International Journal of Business and Management Invention (IJBMI)
ISSN (Online): 2319 – 8028, ISSN (Print): 2319 – 801X
www.ijbmi.org || Volume 7 Issue 8 Ver. III || Month, 2020 || PP—01-08

Trends Affecting PLM Processes of Large Industry Companies

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ABSTRACT: *To survive in today's changing and interconnected world, industrial companies must constantly improve their business processes and keep them up to date to remain globally competitive. This also applies to Product Lifecycle Management (PLM) processes, one of the core areas of industrial companies. Identifying the most important changes that will influence PLM processes today and in the future is part of this research article. With the help of a qualitatively oriented systematic literature research of practical studies and surveys from industry, the topic was approached. Ultimately, this article provides eleven relevant factors, trends and developments that will change and influence the PLM processes of industrial companies. The results show, among other things, a strong influence of digitalization and a further increase in the requirements of the IT landscape underlying the business processes.*
KEY WORDS*: Business processes, PLM, Trends, Industry companies*

Date of Submission: 07-11-2024 Date of acceptance: xx-xx-xxxx

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I. INTRODUCTION

Acronyms such as VUCA (Volatility, Uncertainty, Complexity, Ambiguity) and BANI (Brittle, Anxious, Nonlinear, Incomprehensible) can be found in literature in an attempt to describe the problems of the current world [1]. Examples of these problems and difficulties can be found in many areas. For example, the bureaucratic environment of the twenty-first century is defined by volatility, uncertainty, complexity, and ambiguity [2] and wars or pandemics negatively change the condition of this world [3]. Companies must counteract this change and, for example, set up smart supply chains that are quick to respond to changes or redesign business processes [4]. Especially as the business environment is constantly changing, processes must also grow along with it [5]. PLM processes, whose basic components are summarized and illustrated in Figure 1, based on various sources [6-8], are not excluded from this. The aim of this research article is to research which global trends, changes and developments will have an impact on current and future PLM processes, whereby large industrial companies are considered in this article. In the PLM environment, there are already articles and papers in some areas of research on the trends and developments influencing PLM processes. This is the case, for example, with regard to Artificial Intelligence in PLM [9], Blockchain applications in PLM [10], incorporating sustainability into PLM [11] or Digital Twins and Threads in PLM [12], just to name a few. In the area of large industrial companies with a strong practical focus and high-level view, this is not the case and this blind spot should therefore be closed. To classify companies as large, this article follows the quantitative definition of the German Institute for SME Research, which states that large companies employ more than 499 people and generate more than EUR 50 million in turnover [13].

Figure 1: High level components of PLM business processes

Portfoliomanagement	Development	Marketing	Phase out
• Innovation • Market potential analysis • Technology roadmap • Product strategy	• Market and product requirements • Conception and development • Production preparation	• Market launch • Monitoring product and market development • Supporting SCM and CRM processes	Discharge management

Source: own research

II. RESEARCH APPROACH

The aim of this study was to investigate which global developments, influences and changes affect the PLM processes of large industrial companies today and in the future. The approach of this research project largely followed that of a research project already carried out for the Customer Relationship Management processes of large industrial companies [14] and consisted of two stages. The first step was to select suitable material.

As it was a top priority to incorporate results from practical experience into the study, only suitable material in the form of practical studies or surveys was collected. An attempt was made to select only those whose study participants came primarily from large industrial companies and thus represented practical experience. This selection process was limited to studies published in English or German between 2019 and 2024, whereby a total of 15 studies were identified [15]-[29]. In the second step these were examined in detail and changes and trends that influence the PLM processes of industrial companies were summarized in a list. Only those trends that occurred at least four times were included in the analysis. The research approach identified eleven trends and developments that are very likely to influence the PLM business processes of large industrial companies and were clustered into three categories (chapters 1-3) and are shown in Figure 2. These trends and changes were then described with the help of further specialist literature in order to paint a comprehensive picture of the most important developments.

III. RESULTS - TRENDS AND CHANGES THAT INFLUENCE FUTURE PLM PROCESSES

The relevant developments, changes and trends were in the three categories: changes in (product) development and production processes, sustainability and compliance as well as technological progress and high demands on PLM systems are described in the following chapters.

Figure 2: Influencing factors and changes in the PLM area with an impact on business processes

	[15] Dassault Systèmes SE: n.o. 2023	[16] BearingPoint GmbH: Bahrenburg et al. 2019	[17] Fraunhofer IEM: Dumitrescu et al. 2021	[18] PROSTEP AG & BHC GmbH: Goerisch et al. 2021	[19] Tech-Clarity Inc.: Brown 2022	[20] PwC: Geissbauer et al. 2019	[21] Cognizant Techn. Solutions: Singh/Kansupada 2019	[22] Quadrant 2023: n.o. 2023	[23] Fraunhofer IPK, CONTACT, VDI: Lünnemann et al. 2019	[24] Aras Corp: Guignard 2023	[25] Oracle & engineering.com: Tara 2019	[26] Roland Berger GmbH & VDMA e.V: Langefeld et al. 2022	[27] Capgemini Research Institute: Mitnick et al. 2022	[28] Bain & Company Inc.: Suter et al. 2023	[29] Deloitte: Wellener et al. 2022
1. Changed (product) development and production processes															
Shift towards digital offerings/Smart Products		*x*	*x*	*x*		*x*			*x*	*x*		*x*	*x*		
Increasing product and production complexity		*x*	*x*						*x*						*x*
Shorter innovation cycles		*x*	*x*					*x*			*x*		*x*	*x*	
Individualized mass production		*x*	*x*			*x*				*x*		*x*	*x*		
Agile product development			*x*	*x*		*x*							*x*	*x*	
Increasingly collaborative PLM		*x*	*x*			*x*	*x*	*x*	*x*		*x*		*x*	*x*	
2. Higher focus on sustainability and compliance															
Sustainability takes center stage	*x*		*x*					*x*		*x*		*x*		*x*	*x*
Increased effort in terms of compliance and regulation		*x*	*x*	*x*	*x*							*x*		*x*	*x*
3. Technological progress and high demands on PLM systems															
Increasing digitalization of PLM processes	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*		*x*	*x*	*x*		*x*	
More widespread use of innovative technologies	*x*	*x*	*x*			*x*	*x*	*x*			*x*			*x*	*x*
Changing requirements for PLM systems	*x*	*x*	*x*	*x*	*x*	*x*	*x*		*x*		*x*				

Source: own research

1. Changed (product) development and production processes

"Digital product development also paves the way for the development of digital products and digital services. Digital products generally build on the traditional base offering. [...] Fully-digitized products go beyond enhancements [...] and extend to digital, data-driven services that enhance the physical product" [20].

Although the concept of Smart Products is nowadays commonly known and gets developed further [30] there is still a need to better understanding [31] and no general widespread consensus on the definition of Smart Products [32]. Depending on the field of research, the definition can vary.

From a technological perspective, intelligent products are characterized by "integration of sensors, actuators, processors, software, control technologies, communication technologies and Artificial Intelligence" [33]. Simpler definitions distinguish Smart Products from normal products through the integration of electronic chips and systems that are connected to the internet [34]. They have many benefits as Ünal describes: "Smart Products and services are preferred by customers because they offer more intelligent solutions and personalized functioning" [35]. In addition to Smart Products, digital services are also coming to the fore. Gebauer et al. describe how traditional product manufacturers have been driving the expansion of the service business alongside the traditional core product business for years and how "recently, service business expansion has taken up many of the new digital technologies offered through the digital transformation" [36]. Digital servitization can be cited as an example of this type of service [37]. Here one could mention the transformation of car manufacturers, whose core task was traditionally the production and sale of cars, into mobility service providers [38] that integrate new digital car sharing models into their portfolio [39]. Even if sales increases through digital offerings are still relatively low in practice, the potential is very high [40]. This is also and studies shown in studies: According to current company estimates, the proportion of Smart Products will continue to increase to almost 40% by 2026. However, significantly greater growth is expected in the area of smart services like predictive maintenance or system integration. Here, companies in the electrical industry expect the share of sales to double from around 13% today to around 24% by 2026 [41].

Globalization, increasing product complexity, shorter development cycles and transnational value creation networks are becoming ever more complex [42] and experts see an unbroken trend of increasing complexity within their market services [17]. Although complexity has been around for a long time and occurs across all industries, manufacturing companies in particular are suffering greatly from an ever-increasing degree of complexity [43]. A collaborative study by the consulting firm BearingPoint, in which over 70% of the participating companies had an annual turnover of more than one billion euros at the time of the study, surveyed 50 experts from sectors such as mechanical and plant engineering or the automation and electrical industry in German-speaking countries. According to the study, it can be assumed “that product complexity will continue to increase in the coming years” and a clear majority of 71% of those surveyed are “inadequately prepared for increasing product and production complexity” [16].

Shortening the time to market is often cited in the literature as a desirable goal [20,44,45] and offers companies competitive advantages, faster revenue generation and higher customer satisfaction [46]. Increasing product complexity combined with shorter development cycles pose major risks for companies [47] and especially engineering firms are under increasing pressure to bring new products to market faster [28]. This growing pressure is reflected, for example, in a global study conducted by Deloitte and NASSCOM, which was largely conducted in automotive and transportation, hardware, electronics and other industrial sectors. It found out that “there is a strong push to shorten innovation cycles and get faster to market”. At 43 percent, the importance of the trend of accelerated innovation cycles and shorter time to market was confirmed as one of the top priorities of the surveyed companies [48].

"Not only in automotive engineering, but in almost all industries, there is an increasing trend toward individualized products, in the extreme toward individual one-off products" [49]. Personalization is particularly relevant in the global manufacturing industry and this trend is expected to increase in the future, which will inevitably influence development and production processes [50], although this is not a new concept [51]. In contrast to mass production, which always produces the same product in large quantities identically [52], the combination of standardization with individualization in production is referred to as mass customization or mass personalization” [53]. The management consultancy Roland Berger conducted a study by interviewing managers from medium-sized to large companies with an international presence from various industries such as and identified individualized mass production as a key trend. Mass customization enables companies to design products individually and cost-efficiently according to customer requirements, partly thanks to new technologies, which challenges traditional economies of scale. The study concludes that this will mean “some profound changes for OEMs and manufacturers in their business processes” [54].

Eigner describes how the “industry is undergoing a disruptive change process that only agile and innovative companies” will successfully shape [55]. Agile principles have so far proven themselves in clearly defined areas, such as software development, but offer great potential for product development, provided that the company's organization is comprehensively adapted to agile principles [56]. Agile product development aims to change the existing organization and make it more competitive [57]. Even though companies often combine agile and traditional product development [58] advantages of agile approaches are perceived by companies [59], which is confirmed by practical analyses. A global study by Capgemini, conducted in companies with a turnover of at least one billion US dollars in sectors such as consumer goods and the automotive industry, in which over

1000 participants took part, cites the promotion of agility as a key element in the design process. Emerging Smart Products and services require new design practices where engineering and product teams should adopt an agile approach. The research showed that half of executives surveyed (51%) are allocating funding and setting KPIs focused on agile development and 61% have "hired or contracted agile professionals to guide their teams" [27]. Another study of primarily large companies and corporations from engineering, automotive and transport technology sectors in the German-speaking area found that in the next three years, respondents will focus on scaling agile methods across the project and management level, with participants believing that organizational structures must change in order to introduce agile methods in a more targeted manner [60].

Companies expect an increasing integration of development partners in the PLM process: According to a joint study conducted by the Fraunhofer Institute for Production Systems among 183 participants from industries such as automotive or mechanical engineering, 71% of respondents expect an increase in collaboration partners in the product development process. According to the study, this is primarily due to the emergence of Smart Products that integrate diverse functions into the product system [23]. This type of collaborative product development was made possible by the option of working in a shared development environment based on cloud technology [61] and must also be digitally supported or function purely digitally, because the collaboration networks in many companies, but especially those of the partners and suppliers around the company, are usually geographically dispersed and often international [62]."Companies need to become part of an integrated partner ecosystem that focuses on internal and external co-creation with agile and digitised development processes and methods with a clear customer focus" [20] whereby customers and other stakeholders are increasingly involved in product development alongside development partners [63,64]. Russell and Taylor emphasize the benefits of collaborative working, such as speeding up product development [65]. A study at the Institute for Innovation and Technology, based on personal and group interviews with 36 experts from companies such as Siemens, Osram or Airbus and research institutions, dealt with so-called Collaborative Engineering. The results of the study recommend "mapping production with multi-component systems, which is characterized by a strong division of labour, in a joint, cross-company engineering process", which results in improved collaboration and coordination at an early stage of the life cycle [66].

2. Higher focus on Sustainability and compliance

Balduf et al. state that industrial companies are faced with new questions about what sustainability means for them at product level" and that "development complexity is increasing enormously as a result of the increasing integration of ecological requirements for products along the entire Product Lifecycle [67]. It is becoming increasingly difficult for companies to either adapt or modify existing information systems, including ERP systems, to meet the requirements of sustainable Product Lifecycle Management [68]. This is shown by a study by Dassault Systèmes, in which surveys were conducted among managers in mechanical engineering, high-tech and electronics industries, among others. One key finding is that although product manufacturers today mainly use PLM solutions to improve product quality, in future this will primarily serve to improve product sustainability [15]. In addition, a European study of companies in industries such as automotive, aerospace & defence and mechanical engineering found out that "companies that neglect the green transformation and do not take care of their carbon footprint will no longer be competitive in the short to medium term, and may even be discarded by customers", with 89 percent of the companies surveyed agreeing (36% of them strongly) that lasting economic success requires sustainable action [24]. The study also suggests that Product Lifecycle Management paves the way to becoming a sustainable company because the participating companies that use PLM (software) are better prepared to comply with ESG (Environmental, Social and Governance) standards, have a higher awareness of the importance of recycling and reduction and are significantly further along the path to a circular economy.

Compliance serves to prevent risk and avert damage in the company [69] and, depending on the definition, can be interpreted as "conformity with the law", which leaves "room for interpretation beyond conformity with the law" [70]. Corporate compliance is the entirety of all entrepreneurial activities for compliance with the legal and other external rules as well as the company's internal guidelines by the members of the company's executive bodies and employees [71], whereby external regulations, such as government regulations, influence the (PLM) processes. Experts note that the regulatory landscape is becoming more complex [72] and consequently ensuring compliance requirements is becoming increasingly complex in view of ever-increasing regulation [73]. Stark also describes that compliance with regulations is a very time-consuming task for companies due to increasing and frequently changing legal requirements and that PLM processes in particular are affected by this but can also contribute to solving these tasks [6]. In a global study, PwC surveyed over 4,700 CEOs, two thirds of whom managed companies with a turnover of more than 100 million US dollars. When asked to what extent the way in which their company creates, distributes and captures value will change over the next three years, 47% of participants stated that government regulations will influence this to a large or very large extent. Other significant trends and changes such as climate (30%) or demographic change (27%) were said to have a much smaller influence [74]. A big increase in compliance costs and increasing regulation can be observed in the area of ESG, for example. Wellener et al. advise companies to closely monitor the rapidly evolving ESG landscape and emphasize the impact of this development on companies as they make operational changes across their value chain [30]. Research by ESG Book, a leading sustainability data and technology company, found that ESG regulations have increased by 155 percent globally in the last ten years [75]. This strong growth means that companies have to react to new laws and regulations and keep an eye on them, which would mean additional effort. Although there are empirical studies that come to the conclusion that environmental regulations, for example, can lead to a decline in economic performance, there are also studies that do not find this correlation [76]. In addition to ESG, the area of AI regulations, for example, is also coming to the fore. An Accenture study describes how countries such as Brazil, China and the UK are monitoring the responsible development and use of AI and successively setting standards [77]. Conversely, this means that anyone who wants to develop or sell AI products and services must consider the requirements of the legislation for their organization. According to the study, the majority of companies believe that they will be affected by increasing regulation. Nearly all respondents (97%) believe that regulation will affect them to some extent. The study “The Artificial Intelligence (AI) global regulatory landscape” examines different and country-specific jurisdictions and defines six key trends in legislation. Due to a rapidly evolving AI regulatory landscape, it is advisable for companies to familiarize themselves with the respective AI regulations and to be able to establish robust and clear governance and risk management structures and protocols [78]. Ultimately, other studies also suggest that for many companies, dealing with legal requirements and regulations will shape a large part of development in the future [17] or the fulfilment of globally differing requirements will be a major challenge [16].

3. Technological progress and high demands on PLM systems

Wynn und Clarkson describe how "the traditional separation between product lifecycle stages is disappearing as companies use data to continuously develop their products", whereby digitalization is changing the traditional development process [79]. Digitalization offers great opportunities for the development of new products [80]. The survey and interviews of a study by Roland Berger in cooperation with the German Engineering Federation (VDMA) examined the most relevant trends for German mechanical engineering companies and classified digitalization as very relevant, with continuous, digital and internal data transfer across all interfaces between production, procurement, logistics or R&D, being named as a desirable state [26]. Ultimately, digitalization will also have a strong impact on PLM, as Singh and Kansupada aptly summarize: "PLM must leave the trenches and embrace the digital technologies that are transforming the business" [21].

The term “Digital Twin” is often used in literature in connection with digitalization and PLM and depends heavily on its specific area or application purpose [81]. “The origins of the Digital Twin concept and its associated model is well established in both industry and academic literature" [82] and have existed since the early 2000s [83]. “The market for Digital Twins is growing quickly, which suggests that even they are already used in many different industries the demand will persist for some time" [84]. A study of 200 managers from European industrial companies, conducted by PwC, distinguishes between different types of Digital Twins (product development, production/supply chain, resource or product lifecycle twins) and speak of “enormous potential for a broader application” [20]. Another representative study by the Fraunhofer Institute for Mechatronic Design Technology (IEM) [17] shows that “openness and acceptance of employees and customers with regard to new trends and technologies [...] is a critical success factor for the future” of engineering and cites Artificial Intelligence as an example. The use of Artificial Intelligence in particular opens up a wide range of possible uses for AI applications and specific applications for the various product creation cycles [85]. Another example of the increased use of innovative technologies is the area of augmented and virtual reality, which will continue to grow in the coming years and especially in the early product development processes, in which mainly concept work is carried out [86].

"PLM is implemented using IT systems such as product data management systems. [...] By avoiding errors and misunderstandings, industrial companies can gain advantages in shorter cycles, lower costs, and better quality from the adoption of effective PLM systems [87]. The software systems used in PLM processes will have to adapt to changing circumstances. A global survey of over 150 consumer goods industry executives found that current PLM systems are not meeting future requirements, with only a quarter of respondents believing that their current systems meet both current and future requirements [20]. Kulkarni et al. explain that the implementation of PLM in the modern manufacturing industry brings with it a variety of challenges and cite cloud PLM systems or new PLM architectures enriched with Artificial Intelligence as future trends [88]. Many decision-makers believe that companies are undergoing a major transformation and that PLM technology will be central to product innovation and development [21].

IV. DISCUSSION AND CONCLUSIONS

This research identified eleven changes and trends that will likely influence the PLM processes of industry companies now and in the future. Although some of them appear more often in the practical studies and surveys, the findings should not be ranked against each other, for example to determine whether the increased effort in terms of compliance and regulation is more important than individualized mass production. Nevertheless, it is noticeable that the point increasing digitalization of PLM processes seems to play a significant role in most studies, as it was mentioned very often. This is in line with the findings of a study of CRM processes, in which "Growing digitalization and automation" was also mentioned in almost all of the studies examined [14]. The third point, Technological progress and high demands on PLM systems, appears to be very important for companies, as the associated research results frequently appear in the study material examined. If one takes a closer look at Figure 2, one can conclude that points such as individualized mass production, increasing product and production complexity or shorter innovation cycles can only be mastered through increasing digitalization, consistent IT support (which is reflected in new requirements for IT systems such as PLM software) and innovative approaches.

V. LIMITATIONS AND FURTHER RESEARCH

The relevant developments, changes and trends were divided into three areas: changes in (product) development and production processes, higher focus on sustainability and compliance as well as technological progress and high demands on PLM systems. It is noticeable that production processes have an influence on the trends and changes identified, for example the point Individualized mass production influences the PLM processes of large industrial companies. As the production of goods per se does not fall under PLM, but under SCM processes, this point would also fit into an investigation of SCM trends and changes. The planning of production processes in turn falls under PLM. For this reason, it is not possible to make a precise distinction here. Important is that companies in practice classify this as very relevant. The findings are suitable for general statements in the company class examined. If one wants to dive deeper into these, much more differentiated and in-depth analyses are necessary. This differentiation can be seen, for example, in the fact that companies overall need increased effort in terms of compliance and regulation. This effort can vary from country to country and region to region. An example can be found in cybersecurity regulations, which pose diverse challenges for companies in different countries [14]. However, there are also strong spatial differences with regard to sustainability and its laws [89], which in turn can have an impact on companies and their various locations. The European Green Deal (EGD), for example, not only has a direct impact on the direct European member states, but also on companies that are not part of it [90]. The research showed that the demands on PLM systems will continue to increase. It would therefore be interesting for further research to investigate how these systems will change. In other words, which IT systems of which nature and considering the findings of this thesis will shape the PLM processes of the future.

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