

Integration of sustainability into product development: insights from an industry survey

Sachira Vilochani ^{1,2,✉}, Tim C. McAloone ^{1,2} and Daniela C. A. Pigosso ^{1,2}

¹Technical University of Denmark, DTU Construct, Denmark,

²Technical University of Denmark, Centre for Absolute Sustainability, Denmark

✉ sacvi@dtu.dk

Abstract

Sustainable Product Development (SPD) enables the systematic incorporation of sustainability into product development and can be achieved by implementing a number of management practices. An industry survey was conducted to investigate the capability of manufacturing companies to apply a consolidated set of 61 SPD management practices. The results indicate that despite the high interest for SPD, the uptake of SPD practices in industry is still behind the state-of-the-art literature. Hence, a greater improvement opportunity exists in the industrial uptake in SPD.

Keywords: *sustainable product development, management practices, sustainable design, ecodesign, sustainability*

1. Introduction

Sustainable Product Development (SPD) aims to enable the systematic incorporation of environmental, social and economic considerations into the Product Development Process (PDP) (Vilochani et al., 2023). Over the past years, SPD has been increasingly important for manufacturing companies due to increasingly tougher regulations and market demands, as well as more ambitious sustainability strategies (Mattiola et al., 2014). While conventional design targets such as cost, quality, safety are still leading product performance, the importance of the consideration of sustainability aspects together with lifecycle thinking is significantly increasing (Buchert & Stark, 2019). The systematic incorporation of sustainability into the PDP can be supported by a number of SPD management practices, defined as generic practices involved in the management of the product development and related processes (Pigosso et al., 2014).

The state-of-the-art, as recently systematised by Vilochani et al., (2023, 2024), contains 61 SPD management practices, which can support enhancing the sustainability performance of the developed products, across their entire lifecycle. Nevertheless, despite the existence of large number of SPD practices, there is a limited understanding related to the extent to which these practices are currently being applied by manufacturing companies. Hence, this research intends to identify the current capabilities of manufacturing companies in applying a set of SPD management practices during their PDP through an industry survey. The results of current capabilities are compared with the existing literature on SPD practices to identify possible linkages between the trends of SPD in academic literature and current capabilities of manufacturing companies towards SPD.

The research methodology is presented in Section 2, explaining the steps carried out to conduct the industry survey and comparison with the existing literature. Section 3 presents the results of the survey together with the discussion of main findings. Conclusion and final remarks are presented in Section 4.

2. Research methodology

This research builds on a systematic review of the literature, which results in the consolidation of 61 SPD management practices (Vilochani et al., 2024). The research methodology consists of two main elements: (i) a theoretical study to identify the evolution of SPD management practices based on defined set of segments (Section 2.1); and (ii) an industry survey to investigate the application of SPD management practices in manufacturing companies (Section 2.2).

2.1. Theoretical study

The theoretical study was conducted to assess the recurrence of the 61 SPD management practices consolidated during the systematic literature review (Vilochani et al., 2024), shedding light into their evolutions. The systematic literature review resulted in the identification of 312 studies, which were reviewed for the identification and systematisation of the SPD management practices. The identified practices were classified across eight periods (i) 1999-2001, (ii) 2002-2004, (iii) 2005-2007, (iv) 2008-2010, (v) 2011-2013, (vi) 2014-2016, (vii) 2017-2019 and (viii) 2020-2022. The literature search was carried out in March 2022, and included studies published from 2010 onwards (nevertheless, 41 studies before 2010 were also included due to snowballing). To enable the analysis, the 61 SPD management practices were clustered into eight segments, based on content analysis (Table 1).

Table 1. Key segments of SPD management practices

Segment	Explanation
<i>Corporate sustainability strategy and policy</i>	Develop, deploy and update the company strategy and policy for integrating sustainability into the PDP.
<i>Sustainable product requirements</i>	Identify and deploy product related legislation and customer requirements into the product specifications.
<i>Facilitate sustainability integration into product development</i>	Facilitate the incorporation of sustainability into the PDP by developing specific tools, methods and guidelines.
<i>Sustainable product design and development</i>	Design products with enhanced sustainability performance using the available/new knowledge and tools.
<i>Portfolio and data management</i>	Manage the sustainability integration in the product portfolio and ensure proper data management for SPD.
<i>Supply chain, manufacturing and sustainable technologies</i>	Optimise supply chain, manufacturing and technologies by incorporating sustainability elements.
<i>Sustainability performance monitoring</i>	Measure the sustainability performance of products and processes.
<i>Organisational awareness and communication</i>	Set up the organisational structure and raise the awareness in all the levels of employees on SPD.

The list of 61 SPD management practices together with their identification codes is presented under the corresponding segment in Table 2. The identification codes represent the respective stage of the support process/PDP. The support processes represent the codes; 1-xxx Strategic planning, 2-xxx Programme management, 3-xxx Portfolio management, 4-xxx Technology development. Main stages of the PDP represent the codes; 5-xxx Planning, 6-xxx Conceptual design, 7-xxx Detailed design, 8-xxx Testing & prototype, 9-xxx Production & market launch, 10-xxx Product review, 11-xxx Gate assessment.

Table 2. SPD management practices and identification codes with their respective segments

Segment: Corporate sustainability strategy and policy
(1-001) Develop business, product and market strategies considering sustainability trends
(1-002) Integrate sustainability considerations in the strategic decision-making process
(1-003) Incorporate sustainability into the product-related vision, strategy and roadmaps at a strategic level
(1-004) Effectively integrate product-related sustainability goals into the corporate strategy

(1-005) Formulate the company sustainability policy and/or strategy, incorporating social, environmental and economic goals

(2-002) Deploy and maintain a sustainability policy and/or strategy in the product level

(1-006) Incorporate a feedback mechanism to update the company sustainability policy and/or strategy over time

(5-003) Examine internal and external drivers and barriers for the development of products with a better sustainability performance

Segment: Sustainable product requirements

(5-005) Identify relevant product-related sustainability legislation and/or regulations

(5-006) Deploy product-related sustainability legislations and/or regulations into product requirements

(5-004) Identify customers' requirements and priorities concerning the sustainability performance of products

(5-002) Include sustainability requirements into product target specifications

(5-001) Ensure aligning product design requirements with business model characteristics for enhanced sustainability performance (e.g., durable products for service-based business models)

(2-001) Link strategic sustainability commitments to product development activities and goals

(3-003) Manage trade-offs within and across the sustainability requirements (e.g., social vs. environment; or quality vs. cost)

Segment: Facilitate sustainability integration into product development

(2-003) Establish a prioritised programme for the implementation and management of sustainability into product development

(11-001) Make sustainability considerations part of the decision-making criteria during product development

(2-006) Implement Life Cycle Thinking into the product development and related processes

(2-004) Integrate sustainability into the management systems and practices for product development

(2-005) Develop company-specific guidelines for sustainable design

(2-010) Select and/or customise methods and tools to support sustainability integration into product development

(2-009) Integrate sustainability into existing methods and tools for product development

(2-008) Enhance the company's maturity on the integration of sustainability into product development through process formalisation

Segment: Sustainable product design and development

(5-008) Identify sustainability hotspots throughout the product's life cycle to prioritise the impacts to be minimised

(7-001) Select the most relevant design guidelines to address the sustainability hotspots

(6-001) Design product concepts to deliver functions with better sustainability performance

(6-002) Consider the sustainability performance of alternative design concepts for concept selection

(6-003) Design for sustainable behaviour

(6-004) Improve the interaction between product and service development towards enhanced sustainability performance

(7-003) Select materials based on their sustainability performance (incl. environmental, social and economic impacts)

Segment: Portfolio and data management

(3-001) Strategically consider the sustainability performance of products in the company's portfolio management

(3-002) Assess strengths and weaknesses of the current product portfolio and markets based on sustainability criteria

(2-022) Ensure transparent data collection for sustainability assessments within the company and across the value chain

(2-020) Build an information exchange system within the company for data exchange on sustainable product development processes, practices and projects

(2-014) Use digital methods and tools for sustainable product development, ensuring integration with existing IT systems

Segment: Supply chain, manufacturing and sustainable technologies

(7-004) Collaborate with stakeholders in the value chain (both upstream and downstream) to improve the sustainability performance of products

(9-003) Incorporate sustainability aspects into the identification, qualification and management of suppliers

(7-002) Select and/or develop more sustainable manufacturing and assembly processes

(9-001) Optimise the sustainability performance of existing manufacturing processes

(5-007) Assess technological and market trends related to sustainable product development

(4-002) Identify and/or develop new technologies that can contribute to improve the sustainability performance of developed products

(4-001) Define a strategic roadmap for development and implementation of sustainable technologies

(4-003) Evaluate the sustainability performance of technologies

Segment: Sustainability performance monitoring

(2-007) Define indicators to measure the performance of the sustainable product development programme

(11-002) Define indicators and measure the sustainability performance of products during development

(3-004) Measure and monitor the feasibility of new product development projects in relation to economic, environmental and social impacts

(11-003) Check the sustainability performance of products during the stage-gate assessments

(10-001) Monitor the sustainability performance of products during use and end-of-life

(5-009) Benchmark the sustainability performance of products, both internally and externally

(2-021) Conduct management reviews to evaluate the effectiveness of the integration of sustainability in product development

(9-002) Clearly communicate products' sustainability performance to customers

(11-004) Systematically identify and mitigate potential sustainability risks across the products' life cycle

Segment: Organisational awareness and communication

(2-011) Set an organisational structure for sustainable product development

(2-017) Ensure commitment, support and resources to integrate sustainability into product development

(2-012) Structure a systematic procedure to gather, utilise and improve sustainability-related knowledge in product development

(2-016) Provide training on sustainable product development best practices and tools for relevant employees

(2-015) Raise awareness on the benefits of SPD, by calculating the business case based on key internal and external drivers

(2-013) Achieve the behavioural and cultural changes necessary to support the implementation of SPD tools and methods

(2-019) Use pilot projects as a way to ensure team empowerment and bottom-up knowledge building

(2-018) Ensure appropriate communication across departments and hierarchical levels, concerning sustainable product development

(2-023) Motivate the practice of sustainable design through the establishment of incentive schemes

2.2. Industrial survey

An industrial web-survey targeting manufacturing companies was conducted to collect data regarding their level of implementation of the identified SPD practices, over a period of three months. The questionnaire employed in the survey comprised 10 sections (i.e., 2 sections dealing with general information of companies and 8 sections corresponding to the 8 segments (Table 1), which were further sub-divided into questions related to the capability in which the 61 SPD management practices are currently being applied. A five-point scale was used to formulate the questions related to the capability levels (Table 3), adapted from [CMMI Product Team, \(2006\)](#) and [Pigosso et al., \(2013\)](#).

Data of manufacturing companies without a formalised PDP were not included in the data analysis. As the survey was administered online, responses were expected from any manufacturing company irrespective of their origin, size, type of business etc.

Table 3. Scale used for the survey questionnaire

Capability level	Description
1 - Not applied	The practice is not applied
2 - Ad-hoc	The practice is applied informally and unsystematically
3 - Formalised	The practice is applied, documented, and responsibilities and resources are allocated
4 - Measured	The performance of the applied practice is measured and monitored over time
5 - Improved	The practice is applied and continuously improved

The results from the survey were analysed to identify the capability levels of companies in applying the SPD management practices together with a descriptive analysis of the companies. The distribution of practices with the highest and lowest capability was also analysed across the eight segments, as further described and discussed in Section 3.

3. Results and discussion

3.1. Evolution of SPD management practices in literature with their key segments

Figure 1 illustrates the historical development of the SPD management practices in literature from 1999 to 2022, across the eight segments. Altogether, 465 studies that discussed the SPD management practices were identified. In addition to the total number of identified studies for each period, the distribution of studies within each segment is also highlighted. The results showed a strong academic interest from 2011, which has the highest peak during 2014-2016. This increment can be attributed to the increased research interest on ecodesign, not only the product development itself, but also value chain approach that can influence the overall sustainability performance of products (Pigosso et al., 2015).

A slight decline in the number of studies is visible towards 2022, most likely due to the introduction of other correlated areas to sustainable design such as circular product design and sustainable business models (it is important to note, however, that the review only covers articles until March 2022). Almost all the segments have been increasingly discussed from 2011 onwards, building upon the momentum created by earlier academic literature in the four preceding periods (1999-2010).

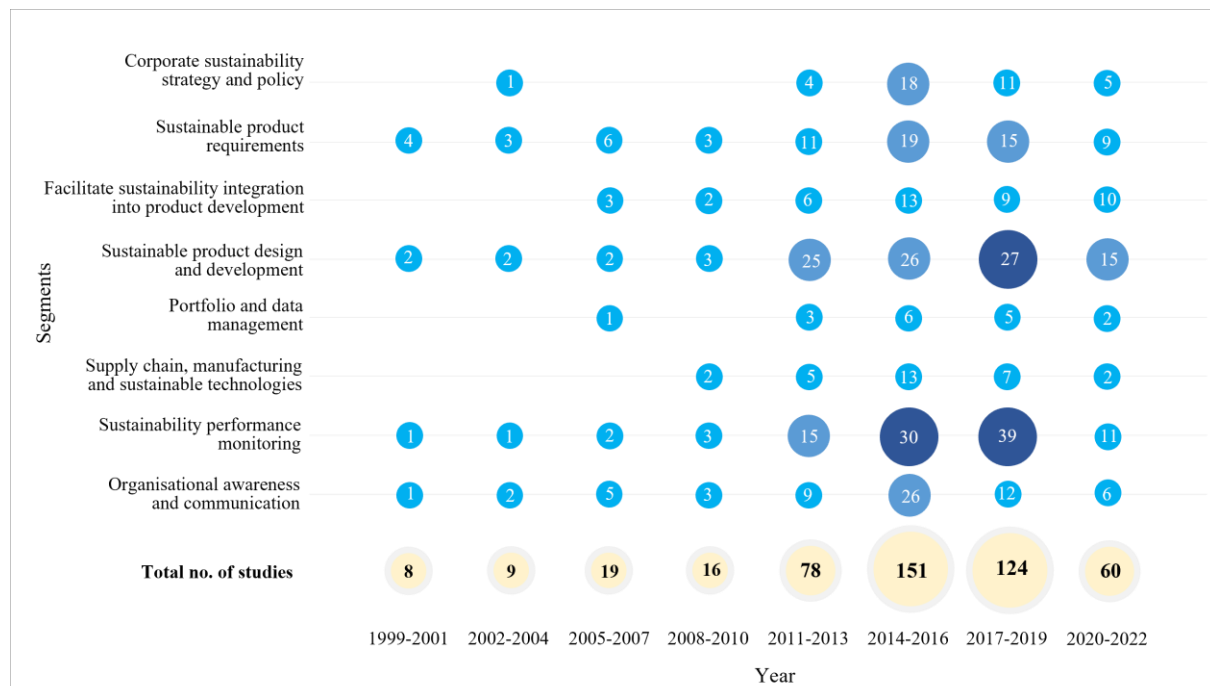


Figure 1. Distribution of studies across the SPD segments over the years

During these initial periods, "*Sustainable product requirements*" and "*Organisational awareness and communication*" were widely discussed, and a significant focus was given to environmental performance evaluation using different tools such as Life Cycle Assessment (LCA). The least discussed segments were "*Corporate sustainability strategy and policy*", "*Portfolio and data management*" and "*Supply chain, manufacturing and sustainable technologies*" within the early periods. "*Sustainability performance monitoring*" is the segment with the two highest number of studies (39 and 30), observed during 2017-2019 and 2014-2016. Corporate sustainability performance monitoring has been on the spotlight for many companies, as a way to improve their sustainability performance and corporate image across product portfolio. More recently, in an effort to develop a tool to systematically assess sustainability performance during product development, [Hallstedt et al., \(2023\)](#) stresses the importance of having well-established sustainability criteria in performance monitoring.

The next highest number of studies were focused on "*Sustainable product design and development*" during 2017-2019. Due to the increasing pressure to achieve sustainability targets, sustainable product design and development has been gaining attention not only by the manufacturing companies, but also by academia ([Ahmad et al., 2018](#)). Further to compliment the rising needs, intense development of new tools and methods were also observed ([Pigosso et al., 2013](#)), leading to higher number of research publications throughout these years. "*Organisational awareness and communication*", "*Sustainable product requirements*" and "*Corporate sustainability policy and strategy*" have also gained some attention (2014-2019). Awareness on the importance of sustainability integration into product development is crucial for a company to improve their sustainability over time. Further, the greater emphasis on commitment of top management to drive the effective implementation of sustainable design via sustainability policies and strategies ([Watz & Hallstedt, 2022](#)) were increasingly discussed over the years. The observed greater interest of the research related to sustainability requirements highlights the importance of sustainability integration into the PDP. Even though the stakeholders can positively influence the sustainability performance of the products through collaborative sustainability practices such as performance monitoring ([Ahmadi-Gh & Bello-Pintado, 2021](#)), a less focus in the literature was observed until 2007 and a dynamic, but slight increment was observed over the years up to date.

"*Facilitate sustainability into product development*" is another segment which has not discussed in the academic literature until 2004 with the lack of adequate tools, methods, guidelines ([Salari & Bhuiyan, 2016](#)). Nonetheless it was started gaining attention over the years with the need of tools, methods and guidelines that support the SPD process. Even though the systematic use and acceptance of existing product design tools is much lower in the industry, a trend has observed to integrate tools from other fields such as incorporation of Cost Benefit Analysis (CBA) to LCA tools ([Ahmad et al., 2018](#)) that might have led to expand the area of research.

3.2. Capability of manufacturing companies in applying the SPD management practices

The survey to investigate the capability of manufacturing companies in applying the SPD management practices was completed by 20 companies, representing 14 different manufacturing sectors (Table 4). The sectors were classified according to the statistical classifications of economic activities (NACE) ([European Commission, 2008](#)). The majority of the companies (90%) are in Europe while 10% of them are from North America. Amongst the 20 companies, 14 respondents bear positions related to sustainability (such as sustainability manager, sustainability specialist, sustainability lead). The other respondents bear the positions representing management, product and research and development related positions.

The sectors offer a broad coverage of both business to business and business to consumer companies, across a number of different product categories. The highest number of manufacturing companies (30%) are within the machinery and equipment sector. The responses from a diverse range of manufacturing companies provided insights into how companies across different sectors act upon integrating sustainability into their PDP.

Table 4. Classification of manufacturing companies participated for the survey

Sector	No. of companies	Sector	No. of companies
Machinery & equipment	6	Non-metallic mineral products	1
Electrical equipment	2	Paper and paper products	1
Basic pharmaceutical products & pharmaceutical preparations	1	Mattresses	1
Rubber & plastic products	1	Medical and dental instruments and supplies	1
Computer, electronic & optical products	1	Wholesale of pharmaceuticals and nursing supplies	1
Wood products (including furniture)	1	Wholesale of wood, construction materials and sanitary equipment	1
Chemicals & chemical products	1	Wholesale trade services of other machinery and equipment	1

The average capability levels of companies across the eight segments are presented in Figure 2, which also includes their relative occurrence in literature on SPD. In general, most of the companies have a formalised way of applying the SPD practices across all the segments, which means that the respondent companies have already started to define systematic processes for the application of the SPD practices, with the allocation of the necessary resources and responsibilities. They are also rethinking ways to improve sustainability and quality requirements by designing and engineering sustainable products across their life cycle (Fuchs et al., 2022). Yet, the fullest capability to apply the practices with a monitoring mechanism and continuous improvement has not yet been achieved by most of the respondents.

Segments	% of companies					% of studies
	Not applied	Ad-hoc	Formalised	Measured	Improved	
Corporate sustainability strategy and policy	5%	15%	40%	10%	30%	8%
Sustainable product requirements	5%	30%	35%	10%	20%	15%
Sustainability integration into product development	0%	20%	40%	30%	10%	9%
Sustainable product design and development	5%	35%	35%	15%	10%	22%
Portfolio and data management	10%	30%	20%	30%	10%	4%
Supply chain, manufacturing and sustainable technologies	5%	15%	35%	30%	15%	6%
Sustainability performance monitoring	0%	40%	25%	20%	15%	22%
Organisational awareness and communication	10%	30%	20%	35%	5%	14%

Figure 2. Comparison of the literature and average capability level achieved by the number of companies over the 8 segments (in percentage)

It can be furthermore observed that 40% of the companies apply SPD management practices addressing "Corporate sustainability strategy and policy" in a formalised way, while 30% of the companies have an improved way of addressing the policy and strategy. Only 5% of the surveyed companies do not apply the practices related to sustainability strategy and policy. It is visible that amongst the eight segments, "Corporate sustainability strategy and policy" has the highest number of companies with an

improved capability. However, corporate sustainability has been discussed in only 8% of the literature for the analysed period (i.e., 1999-2022). Even though there were not many academic studies into the area, companies have already realised and started taking actions to tackle sustainability from its strategic levels. This pattern shows the greater interest of companies to consider sustainability into their products to minimise the impacts as well as to become competitive in the market. Having a comprehensive business strategy, specifically with embedded sustainability can lead the companies to meet the requirements of the stakeholders and helps to extend the performance of the entire value chain (Oertwig et al., 2017).

"Sustainable product requirements" have been discussed in recent studies (2014-2019), but only 20% of the companies are currently applying the practices at an improved level. Most of the companies (i.e., 35%) have a formalised approach, while another 30% still apply the practices in an ad-hoc manner. Even though the companies do not show the highest capability for this segment, a positive trend can be observed, demonstrating their increasing consideration of sustainability requirements (Blagu et al., 2023). Similarly, 40% of the companies have a formalised way of applying the practices related to the "Sustainability integration into product development" segment, which includes a number of practices for facilitating sustainability integration. While only 10% of the companies have achieved the highest capability, not many studies (9%) have discussed this segment. Interestingly, the segments in which the highest number of studies were found (i.e., "Sustainable product design and development" and "Sustainability performance monitoring") have not yet obtained the highest capability in companies, being still applied either in ad-hoc or a formalised level. Even though the tools and methods to integrate sustainability into product development are abundant, some companies still do not have a systematic process for sustainability integration (Pigosso et al., 2013).

Capabilities within "Portfolio and data management" have progressed with 30% of companies currently measuring and monitoring the performance of the practices over time. This shows the efforts of companies to deal with the increased consumer demands for individualised products in minimising the overall impacts and costs of developed products (Medini et al., 2020). However, this is also observed as one of the segments with the highest number of companies at a capability "not applied". Furthermore "Portfolio and data management" is the segment identified with lowest number of studies (4%) among all the segments. Companies need to manage their product portfolio to address the customers' demand for diverse products to maintain their competitiveness in the market. Yet, there is a gap in managing the product portfolio to match the customer demand with limited strategic sustainability perspective in the approaches for portfolio management (Villamil et al., 2022).

A highest percentage (35%) of companies have a measured approach in applying the practices related to "Organisational awareness and communication" but only 5% of the companies have achieved the highest capability (i.e., improved). There are still some difficulties for companies to adopt sustainability practices together with integrating right skills from the employees that drives towards their sustainability goals (Athalye et al., 2009). Even though some studies concluded that the awareness of companies increases in response to stakeholder requests (Ferreira-Quilice et al., 2023), a higher number of companies (10%) that do not apply the practices for this segment was recorded during this survey. Additionally, communication within a company is one of the basic, but crucial function that can gain employees commitment to embed sustainability into the company processes. SPD practices related to "Supply chain, manufacturing and sustainable technologies" are applied mostly in a formalised (35%) and measured (30%) manner by companies. Stakeholder engagement throughout the value chain is important to minimise the costs and environmental footprint while fulfilling customer expectations. Furthermore, there is an urgent need to integrate and collaborate with the cross functional actors to improve the overall performance of businesses (Kota & Bandi, 2015).

4. Conclusion

This article aimed to identify the current capability of manufacturing companies in applying SPD practices, further exploring the relationships between the observed capability of practices in relation to their occurrence in academic literature. An industry survey was conducted to collect the data on capability levels of 61 SPD practices and the data was analysed based on the average capability across the eight segments. The overall results shows that the majority of the companies have a formalised way

of applying the practices for most of the segments. "Corporate sustainability strategy and policy" has the highest average capability for most of the companies compared to all the other segments. Even though the highest number of studies were found on the segments "Sustainable product design and development" and "Sustainability performance monitoring", companies have not yet achieved the highest capability in these segments.

It was noticed that the growing interest in the literature has offered a wide range of potential means to incorporate sustainability into the PDP via the identified management practices. The results also indicate that the manufacturing companies have taken efforts to improve their SPD process, not only by looking at the PDP itself, but also considering other processes such as increasing the awareness of employees, setting up overall company strategy towards sustainability, etc. Moreover, the efforts taken to embed sustainability into the internal processes is clear by having a formalised way of applying the SPD practices related to "Facilitate sustainability integration into product development".

This research concludes that the capability of sustainability integration into the PDP has been gradually improving by the manufacturing companies, but not yet fully exploited across the identified segments. By identifying the trends in academic studies for different segments and the current capabilities of companies towards those segments, this research contributes not only to the SPD literature but also to its practical application by companies. A thorough qualitative analysis of the surveyed companies will be carried out in the future publications to further observe the determinants of the varied capability levels of companies. As a limitation, this research only provides perspectives of real application of SPD practices by looking at limited number of companies. Nevertheless, the perspectives on how the SPD management practices are being applied in the companies could be varied depending on several factors such as the geographical location, manufacturing sector, size of business etc. However, responding to an extensive survey questionnaire in this manner also stresses the interest of the participating companies towards SPD and gaining further knowledge and insights while providing their inputs. Therefore, an extended study could be carried out as future research to obtain further insights covering a wider range of manufacturing companies.

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