lean, digital, and sustainable production systems

Each of these three steps started with an assumption, which was subsequently verified by utilizing an online survey. The first step involved an identification of the production approaches (paradigms) that have an influence on the competitiveness of manufacturing companies and, consequently, on their future viability. The second step was to examine the current and the target state of the companies in relation to the previously identified relevant production approaches. The third step consequently was to investigate the extent to which a comprehensive assessment option is available for analyzing the current and the target state of a company regarding the previously identified paradigms objectively.

In the following, the survey background and the results are presented. A total of 214 participants took part in the survey. Figure 2, showing the background of the participants, indicates that approximately half of the participants were from small and medium-sized companies and half were from large companies. The roles of the participants were diverse, encompassing executives (directors of an organization's operations), mid-level managers (leading a team and reporting to the executives), specialists (experts in a specific field), and operators (directly involved in the production of products). 'Other' includes roles such as consultants or analysts.

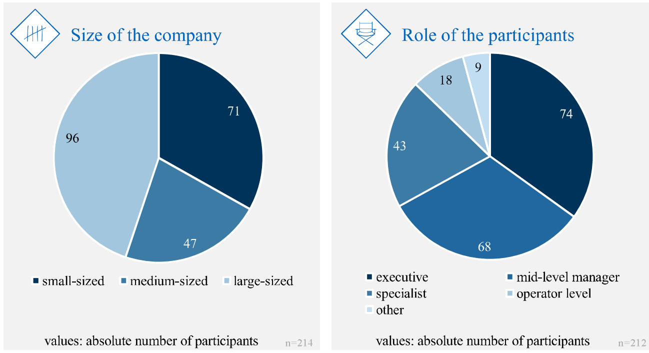

Figure 2: Background of the participants

Moreover, the participants represented a variety of industrial sectors, including mechanical and plant engineering, automotive, electronics, and food and beverage. In terms of the geographical scope of the survey, it should be noted that the participants originated from a range of countries across six continents, including Germany. Most of the participants were from Austria, Argentina, and the United States. Furthermore, the participants possess considerable experience in the production environment. More than half of the participants had more than 11 years of experience at the time of the survey, while less than 15 % had less than two years of experience.

2.1. Future viability of production systems

Manufacturing companies operate in a highly competitive environment characterized by global social and political challenges. Thus, companies need to make their production systems fit for the future. To achieve this, it is necessary to establish appropriate production approaches, which leads to the following assumption (AS):

AS1: Production systems must be lean, digital, and sustainable to be future-proof.

As part of the survey, participants were asked to rate which paradigms they think were relevant to the future viability of production systems. In addition to the three paradigms of lean, digital, and sustainable production, other paradigms could be named. The results showed that around two-thirds of the respondents believe that lean, digital, and sustainable production plays a role in ensuring the future viability of production systems. Furthermore, participants identified other paradigms that they considered relevant to the future viability of their production systems, such as *agile production* or *collaborative machines or people based on artificial intelligence*. However, the number of those mentions was negligible and, except for *flexible production* (mentioned twice), none of the paradigms was mentioned more than once.

In addition, the participants rated the importance of the three paradigms for the future viability of production systems using a 5-point Likert scale (see Figure 3). All three paradigms were rated as *important* or *very important* by more than 80 % of the participants, with lean production rated as *important* or *very important* by 83.7 %, digital production by 83.8 %, and sustainable production by 82.4 %. Furthermore, the survey results show that the two lowest scale levels (*not important at all* and *unimportant*) were chosen by less than 2.5 % of the participants for all the three paradigms.

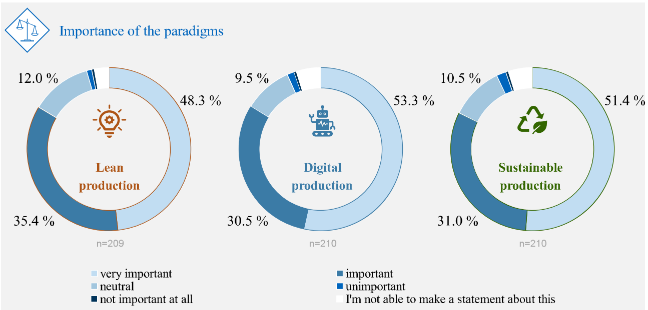

Figure 3: Paradigms for the future viability of production systems and their relevance

As a result, the survey has shown that the three production approaches of lean, digital, and sustainable production are essential for the future viability of manufacturing companies, confirming assumption AS1.

2.2. Current and target state of the paradigms

The confirmation of AS1 indicates the need to implement the three paradigms in production systems to make them future-proof. It is therefore necessary to examine how far companies have progressed in implementing the three paradigms and to what extent this corresponds to the desired state. The resulting assumption is as follows:

AS2: A comprehensive implementation of lean, digital, and sustainable production has not yet taken place generally in the companies, but the willingness to do so exists.

Regarding the current situation (see Figure 4 left), only around 10 % of the respondents stated that lean production is fully implemented, compared to around 10 % who have no implementation plan at all. Similarly, only 7.5 % of the respondents believe that digital production is fully implemented in their company, compared to over 12 % of the respondents who have no plans to implement digital production. A similar picture emerges for sustainable production, with nearly 9 % of the respondents stated that it is already fully implemented in their company, while over 12 % of the respondents believe that there is no plan for implementation. This shows that, for all three paradigms, the proportion of those who do not have an implementation plan is greater than the proportion of those who have already fully implemented. In terms of the target state in the next five to seven years (see Figure 4 right), the lean paradigm is mostly or fully implemented at almost 70 %, and the digital and sustainable paradigm is mostly or fully implemented at more than 70 % of the companies. Furthermore, almost none of the participants (less than 2.5 % for digital and sustainable production and nearly 6 % for lean production) stated that they did not have an implementation plan for the three paradigms. Thus, the intention of a comprehensive implementation is present in all three paradigms.

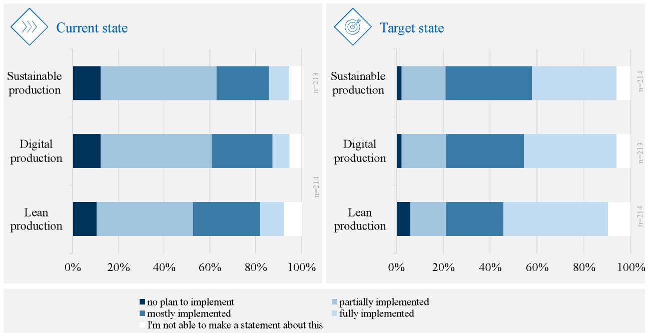

Figure 4: Current and target implementation state of the paradigms

The results of the survey have indicated that the implementation of the three paradigms of lean, digital, and sustainable production has already begun, but is not yet sufficiently done. The survey has also shown that the target states of the companies in relation to the three paradigms are higher than the current actual states and that there is therefore an attempt to improve. AS2 has therefore been confirmed.

2.3. Assessment approach for the paradigms

To provide companies with transparency regarding their implementation status and ambitions in relation to the three paradigms, an approach (e.g., tool or procedure) is needed to assess the current state and the target state. The resulting assumption is as follows:

AS3: Currently, there is no comprehensive and objective approach to assess lean, digitalization, and sustainability in production.

Further survey results showed that less than half of the respondents stated that their company has a procedure that allows for a comprehensive and objective assessment of the current or the target state of the production system in relation to the three paradigms. Here, the results indicated that only less than 10 % of the respondents fully agree with the statement that they have such a tool or procedure. However, more than 20 % of the respondents do not have an assessment tool or procedure for both the actual and the target state. In addition, over 25 % of the respondents neither agreed nor disagreed that they have an objective and holistic tool or procedure.

While there have been some isolated assessment approaches, there is a general lack of a holistic and objective assessment model. From the industry's point of view, this has led to the need for a way to assess the current and target status of lean, digital, and sustainable production. AS3 has therefore been verified.

Maturity models provide an approach for monitoring the progress of an organization concerning a domain [25, 26]. They provide a way to assess the status quo or target state of an organization or production, usually by using maturity levels that logically build upon each other within the domain under consideration [25, 26].

Considering the three established and confirmed assumptions (AS1 to AS3), it can be stated that the three approaches of lean, digital, and sustainable production are essential for companies to survive and remain competitive in the future. Although companies recognize this and the paradigms have been known for several years, they have yet to be implemented comprehensively. However, companies are striving to improve within the three production approaches. This requires a maturity model as a tool for creating transparency and identifying improvement potential that takes all three paradigms into account and ensures an objective assessment.

Based on a literature review, the following chapter will analyze the extent to which such approaches already exist from a scientific perspective.

3. Literature review

The systematic literature review (SLR) is a method for the systematic identification and evaluation of all relevant literature and thus, in a scientific context, pursues the goal of a complete review of the existing literature in the area under consideration [27]. A systematic approach is characterized by a clear structure, transparent documentation, and a comprehensive and unbiased perspective [28]. To ensure this, a multi-stage process was used, which can be divided into three phases: *planning the literature review*, *conducting the literature review*, and *reporting and publishing* [28, 29].

In the following, the three-phase approach is adapted to the present framework. The overall objective of the literature review was to determine the extent to which maturity models have been analyzed holistically in relation to the three paradigms. The search was conducted within the Scopus and Web of Science (WoS) databases using the three search groups *maturity*, *industry*, and *paradigm*. The first search group ensured that the search included only publications that dealt with maturity in the form of models or their characteristics. The second search group ensured that the industry focus was on production. Finally, the third search group integrated the paradigms of lean, digitalization, and sustainability into the search code, which is why it is divided into three sub-search groups. In addition, the terms within the search groups were linked with an 'OR' operator. All sub-search groups of 'paradigm' were linked to the search groups 'maturity' and 'industry' with an 'AND' operator to identify the maturity models of the respective paradigm.

Because of the search in two databases, the SLR was split into two searches, which is due to the different structures of the literature databases. The result before filtering was more than 2000 publications identified in both databases, as shown in Figure 5. The publications were then filtered by research areas, called subject areas (SA). As the SA in WoS is very narrowly defined, this filter was only applied in Scopus, where the SA is formulated more generally, based on the respective disciplines associated with the articles. All three search codes were filtered to 'Engineering' and 'Business, Management and Accounting', with 'Computer Science' added to the digital production search code and 'Environmental Science' added to the sustainable production search code. Both databases were then filtered by language (German and English) and document type (DT) with 'article', 'conference paper', or 'review'. This resulted in a total of 1008 publications in Scopus and 677 publications in WoS (see Figure 5). Duplicate matching and title and abstract screening reduced the number of publications by a further 80 %. In total, the full-text screening identified more than 60 relevant open access publications, most of which were assigned to the digitalization paradigm.

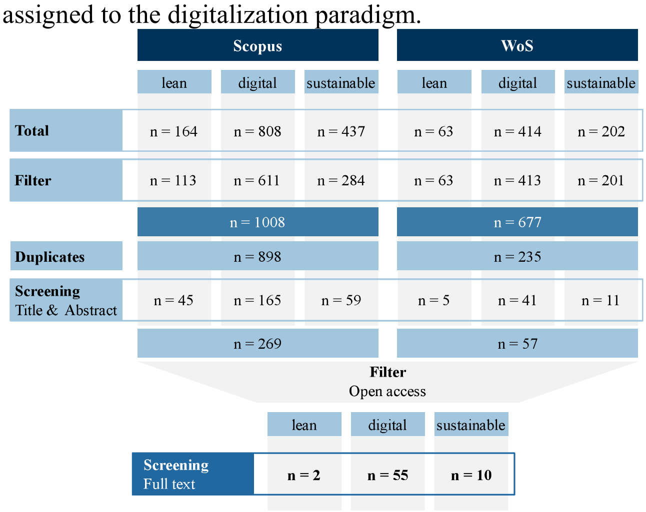

Figure 5: Search process in databases

The resulting publications were finally analyzed based on six evaluation criteria with three degrees of fulfillment, derived from the motivation of the current situation, the assumptions, and the objective. The *comprehensiveness* criterion results from the need for a comprehensive and complete view of the object of investigation (the company) in relation to the chosen paradigm. It therefore provides information on the extent to which the maturity model takes the paradigms into account comprehensively, i.e., not just individual areas. The *multidimensionality* criterion (MD) assesses whether and to what extent a differentiated consideration and evaluation of the respective paradigm takes place on several levels of abstraction. This can be done, for example, by describing sustainable production at different levels and specifying the dimensions. It therefore provides information on whether the maturity model takes into account different levels of aggregation of the paradigm. The *area of application* (AA) considers the overlap between the area of application of the maturity model and production and analyzes whether and to what extent production is considered as a whole. The *adaptability* criterion examines whether the maturity model is universally valid and still allows for adaptation to different companies with different characteristics. For example, the model should not only be valid for a specific use case or company size, but should still allow for adaptation to the company's needs. The *interdependencies* (IDP) criterion is used to check whether the maturity model comprehensively takes into account the interactions, i.e., within and between the paradigms. The *model type* criterion distinguishes between the direction of the assessment, i.e., whether the model is descriptive (current state) or prescriptive (target state).

Table 1 shows an excerpt of relevant publications with the highest degree of fulfillment of the evaluation criteria. Only a small proportion of the models consider a cross-paradigm view of production. In addition, none of the maturity models fulfills the criterion of *holism* across paradigms. Only the models of Wessing & Müller [24] and Mittal et al. [30] consider all three paradigms of lean, digital, and sustainable production. The former includes the paradigms in the model design, but stops at naming the paradigms, i.e., they are not elaborated in breadth or depth. The latter focuses primarily on digital production and only marginally addresses the other two paradigms, without considering them as independent or equal paradigms and as comprehensively as digital production. In addition, it becomes clear that although there are already models that take a multidimensional view of the paradigms into account, none of them guarantees this for all three paradigms. In addition, there is no model that both comprehensively addresses the interdependencies and allows for customization to an organization's needs.

Table 1: Results and evaluation of the literature (excerpt)

Source	Criteria											
	Holism			MD			AA	Adapt-ability		IDP	Model type	
	lean	digital	sustainable	lean	digital	sustainable	production	general	company-specific	comprehensive	descriptive	prescriptive
[31]	●	○	○	●	○	○	◐	●	○	○	●	●
[32]	●	○	○	●	○	○	●	●	○	○	◐	◐
[33]	◐	●	○	◐	●	○	●	◐	○	○	◐	◐
[30]	◐	●	◐	◐	●	◐	●	◐	○	○	●	●
[34]	○	●	○	○	●	○	●	◐	●	◐	●	●
[35]	○	●	○	○	●	○	●	◐	●	○	●	●
[36]	◐	●	○	●	●	○	●	●	◐	○	●	●
[37]	○	●	○	○	●	○	●	◐	●	○	●	◐
[38]	○	●	○	○	●	○	●	●	●	○	●	●
[39]	○	◐	◐	○	◐	○	●	○	○	○	◐	◐
[40]	○	○	●	○	○	●	●	◐	○	○	◐	◐
[41]	○	◐	◐	○	●	●	●	●	○	○	●	●
[42]	○	●	●	○	●	○	●	◐	○	◐	◐	◐
[24]	◐	◐	◐	○	○	○	●	◐	○	◐	○	○
[43]	○	○	◐	○	○	●	◐	●	◐	○	●	●
[44]	●	●	○	◐	◐	○	●	●	○	◐	●	●

○ not fulfilled ◐ partially fulfilled ● fully fulfilled
MD: multidimensionality; AA: application area; IDP: interdependencies

Thus, none of the models provides a comprehensive, cross-paradigm, holistic view of production. Furthermore, no model takes a multidimensional, company-specific view that considers interdependencies.

From the previous sections, it becomes clear that there is a lack of a holistic maturity model for the production paradigms relevant to future viability, which provides an objective assessment option and enables a tangible assessment, considering synergy potential and company-specific needs. To realize this potential, relevant requirements for the maturity model must first be defined.

4. Requirements for a maturity model for future-proof production systems

The definition of requirements serves to establish the necessary functions and capabilities of a new system, thereby providing the foundation for the achievement of successful project outcomes [45, 46]. To capture the requirements for the maturity model for the production of the future, the findings from the motivation and literature review as well as those from the expert interviews were used. The structure of the expert interviews was based on the agile method for gathering user stories, which follows the idea of capturing requirements in natural language without a high degree of abstraction [47–49]. The goal of user stories is to ask potential stakeholders of the model about aspects that are relevant to them [50, 51].

In total, 11 industry experts were interviewed. Each interview lasted between 45 and 60 minutes and was conducted online. In general, a person can be described as an expert if he or she possesses retrievable and unambiguous knowledge in a limited area [52]. This also means that their statements are well-founded and not noncommittal and not arbitrary [53]. To this end, the experts were also asked to rate their knowledge of the three paradigms at the beginning of the interview. A five-point scale from 0 (no prior knowledge) to 5 (expert knowledge) was chosen. Table 2 shows that the experts have extensive knowledge in all four areas relevant to the interview, namely lean, digitalization, sustainability, and maturity models. It can be seen that this applies to the individual expert ratings as well as to the overall expert ratings.

Experts from different industries, such as automotive, mobility, and water technology, as well as from consulting, took part in the interviews. Care was also taken to ensure that different roles were represented, including both low-level management (LLM) and mid-level management executives (MLM) as well as specialists or consultants (see Table 2). A guideline was developed for the expert discussions, which contained a brief introduction to the project, an overview of the basic terminology, and an explanation of the user story structure.

The process of creating user stories can be summarized under the three Cs (Card, Conversation, Confirmation) [47, 51]. The card describes what the maturity model should fulfill for future-proof production systems. To this end, the user story card contains information about the stakeholder (i.e., the perspective), the function or requirement to be fulfilled, and an associated justification [47, 48]. The user stories were then converted into requirements.

A total of 15 requirements for a maturity model for future-proof production systems were identified and are shown in Figure 6. They are divided into *general requirements* (index G), *content requirements* (index C), and *structural* *requirements* (index S). While the general requirements describe the quality criteria and application-related criteria to be covered by the model, the content requirements relate to the content properties and characteristics of the model and the objective that the maturity model should fulfill. This means that their focus is on ensuring a useful solution approach. Structural requirements address the structure or architecture of the model, considering the objective.

Table 2: Expert panel

<table>
<tr><th rowspan="2">#</th><th rowspan="2">Industrial sector</th><th rowspan="2">Job profile</th><th colspan="3">Experience in years</th><th colspan="5">Existing prior knowledge</th></tr>
<tr><th>$\geq 5 < 10$</th><th>$\geq 10 < 15$</th><th>≥ 15</th><th>$\tilde{x}_{L,D,S}$</th><th>$\tilde{x}_L$</th><th>$\tilde{x}_D$</th><th>$\tilde{x}_S$</th><th>$\tilde{x}_M$</th></tr>
<tr><td>1</td><td>Commercial vehicle</td><td>LLM</td><td>X</td><td></td><td></td><td>4</td><td rowspan="11">4</td><td rowspan="11">3</td><td rowspan="11">3</td><td rowspan="11">4</td></tr>
<tr><td>2</td><td>Automotive</td><td>LLM</td><td></td><td>X</td><td></td><td>4</td></tr>
<tr><td>3</td><td>Helicopters</td><td>Specialist</td><td></td><td></td><td>X</td><td>3</td></tr>
<tr><td>4</td><td>Strategy consulting</td><td>Consultant</td><td>X</td><td></td><td></td><td>4</td></tr>
<tr><td>5</td><td>Commercial vehicle</td><td>Management support</td><td>X</td><td></td><td></td><td>3</td></tr>
<tr><td>6</td><td>Commercial vehicle</td><td>LLM</td><td>X</td><td></td><td></td><td>3</td></tr>
<tr><td>7</td><td>Automotive supplier</td><td>MLM</td><td></td><td></td><td>X</td><td>4</td></tr>
<tr><td>8</td><td>Water technology</td><td>Project lead</td><td>X</td><td></td><td></td><td>3</td></tr>
<tr><td>9</td><td>Mobility</td><td>MLM</td><td></td><td>X</td><td></td><td>3</td></tr>
<tr><td>10</td><td>Mobility</td><td>LLM</td><td>X</td><td></td><td></td><td>3</td></tr>
<tr><td>11</td><td>Automotive</td><td>Internal consultant</td><td></td><td></td><td>X</td><td>5</td></tr>
<tr><td colspan="11">$\tilde{x}$: Median; Indices: L: Lean; D: Digital; S: Sustainable; M: Maturity
LLM: low-level management; MLM: mid-level management</td></tr>
</table>

In addition to the general quality criteria *objectivity*, *reliability*, and *validity* (G-1 to G-3) [54], *applicability* (G-4) addresses the requirement that the maturity model should be intuitive and easy to use to ensure straightforward and low-effort application in practice. *Traceability* (G-5) addresses the need for a maturity model that is understandable through a clear description of its contents, to ensure the comprehensibility of the assessment results. G-6 describes the need for the maturity model to be universally valid, i.e., independent of factors such as company size or industry, thus enabling comparability within the company and across company boundaries. G-7 addresses the adaptability of the model to the needs and characteristics of an organization. This is to ensure that only those elements are assessed that are most relevant to the company's current situation.

With regard to the six identified content requirements, C-1 (*interdependencies*) ensures that the maturity model considers or shows the interdependencies of the three paradigms of lean, digital, and sustainable production to recognize or consider synergies. This also makes it possible, for example, to prioritize the elements after the assessment. The *holism* requirement (C-2) refers to the need for a holistic view on the object of investigation (the company) regarding the paradigms relevant to future viability to comprehensively consider all relevant areas of the paradigms. C-3 describes the requirement that the maturity model must be designed in such a way that the extent to which individual elements of the paradigms influence the targets of a production company becomes apparent, so that both a targeted assessment and a prioritization of actions are possible. The *model type* (C-4) implies that the model to be developed enables the assessment of both the current and the target state, and the *area of application* (C-5) of the maturity model considers the production orientation of the model. Both requirements therefore aim to create transparency about how good a company is already in its production regarding the three paradigms and to identify or derive improvement measures. The *extended functionality* (C-6) is intended to ensure that the user of the model has certain options to customize or display additional information, such as the ability to add notes or prioritize elements in the evaluation.

The requirement that the maturity model must be designed in such a way that the paradigms are described on several levels is addressed by the structural requirement of *multidimensionality* (S-1). This is to ensure different levels of granularity and thus information content of the paradigms in order to enable aggregation of the assessments and thus to provide role or hierarchy-dependent results. It allows, for example, a production engineer to see a more detailed view of the maturity levels to gain deeper insights into the assessment within the paradigms, while a plant manager can see an overall assessment of how lean, digital and sustainable the production system is. S-2 (*level of detail*) requires the model to describe the individual paradigms concretely and uniformly so that the elements to be assessed are tangible and all necessary information is available.

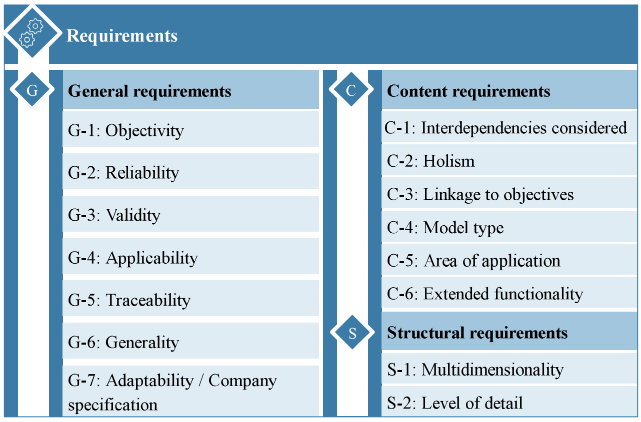

Figure 6: Requirements for a maturity model for future-proof production systems

The 15 requirements identified for a maturity model for a future-proof production system show that in addition to the seven general quality and application criteria, the content requirements are important for the model development to ensure a theoretical and practical contribution. In addition, it becomes clear that *multidimensionality* and *level of detail* are important criteria to capture and manage the complexity and breadth of the subject area. Thus, the expert-based requirements represent an extension of the previously introduced requirements based on the motivation of the research.

5. Discussion

Manufacturing companies are facing an increasing number of challenges due to the volatile environment. To meet these challenges, production systems need to be designed for the future. This article has shown that the three paradigms of lean, digital, and sustainable production are relevant to ensure future viability. In addition, it has become clear that although the concepts of lean, digital, and sustainable production are well known and there is a desire among companies to fully implement them, they have yet to be fully implemented. The article also highlights the importance of a maturity model as a tool for companies to create transparency through the ability to evaluate the three paradigms. In addition, the relevant requirements for a maturity model for future-proof production systems were defined as a basis for the development of a maturity model. For this purpose, 15 requirements were identified, which can be assigned to the groups general, content, and structural requirements.

A special feature of the paper is that the study's results were derived based on an international expert group and used to evaluate the assumptions made. The confirmed assumptions derived from the global results of the study were also analyzed for their specific applicability to the German market by examining the German results individually. The results showed that the assumptions can also be confirmed for the German market. Furthermore, the expert interviews conducted for the requirements analysis were limited to 11 participants, which provides an opportunity for a further expansion of the work. However, the empirical study was conducted in addition to the literature-based data collection. Moreover, the interviewees were experts in the area of the study and contributed knowledge from different industries and companies, with a high degree of overlap in the requirements mentioned for the maturity model.

The next step is therefore to develop a maturity model for future-proof production systems, considering the defined requirements. The developed maturity model will then be applied in the industry and the requirements will be evaluated for fulfillment as part of a validation process.

Acknowledgements

The authors would like to thank the Bundesministerium für Wirtschaft und Klimaschutz (BMWK) for the generous support within the research project SmartMan (13IK033J).

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