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Early supplier involvement challenges in new product development projects: a bibliographic overview of lean production in the automotive industry

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ABSTRACT
The research is based on a literature review focused on early supplier involvement in new product development processes while working towards Lean production, especially for the automotive industry, where all actors must be fast and accurate. For practitioners, early supplier involvement is a topic that deserves serious attention since it impacts on decentralisation, promoting gains in quality, quantity, and execution time, as well as cost reduction and/or the acquisition of technical knowledge in developing products and production processes. The authors first introduce the key concepts, issues, and theoretical foundations concerning early supplier involvement challenges and new product development within organisations that affect their core processes and outsourcing strategies when seeking collaboration to develop more sophisticated technologies that a new product requires. The authors critically explore these issues, especially concerning earlier supplier involvement and its connection to the Lean philosophy, pursuing process tunning, considering production quantity, quality, and time, as well as avoiding penalising interruption within the automotive industry. The study provides the first critical review of potential challenges for a successful early supply involvement and, consequently, a successful new product development process decentralisation and the acquisition of technical knowledge in developing products and production processes needed to satisfy customers.

KEY WORDS
concurrent engineering, new product development, early supplier involvement, lean, production, automotive industry, feasibility

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Introduction

In today's competitive landscape, particularly in such industries as automotive, the imperative to accelerate time-to-market for new products is driving organisations to streamline their new product development (NPD) processes. This urgency arises from the need to swiftly seize market opportunities, enhance market share, and optimise returns on investments. The NPD represents a cornerstone of organisational success, encompassing the journey from generating new product ideas to transforming

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them into successful market offerings. Concurrent engineering (CE) emerges as a strategic approach, facilitating simultaneous design and development of all processes, with rapid access to pertinent information for informed decision-making. While NPD and CE have undergone continuous refinement over time to expedite series production, the integration of Lean product development (LPD) further enhances the NPD performance, leveraging CE as a key tool. However, amid these advancements, a notable gap exists in ensuring the feasibility of manufacturing processes for the final product, particularly when involving external suppliers. This critical concern underscores the importance of early supplier involvement (ESI), which seeks to bolster project feasibility, especially in external component manufacturing, through collaboration with suppliers possessing manufacturing expertise.

Furthermore, contemporary organisations increasingly outsource non-core processes to suppliers, capitalising on their cost advantages and technical proficiencies. As products demand increasingly sophisticated technologies, collaboration with suppliers becomes imperative to tap into specialised expertise, necessitating early supplier engagement in NPD processes (Stief et al., 2018; Pech et al., 2021). The central focus of this study is to explore the challenges associated with successful ESI implementation in NPD supported by CE, emphasising the pivotal role of ESI in enhancing NPD performance. This paper conducts a literature review to assess the relevance of ESI in current industrial contexts and evaluate its implementation while identifying associated challenges. Despite the abundant literature on supplier involvement in product development, quantitative studies linking this aspect with critical supply chain topics, such as risk management and information flow, remain scarce.

This paper follows a structured approach. Section 1 delineates the research methodology employed in this study, providing transparency regarding the adopted approach. Section 2 delves into a comprehensive literature review, exploring pertinent aspects of NPD and methodologies aimed at enhancing its performance. Key methodologies, such as Research and Development (R&D), Voice of Customer (VOC), and Design for Manufacturing and Assembly (DfMA), are examined, alongside critical insights into CE methodology for internal process enhancement. Additionally, LPD is discussed, offering insights into optimising the entire NPD process and introducing the pivotal role of supplier involvement. In Section 3, Results and Discussion, the focus shifts towards a detailed examination of supplier involvement, delving into the main challenges associated with its implementation. This section provides a nuanced understanding of the dynamics surrounding supplier engagement in NPD processes, paving the way for insightful discussions. Finally, the paper draws comprehensive conclusions regarding the NPD process and its implications for supply chain performance. Critical aspects driving the supply chain performance are highlighted, emphasising the imperative for organisations to evolve to effectively meet the diverse requirements of customers and end-users.

1. Research methods

Two methodological approaches were employed to conduct this study. First, a non-structured literature review identified the most relevant approaches affecting NPD and supplier involvement in this process. Next, a content analysis was performed on the selected documents from the literature review. A non-structured literature review is a technique for evaluating current literature on a specific topic without a pre-established framework or set of standards. Unlike systematic literature reviews, which follow a structured process with predefined search terms, inclusion/exclusion criteria, and data extraction methods, non-structured reviews offer a more flexible and exploratory approach. This method facilitates in-depth exploration of the subject, involving extensive reading and note-taking. Various sources, such as scholarly journals, books, conference papers, reports, and online databases, can be used to gather relevant information (Saunders et al., 2019).

This approach is particularly useful for exploratory research, where the primary objective is to comprehensively understand a specific subject, identify key discussions, and formulate hypotheses for future investigation. However, non-structured reviews may lack the reproducibility of structured reviews and are susceptible to researcher bias in the literature selection and interpretation. Therefore, researchers must maintain transparency in their methodology to minimise bias and ensure the reliability of their findings.

The limitations of unstructured reviews can be mitigated through a rigorous content analysis. Content analysis is a research method used to analyse qualitative data, predominantly text-based, to identify patterns within the data. This method involves comprehending the content in textual or visual resources, including interviews, articles, and other documents. Essentially, it is a systematic and organised technique for analysing information, allowing researchers to uncover insights that may not be readily apparent through qualitative or quantitative methodologies alone (Neuendorf & Kumar, 2016). The purpose of the applied research method was to investigate recent developments and innovations in NPD, CE and LPD tools and methodologies, particularly focusing on how these advancements improve results and performance. Additionally, the research aimed to examine the extent to which these methodologies incorporate ESI as an integral part. This investigation was especially pertinent to understanding the role of ESI in enhancing the feasibility of projects, particularly during their initial phases. In summary, ESI is typically included in NPD only when the article specifically focuses on ESI. NPD, CE, and LPD methodologies generally emphasise client relationships to a lesser extent, particularly during the early stages of a project.

The literature review was conducted using published studies from the Scopus and Web of Science databases, focusing on the challenges of ESI in NPD projects. The review involved a series of sequential searches to refine the results based on specific inclusion and exclusion criteria. The search utilised a set of keywords: "NPD", "CE", "LPD", and "ESI", looking for their occurrence in the "Article title", "Abstract", and "Keywords" fields. There were no time frame restrictions, allowing for an examination of how the topic has evolved over the years. The inclusion criteria comprised documents from international journals and conference proceedings written in English. The search yielded a total of 150 documents. These selected documents were then subjected to a descriptive analysis.

2. Literature review

This section presents the most relevant approaches from the literature supporting the NPD process, mainly the CE and LPD. This literature review aims to show that topics such as NPD, CE, and LPD always present innovations and new methodologies to help/support the organisation launch a product aligned with customer/society expectations. However, the scope of innovations focuses on improving performance in the stages that, in most cases, still occur within the organisation, almost always upstream of the industrialisation phase of the individual components (external suppliers) and the final product (organisation). Normally, these innovations do not reflect improvements in the industrialisation process to guarantee a validation phase without any problems (or minimal) and, consequently, to avoid delays in the agreed deadlines.

2.1. New product development

Organisations universally recognise the importance of refining the NPD process to ensure each new product's successful and timely launch. This process typically comprises five distinct phases, beginning with opportunity identification, which detects market or technology gaps, then concept development, product design, process design, and concluding with commercialisation and product launch (Kowang & Rasli, 2011). However, despite these efforts, Cooper (2019) presented sobering statistics indicating that many new products fail to achieve commercial success. Of every seven to ten new product concepts, only one emerges as a commercial success, with only 13 % of companies meeting their annual profit goals from new product efforts. Cooper outlined twenty critical drivers of success, categorised into tactical, business-level, and systemic factors, emphasising the need for a comprehensive strategy to drive successful NPD outcomes.

Notable among these drivers are "VOC: Building the voice of the customer" and "Quality of execution", highlighting the importance of customer involvement throughout development and the need for flawless execution to minimise waste (Cooper, 2019).

Thompson et al. (2018) and Tai (2017) delved into the critical aspects of NPD from complementary perspectives. Thompson and colleagues emphasised the pivotal role of DfMA in minimising late engineering changes (ECs) and optimising time-to-market efficiency. Their research underscored the importance of integrating production considerations early in the process and leveraging CE to enhance productivity and product quality. Additionally, they proposed using key performance indicators (KPIs) to continually monitor and refine NPD processes (Thompson et al., 2018). Concurrently, Tai (2017) shed light on the evolving NPD landscape, stressing the increasing complexity of interorganisational collaborations and the growing importance of information technology (IT) solutions like product lifecycle management (PLM) systems. The research advocated for the strategic use of PLM systems to streamline workflows, facilitate resource coordination, and effectively harness external knowledge. Companies can achieve superior NPD performance in today's dynamic market by focusing on process management capabilities and aligning activities with PLM systems (Tai, 2017).

Melander & Lakemond (2015) highlighted the crucial role of supplier collaboration in navigating technological uncertainty and fostering innovation in NPD projects. They advocated for collaborative initiatives that unite buyers and suppliers, leveraging their combined expertise to drive product development. Despite the challenges posed by technological unpredictability, collaborative projects offer opportunities for dynamic adaptation while mitigating risks through strategic organisational separation (Melander & Lakemond, 2015). These insights underscore NPD's dynamic and multifaceted nature, emphasising the importance of strategic foresight, organisational agility, and collaborative partnerships in driving innovation and securing sustainable competitive advantage in today's rapidly evolving marketplace.

Liu (2019) delved into R&D internationalisation and NPD recentralisation, highlighting the importance of understanding the dual functions of R&D: research and development. While research generates scientific achievements and patents, development drives new product innovation. However, patented knowledge may not translate into profitable innovations without proper NPD practices. R&D internationalisation involves creating or acquiring R&D centres abroad, often leading to a decentralised structure initially. Yet, as the number of autonomous R&D units grows, coordination challenges emerge, prompting recentralisation for better control and knowledge leverage on a global scale. These recentralisation processes are unprecedented in R&D internationalisation. Cheng & Yang (2019) investigated the relationship between creativity processes and new product performance, which is crucial for competitive advantage. Innovation stems from organisational creativity, with employee engagement in the creative process (CPE) playing a vital role. CPE involves problem identification, information search and encoding, and idea generation, which can overlap to expedite NPD. The study provides a comprehensive model connecting creativity research with NPD outcomes, highlighting the importance of CPE components as antecedents of new product performance. Moreover, it identifies NPD speed as a critical mediator in the relationship between CPE and new product performance.

Zhang and Min (2019) focused on knowledge hiding (KH) in NPD project teams, distinct from knowledge sharing, which poses challenges to team performance. While knowledge is essential for organisational sustainability, KH impacts project team performance negatively, mediated partially by team learning. KH often occurs in NPD project teams, hindering performance. The study based on data from 92 NPD project teams in China revealed a negative association between KH and project team performance, moderated by team stability. As team stability increases, the negative impact of KH on project team performance weakens, emphasising the importance of knowledge sharing within NPD teams.

Further, Waal & Knott (2019) investigated how small high-tech companies utilise tools to support their NPD activities. Their mixed-methods approach began with a survey of 99 companies, examining 76 tools across 12 functional perspectives on NPD, revealing significant variability in the considered scope. Addressing the prevalence of variability in tool use rigour and its drivers, the study sheds light on the differences between small and large companies in their approach to business processes and innovation systems.

In contrast, Chang (2019) delved into the realm of customer engagement during the NPD phase, analysing its impact on new product market performance. Their research scrutinised the synergistic or detrimental effects of engaging customers across different NPD stages. While traditional wisdom suggests engaging customers in distinct stages, Chang's findings indicate that simultaneous engagement across multiple stages yields more favourable outcomes. Particularly, involving customers in the ideation and development phases fosters synergistic effects by integrating customer knowledge into product ideation. However, relying solely on internal interpretations of customer data may limit its effectiveness. Ultimately, Chang's study underscores the importance of strategic customer engagement throughout the NPD process for optimal market performance.

2.2. Concurrent engineering

In the context of CE, the fundamental principle guiding the development of new products, known as NPD, is the comprehensive consideration of all aspects of a product's lifecycle right from the project's inception. CE was initially introduced in 1988 by the Institute of Defence Analysis (IDA), signifying a paradigm that involves designing a product simultaneously with its downstream production and support processes (Zidane et al., 2015). Unlike the traditional sequential development approach, CE fosters parallel work-in-flow activities within the NPD process, encouraging the simultaneous advancement of various project components. For instance, product design and planning activities can proceed concurrently, allowing for integration with production planning and control or even initiating product planning before finalising the concept. While this approach does not shorten the duration of individual activities, it effectively reduces the overall development timeline. Moreover, the parallel nature of work facilitates seamless information exchange among stakeholders, minimising unforeseen errors and the need for corrective actions later in the development process (Valle & Vazquez-Bustelo, 2009). At its core, CE embodies a holistic engineering and management philosophy addressing product lifecycle concerns, with its most notable aspect being the adoption of multidisciplinary and cross-functional team structures (Shouke et al., 2010). Organisations implementing CE have witnessed tangible improvements in various performance metrics, such as quality, cost, and time. Some reported benefits include reductions of 30–60 % in time-to-market, 15–50 % in lifecycle costs, and 55–95 % in engineering change orders (Fine et al., 2005). CE relies on three fundamental elements to realise such objectives: simultaneous workflow, timely involvement of all relevant stakeholders in product development, and fostering a collaborative teamwork environment (Koufteros et al., 2001; Valle & Vázquez, 2009). The typical image of CE implementation is the simultaneity obtained by how tasks are scheduled and the interactions between the different actors (people and tools) in the product development process.

A second aspect is the integration and/or relationship between the process and the information/knowledge content happening "between" and "within" the project stages, considering all the technologies and tools used in the product development process (Zidane et al., 2015). The dynamics of technological advancements and market shifts often introduce uncertainties and complexities into product development, prompting companies to explore structural adaptations to enhance their competitiveness. CE emerges as a potent mechanism for mitigating uncertainty and improving organisational agility (Koufteros et al., 2001). A crucial aspect entails early requirements analysis by multidisciplinary teams and careful consideration of all lifecycle aspects affecting a product, facilitating integrated concurrent design (Zidane et al., 2015). By addressing lifecycle issues upfront, projects can achieve a "right the first time" outcome, leading to cost savings and accelerated product development, sometimes by up to 70 %, while precisely meeting customer needs (Sapuan & Mansor, 2014).

Furthermore, implementing CE necessitates organisational changes spanning manufacturing techniques, quality management, market strategies, and employee mindsets. Such adaptations enable handling complex products while maintaining high quality, achieving accelerated deliveries, and reducing manufacturing costs, with approximately 80 % of production costs attributed to the design phase. This strategic readiness equips organisations to swiftly respond to evolving market demands and reduce time to market (Zidane et al., 2015). CE implementation typically unfolds through two approaches: team-oriented CE and IT-centric CE, particularly, CE-oriented and knowledge-based engineering (KBE) (Sapuan & Mansor, 2014).

Leveraging computer tools and technologies, such as the Pugh concept selection matrix and Pugh total design approach, aids in expediting the CE process, streamlining cycle times, and ensuring comprehensive product design management (Sapuan & Mansor, 2014). Additionally, simultaneous engineering offers a strategic framework to compress the time-to-market for new products, facilitating swift market entry, even amidst simultaneous NPD processes.

Nelson et al. (2016) advocated adopting the Graphical Evaluation and Review Technique (GERT) to address complexities in concurrent NPD, including bidirectional project interdependencies and resource limitations. Originating from Drezner and Pritsker (1965), the GERT model provides a robust platform for estimating project completion times by accounting for dynamic information flows and coordination complexities within concurrent NPD processes (Nelson et al., 2016). Its graphical representation aids in visualising communication and information flows, offering managers a comprehensive understanding of the NPD process dynamics.

Assessing the progress of CE implementation within companies is crucial for enhancing efficiency and effectiveness. Karningsih et al. (2015) investigated CE implementation in Indonesian companies, utilising the Simultaneous Engineering Gap Analysis (SEGAPAN) checklist and Analytical Hierarchical Process (AHP) for evaluation purposes. The study aimed to quantify the level of CE implementation, identify implementation difficulties, and provide a case study on CE implementation in the context of the Asian/Indonesian industry. SEGAPAN comprises six domains: management role, corporate culture, cross-functional teams, co-design, communication infrastructure, and tools and techniques. Each domain encompasses multiple factors, with AHP utilised to quantify the weight of each factor in the CE implementation compliance domain. The CE rate, classified into three levels (excellent, average, and poor), gauges the extent of CE implementation within a company. The study revealed that although Company X achieved an excellent level of CE implementation, three impediments hindered further progress: inadequate management role, resistance to cultural change, and insufficient cross-functional team collaboration. These challenges stemmed from senior management's limited understanding of CE implementation, exacerbated by a lack of clear implementation strategy and structure dating back to the financial crisis of the 1990s. Company X plans to address these issues by restarting the CE implementation using a well-structured strategy, possibly employing the Change Acceleration Process (CAP) approach. Additionally, Company X commenced implementing Lean Manufacturing (LM) in 2013, aligning with CAP steps, including CE training, knowledge sharing, and recruitment process modifications (Karningsih et al., 2015). Similarly, Ganagambega & Shanmugam (2012) assessed CE utilisation levels in Malaysian small and medium-sized enterprises (SMEs) through supplier surveys. Despite a lack of understanding of CE concepts, most Malaysian SMEs embraced CE principles in their NPD processes. The study highlighted the importance of effective communication and workforce competence, emphasising training and motivation to enhance product development team skills. Ganagambega & Shanmugam (2012) proposed developing user-friendly, rapid application methods to promote CE adoption in SMEs and advocated for increased awareness and education through training initiatives. These efforts aim to facilitate the integration of CE practices into SME operations, fostering innovation and competitiveness in the marketplace.

2.3. Lean product development

LPD is particularly important during the product design phase and naturally has implications for production. The focus on LPD is based on the challenges in (i) managing the development of new sustainable products that offer value to customers, (ii) reducing time to market, and (iii) the efficient use of resources (Sousa & Dekkers, 2019). LPD is a product development method that uses Lean principles and focuses on reducing waste, accelerating delivery, and increasing profit and customer value. According to the literature, Lean principles should not be applied in manufacturing only but should also be extended to other processes, especially those further up the production chain, such as the product development process (PDP), which has great opportunities for applying these principles. It is important that the product is developed based on Lean principles, so that possible waste from the PDP is avoided at the time of manufacture. LPD involves applying Lean principles learned in LM and Lean practices specific to product development in the PDP (Pinheiro & Toledo, 2016).

LPD handles the complete process from collecting and generating ideas, going through evaluating the potential for success, developing concepts, evaluating them to create the best concept, detailing the product, testing/developing it, and delivering it to manufacturing (Mynott, 2012; Rauch et al., 2017).

Table 1 highlights the trends in developing new products in the automotive industry in recent decades. As of 2010, the trend is towards the product development process according to the Lean methodology. It has focused on "innovation" and "feasibility". Therefore, the customer's expectations regarding the product, the customer focus, the "value" or "price" that the customer attaches to that product and the function of the product have emerged in the current social and economic context. "Lean tools" in the value stream, therefore, "Lean management" in the final product, includes important issues and interdisciplinary approaches (Paker, 2021).

LPD, akin to LM, emphasises innovation and the development of new products, albeit with distinct foundational principles. Dombrowski & Schmidtchen (2014) provided a comprehensive overview of key Lean methods in product development, categorising them into seven fundamental principles (Fig. 1). In the automotive sector, the efficacy of the LPD process is gauged by the efficiency of the value stream and the global market penetration of the final product. Consequently, identifying and eliminating non-value-adding elements or processes are paramount, as are those that encumber the system (Paker, 2021). An essential tenet of the LPD process involves the eradication of activities that fail to contribute value, thereby mitigating waste.

Tab. 1. Trends of NPD in the automotive industry

Phase	Period	Focus on	Management of organisation	Technology	Tools/methods
Industrial age	1850	- Specialisation	- Functional Hierarchy	- Mechanisation	- Scientific management
Information age	1908	- Productivity performance - Cost reduction	- Line production - Order/Controls	- Serial production - Standardisation - Data storage	- Task specialisation - Financial Modelling
1st wave: Sequential Process	1970	- Quality management - Continuous flow - Task efficiency	- Diversification of companies - Fusions and acquisitions	- Automation information - Technology management	- Total quality management (TQM) -Statistical process control - Process improvement methods
2nd wave: Concurrent process	1990	- Process innovation - Best practices, faster - Business over the Internet	- Flat organisations - Value added for customer operational excellence	- Enterprise Architecture - Enterprise Resource Planning (ERP) - Customer Relationship Management (CRM) - Supply chain management	- ABC analysis - Six Sigma - Process redesign - Methods of reengineering
3rd wave: Process management	2000	- Adaptability agility	- Network-centric organisation - Hyper-competition	- Enterprise - Application integration - Architecture oriented on services	- Balanced Scorecard (BSC) - BPM systems - Outsourcing
4th wave: Lean culture	2010	- Continuous change - Dissipate - Muda	- Market growth - Process effectiveness before efficiency - Poke-yoke - Fix right the first time	- Performance management software - Business Process Management (BPM) Systems	- Outsourcing - Project field - Communication discipline - A3 contact (Lean)

Source: Elaborated by the author based on (Paker, 2021).

Companies must prioritise learning and effectively implementing value stream techniques and LPD strategies to enhance their competitiveness and pinpoint and eliminate waste within their business value streams. In the automotive industry, it is crucial for companies to assess their current position and future direction regarding the simplicity of their value stream, remaining adaptable to drive continuous improvement (Paker, 2021). Another critical focus area is applying Lean methodology in NPD, particularly in small and medium-sized enterprises (SMEs). Rauch and colleagues (2017) shed light on the limited research surrounding the adoption of Lean in the R&D departments of SMEs. Their study offers a unique evaluation of the applicability, benefits, and critical factors of LPD for SMEs, drawing insights from a survey conducted across 54 SMEs in Italy (Rauch et al., 2017). Furthermore, their research explores the impact of emerging Industry 4.0 techniques on product development and how they may influence the efficacy of Lean practices within this domain.

The primary findings underscore the swift introduction of several Lean methods, offering substantial potential for improvement, especially when combined with Industry 4.0 technologies, which serve as catalysts for enhancing efficiency in product development (Rauch et al., 2017). Another notable application of Lean methodology is within the supply chain. While manufacturers readily embrace Lean development principles, suppliers often struggle to align with these methodologies. Research by Dombrowski & Karl (2017) highlighted the limited applicability of these methods and principles to suppliers, attributed to differences in process structure and specific tasks. Although their study was based on subjective evaluations through expert interviews, it concluded that the Lean development system must be tailored to suit the specificities of SMEs. Their findings offer valuable insights for adapting the Lean development concept to SMEs, emphasising the need for tailored approaches. Certain principles, methods and tools vary in relevance for SMEs, requiring careful consideration and adaptation. For instance, principles such

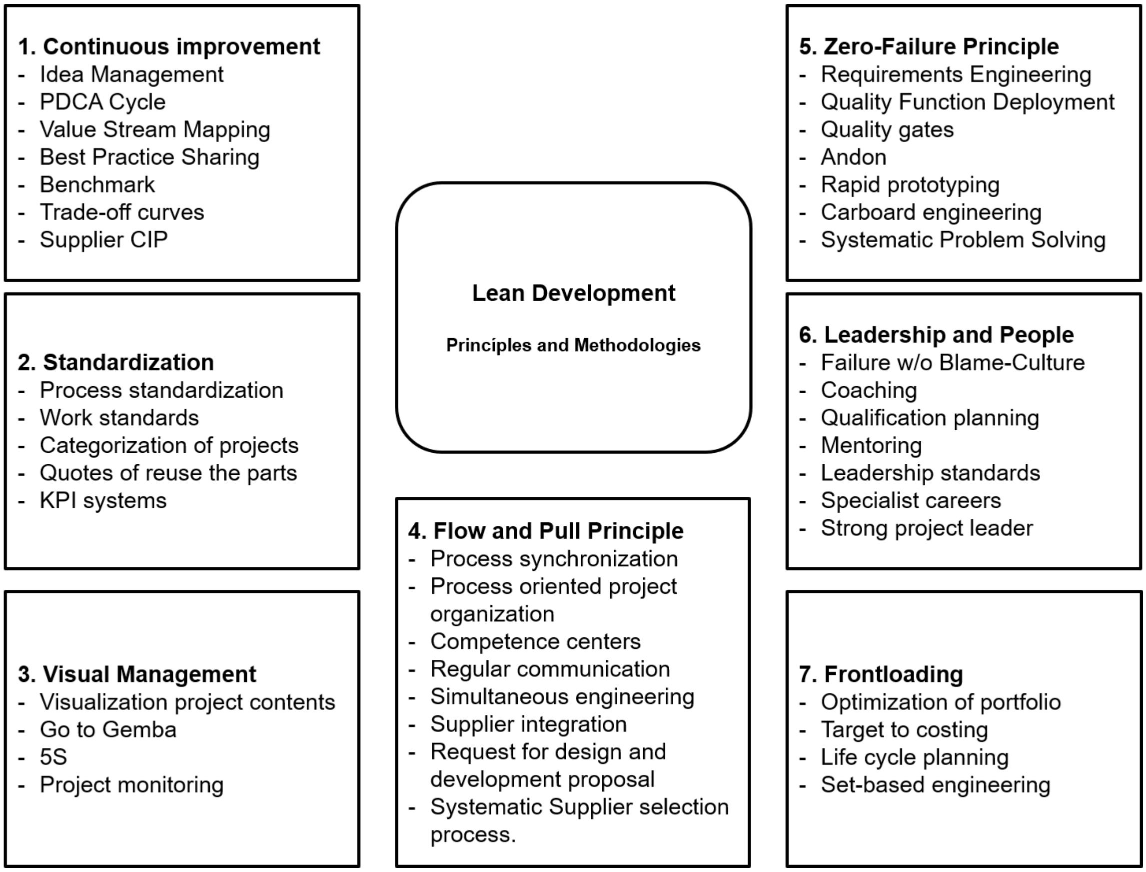

Fig. 1. Lean product development principles and methods

Source: Elaborated by the authors based on (Schmidtchen, 2014).

as standardisation, zero defects, and anticipation must be systematically integrated into Lean development systems for SMEs to ensure effective implementation and success.

The discussion continues on the discourse around sustainability, sustainable products, and sustainable product development. A systematic literature review conducted by Souza & Dekkers (2019) explored existing LPD methods and tools to assess their contributions to sustainability. The findings suggest that while there is no shortage of methods and tools, their practical application is lacking. From a sustainability perspective, most tools and methods predominantly focus on economic and environmental dimensions, with only a few encompassing the social dimension or addressing all three dimensions collectively (economic, environmental, and social). Given that sustainability inherently integrates economic, environmental, and social aspects, understanding their interdependencies emerges as a critical issue warranting further attention from researchers. Thus, a deeper reflection is needed on how these methods and tools can effectively contribute to each dimension of sustainability. Additionally, the review identified certain limitations, such as the scant exploration of potential conflicts, synergies, or overlaps between LPD and sustainability in literature and practice. While practices may be designed with sustainability in mind, they often fall short of embracing the holistic concept of sustainability.

3. Results and discussion

This section discusses the main insights concerning the challenges of ESI in NPD projects.

3.1. Importance of ESI in NPD projects

The significance of supplier involvement in NPD projects is increasingly recognised as product lifecycles shorten and technological advancements become more sophisticated. Companies often focus on their core processes while outsourcing others, leveraging potential cost advantages or tapping into suppliers' technical expertise in product development and production processes. As products become more technologically complex, organisations rely more heavily on supplier collaboration to ensure access to the necessary technologies required to meet customer demands. Consequently, NPD processes often span the supply chain, reflecting a decentralised approach. Supplier involvement programmes are generally viewed favourably in NPD endeavours, offering benefits such as enhanced product quality, reduced time to market, and lower development and production costs (Ramanathan, 2014). Addressing technological uncertainty emerges as a pivotal aspect of supplier integration research. Studies suggest that sharing costs, information, and technology with suppliers can mitigate technological uncertainties. Organisations frequently partner with key suppliers to steer technology development efforts and drive cost reductions in response to such uncertainties. However, in the context of production chains, integration tends to be more standardised, and the degree of supplier involvement may have less bearing on process success (Bornia & Lorandi, 2008).

Fostering effective interaction within the supply chain requires understanding the characteristics and nuances of partners, particularly suppliers, in terms of organisational structure, cultural aspects, and technological competencies. The nature of the relationship established at the supplier-organisation interface in NPD significantly impacts performance (Bornia & Lorandi, 2008). First-tier suppliers encompass various configurations: (1) "Partner to Risk Sharing" involves one company associating with another to coordinate development and share risks under long-term contracts. The partner is deeply involved in all NPD stages. (2) "Technological Partner" entails technology transfer, often from suppliers or machine suppliers, especially when their technology is a differential or through universities and research centres. (3) "Co-Developer" refers to a supplier participating in defining subsystem requirements and development, actively contributing to the design team and final product specification. Second-tier suppliers, termed "Service Providers", receive product requirements and specifications from the customer (organisation) and develop tailored solutions (Bornia & Lorandi, 2008).

Lastly, "Standard Parts Suppliers" focus on timely and cost-effective delivery, particularly for commodities that are not strategically vital to customers, often selling products through catalogues (Bornia & Lorandi, 2008). Eisto et al. (2010) delineated collaboration levels between the organisation and the supplier, starting with the "Order Delivery Level" (Level I), where the organisation contacts suppliers upon project completion. Initial contact typically involves a request for quotation, with part designs and related components mostly finalised. Minor adjustments may be feasible, such as wall thickness modifications or draft additions for castings. The organisation compares quotations from multiple suppliers before selecting one, providing delivery dates. ESI is not used at this collaboration level (Eisto et al., 2010).

In the "Cooperative Level" (Level II), organisational and supplier processes partially overlap, fostering cooperation in design. Suppliers can provide feedback and assess part designs before finalisation, enabling adjustments to simplify manufacturing processes. Contracts gain significance at this stage as suppliers contribute to enhancing the organisation's component designs, leveraging their resources for improvement (Eisto et al., 2010). At the "Partnership Level" (Level III), suppliers are engaged at the project outset, and processes fully align. This alignment allows each supplier's expertise to be strategically applied to the organisation's project at the appropriate juncture. This level is well-suited for intricate or critical parts of the final product. Instead of prioritising the lowest quote, partners collaboratively innovate value-added solutions. Such innovative solutions offer greater long-term cost and time reductions compared to price-driven competition, optimising both the product and production chain (Eisto et al., 2010). Simulations exemplifying collaborative approaches between organisations and suppliers aim to gain deeper insights into potential part-filling outcomes during the initial NPD phase. Interpretation of simulation results allows users to propose design changes or die-casting system modifications, which are particularly effective when executed in the product design phase before finalisation. Conversely, making such adjustments after the design is frozen limits process parameter alterations and forfeits opportunities for enhancing manufacturability.

Another significant aspect concerns supplier selection. Giuseppe & Calabrese (2018) introduced additional criteria gaining relevance, focusing on the impact of reputation on supplier selection within the European automotive industry, particularly among Tier 1 suppliers. Their empirical approach involves detailed descriptions of strategies and databases, drawing data from purchase contracts in the European automotive components market. Their findings underscore the critical role of reputation, suggesting that suppliers serving diverse customer bases or those heavily engaged with premium brand customers stand better chances of securing additional orders and expanding their customer portfolio, including non-premium customers, in subsequent periods (Manello & Calabrese, 2018). This perspective aligns with Schoenherr and Wagner's (2016) proposition regarding supplier involvement in the fuzzy front end of NPD. In a dynamic market that prioritises "faster, better, and cheaper" products, innovation becomes imperative for maintaining competitiveness. This necessitates increased supplier and customer involvement, particularly in NPD endeavours. The core concept is to engage suppliers as early as possible in the NPD process, particularly during its initial phase — idea generation, refinement, product definition, and project evaluation, collectively termed the "fuzzy front end" (FFE) of the NPD process. Despite its criticality, FFE is often characterised by poorly defined processes, ad-hoc decisions, errors and uncertainties, with limited emphasis on supplier involvement. The proposition here emphasises the perspective of social exchange theory (SET) since supplier involvement in NPD involves a social exchange. SET proves valuable in exploring company relationships by offering deeper insights into underlying dynamics and tapping into significant social relationship components like homophily and benevolence (Schoenherr & Wagner, 2016).

Environmental concerns and supplier involvement in green supply chains hold significant relevance in today's landscape. Pressing issues like climate change and biodiversity loss demand urgent responses. Also, consumer demand for eco-friendly products is growing, prompting stricter environmental regulations over time. Caniels et al. (2013) aim to elucidate the factors driving supplier participation in green supply chain initiatives. They propose a conceptual framework delineating supplier involvement driver, including customer requirements, supplier readiness, relational norms, and client influence. Essentially, this initiative calls upon companies and suppliers to embrace sustainability practices. Delayed action on this front makes it increasingly challenging for suppliers to adapt their production processes and bolster their knowledge base to assume leadership in "green" production.

Furthermore, it hampers their market competitiveness vis-à-vis existing suppliers who are already well-versed in sustainable practices, necessitating substantial investments from new entrants to level the playing field. Notably, the image and public perception of an automotive original equipment manufacturer (OEM) regarding corporate social responsibility (CSR) hinge not only on its own CSR performance but also on that of its supply chain members, particularly its suppliers, given the OEM's responsibility for the sustainability of the entire chain (Caniels et al., 2013). In a separate study, Ghadimi et al. (2017) proposed a fuzzy inference system based on an audit checklist to assess supplier sustainable performance comprehensively. This system considers all facets of sustainability, providing a practical framework to evaluate and select the most sustainable suppliers. It was applied to select sustainable suppliers at a French automotive parts manufacturer licensed under a French automotive organisation. The objective was to evaluate potential suppliers accurately and facilitate informed decision-making. The collected data was processed using the proposed fuzzy inference system to mitigate inaccuracies, ultimately presenting a ranking of suppliers with less uncertain sustainability performance scores, enabling reliable sourcing decisions. Although this approach may be generic, the formulation of sustainability criteria and sub-criteria must be aligned with the specific sector, in which a company operates. Consequently, criterion sets must be adapted for other analyses to ensure proper functionality (Ghadimi et al., 2017).

3.2. Challenges in the application of ESI

The known fragility concerning the ESI applied in the NPD is based on the few available studies. They typically consider various NPD decisions of a single organisation, including product positioning, CE, and common components (Ramanathan, 2014). Studies investigating the NPD with ESI application consider, as conflicting issues, the balance of the main decision variables (project quality, quality of compliance, and ESI extension) in relation to internal and external environmental conditions. Partitioning product development processes along the supply chain — when applying ESI — produces a wide variety of transactional externalities and inefficiencies as the level of supplier involvement increases and the technologies

Tab. 2. Summary of the challenges in the application of ESI

Challenges	Main topics	Reference
The impact of supplier involvement in product development on supply chain risks and supply chain resilience	Identifying dependencies between Supplier Involvement Product Development (SIPD), risk and supply chain resilience; a lack of valid and reliable measurement models.	Wieteska (2018)
Lack of an easily applicable tool to assess the quality of a proposed innovation and the quality of the supplier that proposed the idea	Supplier innovation may also imply a high level of dependence of a buying company on its innovative supplier, representing a potential risk for a buying company by (a) risk of supplier incompetence in project execution and (b) supplier resource dependence for its innovation capacity and a denial of access to these.	Goldberg & Schiele (2018)
Effect of uncertainty, supplier involvement, supplier performance, and partnership quality on buyer-supplier relationship	Evaluate how the relationships between firms and suppliers will affect the supply chain of manufacturing and non-manufacturing companies, especially the effect of uncertainty, ESI, supplier performance, and partnership quality on buyer dependence on the supplier.	Mudasser et al. (2022)
NPD processes are often decentralised in the supply chain	Develop analytical models to shape the NPD project environments in which the organisation must engage in cooperation with its suppliers.	Ramanatha (2014)
Effect of ESI on firm performance through teamwork and NPD	It is important to have a proper insight into manufacturing management to understand how ESI affects teamwork, new product and development. It is observed that teamwork affects NPD and firm performance. Moreover, NPD affects firm performance. In addition, ESI indirectly affects firm performance through NPD and teamwork, respectively and simultaneously.	Oktapia et al. (2022)
The suppliers may be reluctant to make huge/continuous product-specific (and/or manufacturer-specific) investments due to a lack of incentives and bargaining power	NPD characterised by weak-defined product requirements, unreliable demand forecast, unproven production technology and significant up-front costs, which brings considerable risks on developing new products with strong strategic implications but modest financial payoffs in the short-run. The firm can potentially mitigate by engaging suppliers with proven know-how, knowledge, expertise, and capacities, but how long can the supplier afford to explore promising leads for radical innovations and how much design effort should be allotted to the project?	Chiang & Wu (2016)
ESI requires a continuous information flow supported by robust information systems that can ensure data availability and reliability as well as information and knowledge confidentiality to chain members	Information systems provide a high integration level, which is not possible among supply chain members since companies use different systems, obstacles arise from distinct system structures, such as application languages and databases, and management systems not being compatible with each other; this generates further manual activities that render data exchange more complex and less accurate. Information systems, such as ERP, positively impact product quality improvement, development time reduction and cost gains, increasing sector competitiveness, especially because these systems allow faster information sharing among chain members.	Junior et al. (2019)
NPD environments typically have high levels of technological uncertainty	It is a key variable in research involving supplier integration. Technological uncertainty can be reduced by sharing costs, information and technology. Organisations often team up with their key vendors to influence the direction of their technology development and cost reduction efforts.	Bornia & Lorandi (2008)
Perception of CSR	The image and public perception of an automotive OEM with regard to CSR does not only depend on its own CSR performance but also on the CSR performance of its supply chain members, in particular its suppliers, since the OEM is responsible for the sustainability of the entire chain.	Caniels et al. (2013)
The influence of reputation on supplier selection in the automotive industry	Especially in the European automotive industry, suppliers (a) who serve a diversified customer base or (b) with strong exposure to premium brand customers have better chances of obtaining additional orders and expanding their customer base even further, consequently winning more orders also from "non-premium" customers in the subsequent period.	Manello & Calabrese, 2018

required become progressively more sophisticated. Table 2 compiles the main challenges faced in implementing ESI more robustly, considering the literature review densely explored in this paper.

Conclusions

The article underscores the significance of internal processes within organisations, particularly focusing on key methodologies like NPD, CE, and LPD. These methodologies aim to boost performance and facilitate successful product launches within specified timelines. However, the analysis reveals a gap in the depth of industrialisation phases associated with these processes, particularly when organisations face challenges due to insufficient technical knowledge for developing complex products and production processes. In today's competitive landscape, organisations, especially in sectors like automotive, confront the urgent need to swiftly introduce innovative products to the market.

NPD, especially when incorporating new technologies, demands more efficient responses to meet customer/end-user requirements. To achieve this, organisations must tap into resources from the supply chain to address internal gaps, expedite time-to-market for customised products, meet deadlines, and enhance customer satisfaction.

A critical aspect highlighted is the adoption of techniques such as decentralisation of the NPD process, with a focus on ESI, to acquire crucial technical knowledge essential for complex product and production process development. ESI plays a pivotal role in successful decentralisation, leading to quality enhancements, reduced execution time, and cost savings. Moreover, the article conducts a thorough analysis of ESI challenges and their impact on NPD within organisations, particularly regarding outsourcing strategies and collaboration with external partners. It underscores the significance of ESI for process optimisation, ensuring production quantity, quality, and timely delivery, thus averting disruptions in the automotive industry.

Furthermore, the paper provides invaluable insights into NPD, especially in scenarios involving external partners in the supply chain. It identifies opportunities to address emerging process requirements and offers an initial review of potential challenges for successful ESI. Ultimately, integrating ESI with Lean production approaches can mitigate issues during mass production, driving efficiency in product development processes.

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