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Procurement integration with PLM and PM in development and engineering phase: PODIUM engineering srl

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Summary

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1. Context Analisys and Research Motivation

Project management, Procurement, and Product Lifecycle Management (PLM) are often managed separately within engineering firms, which is a chronic and deeply ingrained problem. Despite the fact that these tasks work together to successfully realize engineering products, they are often administered as distinct domains with little cooperation. In contemporary engineering contexts, where products are characterized by high complexity, extended lifecycles, and significant interdependencies between technical, organizational, and supply chain choices, this separation becomes more and more troublesome. The historical evolution of engineering organizations around functional silos is a major contributing reason to the existence of misalignment. Different organizational units, specialized abilities, and function-specific performance metrics have resulted from the evolution of engineering, project management, and procurement to meet particular operational demands. While project management is mostly evaluated on schedule adherence and budget control, procurement responsibilities are frequently evaluated on cost effectiveness, contract compliance, and supplier performance. In contrast, engineering departments have frequently developed PLM efforts as a means of managing technical data and documentation, since the aim in organizations like Podium Engineering is keep track of the product development , resulting in local optimization, in which each function aims to optimize its own goals without fully taking system-wide effects into account, supported by this functional viewpoint. Decisions are made primarily on short-term or function-specific goals rather than the product's overall performance throughout its lifespan, which perpetuates this fragmentation due to the absence of a common viewpoint. The drawbacks of this strategy become more apparent when engineering projects get more complicated and include a wider range of stakeholders. There are several interrelated levels at which project management, procurement, and

PLM are out of alignment. Project planning procedures and procurement activities are frequently loosely connected at the process level.

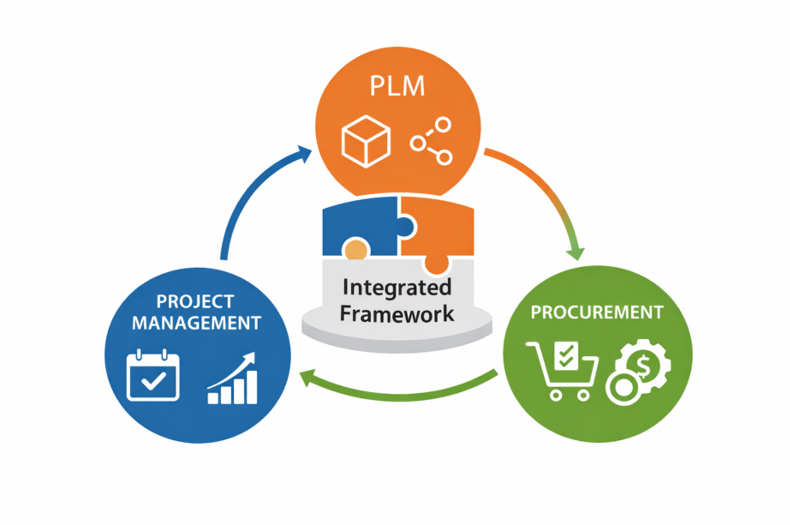

Fig.1 Integration Between Project Management, Procurement, and PLM

The option for early supplier participation and proactive risk management is diminished in many businesses because procurement is only triggered after design decisions have been fully determined. This reactive approach restricts adaptability and makes it more difficult to deal with changes that arise throughout the project lifespan. The disjointed handling of project and product data reflects the mismatch at the information level. Although PLM systems often provide extensive data on product configurations, structures, and change histories, procurement procedures and project control systems do not routinely incorporate this data. Inconsistencies between design intent and acquired components are more likely when procurement teams rely on static documentation or disjointed information systems. In a similar vein, project managers might not have immediate access to the state of engineering modifications and how they affect schedule and procurement. Misalignment gets worse at the organizational level by ambiguous roles and responsibilities. While procurement experts might not be completely involved in the early engineering stages, project managers can have little control over procurement decisions, and this division makes it harder to hold people accountable for cross-functional outputs, and it frequently leads to coordination being done informally rather than through formal procedures. Misalignment has serious and varied operational repercussions, delays and rework resulting from late or poorly planned modifications are among the most frequent consequences. It's possible that engineering changes made during the project execution phase won't be immediately reported to procurement, which might result in the purchase of parts that don't match the most recent requirements. These circumstances undermine overall performance by increasing expenses and lengthening project schedules. Additionally, the organization's ability to manage risk and uncertainty is diminished by the absence of integration. Risks associated with suppliers, such as lengthy lead times, capacity limitations, or reliance on a single source, are sometimes discovered only after procurement operations have begun. Procurement choices are made with little foresight in the absence of integrated PLM and project data, which increases susceptibility to interruptions and decreases schedule dependability. Misalignment has significant strategic ramifications in addition to immediate operational problems, the PLM's function is limited to data storage rather than strategic decision support when it is not connected with project management and procurement procedures. This restricts the company's capacity to use PLM for lifecycle optimization, including weighing trade-offs between design options, sourcing tactics, and long-term operating expenses. Short-term cost reductions may take precedence over long-term value generation in procurement decisions made without taking lifecycle concerns into account. For instance, choosing suppliers or parts without taking management, upgradeability, or maintainability into account might lead to higher costs and less flexibility throughout the product's lifespan. Such lost chances can have significant operational and financial repercussions in engineering-intensive sectors, where products frequently last for decades. Organizational learning and knowledge reuse are also hampered by misalignment. Lessons acquired from supplier performance, design modifications, or integration difficulties are examples of engineering knowledge produced during projects that are frequently not methodically recorded or repurposed. Important insights remain scattered across functions and are challenging to leverage in subsequent efforts in the absence of a cohesive PLM-based architecture that links projects, procurement, and lifecycle data. Even though the advantages of integration are becoming more widely recognized, many engineering firms encounter considerable obstacles when trying to coordinate project management, procurement, and PLM. The organizational complexity involved with changing roles, responsibilities, and decision-making procedures is one significant obstacle. Functional units used to autonomy may oppose integration as it necessitates cross-functional cooperation and frequently upends established power structures. The lack of efficient governance structures is another significant obstacle, integration projects run the danger of being disjointed and reliant on individual efforts rather than being integrated into company routines if ownership of cross-functional procedures is not explicitly established. Due to the inherent complexity of departmental and business unit cooperation, this problem is most noticeable in big companies. Additionally, technological aspects are also important. Although PLM solutions offer sophisticated data management and integration capabilities, their effective implementation necessitates complementary adjustments to processes and competences. Businesses that prioritize system implementation over resolving procedural and cultural issues frequently miss out on the anticipated advantages, because of this, PLM solutions could continue to be underused, perpetuating rather than correcting current mismatch.

2. Literature review: state of the art

2.1 Procurement's importance in Supply Chain Management

A deeper comprehension of supply chains, their design and management, and their crucial role in contemporary business has become imperative due to the fast trend toward globalization that has taken place over the past 50 years, and in fact has grown exponentially since the introduction of global telecommunications. Focused on coordinating the network of businesses involved, from the source of the raw materials used in production to the finished items that are delivered to the final customer, recent worldwide upheavals like the COVID-19 epidemic, the conflict in Ukraine, and the conflict in the middle east have made supply chains more closely examined overall, but particularly on one crucial component: procurement. What is procurement exactly? "Procurement is the process of identifying needs, sourcing suppliers, negotiating terms, and acquiring goods, services, or works, typically through competitive bidding or tendering. In simpler terms, procurement is how organizations obtain the resources they need to function effectively." [1](Overvest, 2023) .

In order to maintain a competitive edge, these demands have needed more agility, a challenge to maintain control over all necessary technologies, and a strategy shift toward focusing on "core" strengths. Due to this need, businesses in a variety of sectors are increasingly outsourcing goods and services to outside vendors, expanding their supply networks and emphasizing the value of supplier relationships, this trend is known as "deverticalization". Initially seen just as an operational duty, procurement departments and specialists are today acknowledged as essential to the successful and efficient administration of supplier relationships, which directly affects the company's ability to create value and the supply network. Because procurement plays such a transformational role, practitioners need to be supported by an appropriate organizational framework, provided with adequate power, and furnished with the requisite abilities, resources, and interdepartmental. assistance to reach their potential as valuable drivers. The planning, sourcing, manufacturing, and delivering/returning functions of supply chains may be separated apart (figure 2). All actions pertaining to the procurement of raw materials from suppliers (Source), manufacturing/production schedules/capacity planning (Make), distribution planning, and final delivery to the customer (Deliver) are coordinated and strategically established by the planning component. The sourcing function is where the process starts and where procurement shows its primary value by controlling the purchase of materials, lowering costs through contract negotiations, minimizing supply disruptions and preserving supply continuity, and guaranteeing product quality[2] (CAPS Research, 2023).

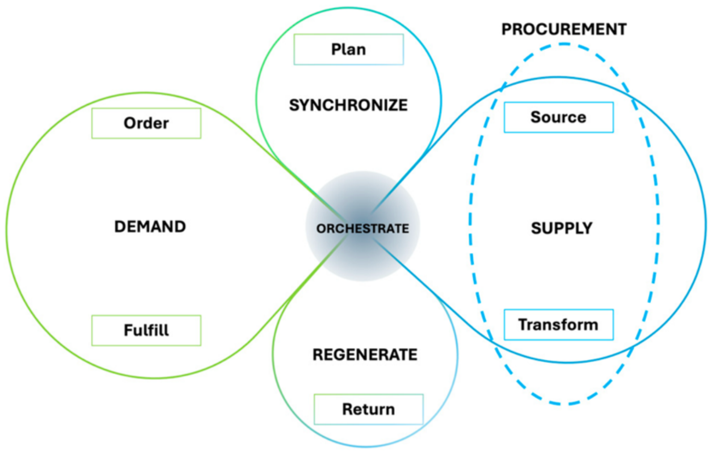

Fig. 2 SCOR model and the procurement area

Effective procurement strategies, however, encompass more than just cutting costs; they also include improving quality, guaranteeing supply continuity (and consequently production), maintaining product integrity, and adopting sustainable methods.

Understanding the differences between procurement, sourcing, and purchasing is essential to comprehending an organization's operational and strategic actions in the field of supply chain management. The procurement field has been defined and handled using several terminology in the business environment, according to the literature and current professional organizations.

Procurement is the strategic framework that manages the entire process of acquiring goods and services, from initial need to integration into company operations. This extensive procedure entails determining the needs of the business, creating procurement rules, doing market research, choosing suppliers through a thorough assessment process, negotiating contracts, and cultivating strong supplier relationships. Procurement takes into account risk, quality, sustainability, and ethical standards with an emphasis on long-term value rather than merely short-term cost reductions.

Sourcing is a crucial aspect of procurement that entails discovering and assessing vendors to meet the organization's demands. It is a proactive effort that takes into account aspects like quality, cost-effectiveness, and service excellence in order to build a pool of trustworthy suppliers that can support the business's strategic objectives. Crucially, sourcing is not the same as buying, rather, by continuously managing the supplier base, it lays the foundation for upcoming procurement efforts.

The transactional part of the procurement process, on the other hand, is purchasing, which concentrates on the immediate operational requirements of acquiring products and services. This includes handling payments, receiving items, and carrying out purchase orders. Securing the required inputs at the best terms and price for the business's current needs while preserving efficiency and cost-effectiveness is the aim of this process. Supply Management involves managing the flow of products and services from supplier to organization, ensuring they meet operational expectations. The supply chain's other essential tasks are connected by supply management. When combined, these various breakthroughs of this important business function are summarized as follows: The "Source" function, which oversees external resources (materials, contracts, suppliers, intellectual property, services, and the like) to ensure cost considerations are met, supply continuity is achieved, and performance targets (cost, quality, etc.) are met to achieve superior organizational performance, is where the supply chain and most business processes start.

What do Organizations Buy? Developing an understanding of the variety of goods a business purchases is crucial to appreciating the intricacy of procurement management. A uniform classification aids in the methodical management of various products and services, even when the range of purchases varies among firms. This classification has historically been in line with accounting procedures, which group purchases according to how they affect financial statements.

Raw materials, components, consumables (often referred to as maintenance, repair, and operating supplies, or MRO)[3] (Monczka *et al.*, 2021), services, and capital equipment like machinery are the five main categories into which purchases typically fall. These categories are evaluated using two criteria: their direct or indirect relationship to the company's production and their contribution to operational expenses relative to capital assets. Operating expenses (Opex) are costs incurred during ordinary business operations throughout an accounting period. These consist of supplies, materials, and a range of services including upkeep, cleaning, and administrative costs. In the context of procurement, Opex includes both MRO supplies and services required to sustain company operations as well as raw materials and components necessary for production. Services range from logistics to professional services like consulting and facilities management; these are essential for operational efficacy even though they are not physically visible in the final product. Despite their lower individual costs, the total spending on these items can be significant due to their volume and variety. Investments in assets that are anticipated to benefit the business over more beyond a single fiscal year are represented by capital expenditures (Capex).

This can include both common equipment and highly sophisticated gear made to meet particular business requirements. Capex purchases stand out due to their larger monetary value, infrequency, and potential for value volatility depending on the state of the economy. When discussing direct versus indirect purchases, raw materials, parts, systems, and services that are essential to the finished product are considered direct purchases. This also includes manufacturing services that suppliers offer that are crucial to the production process, such painting or labeling, MRO materials and services that are required for business operations but are not included in the final product or service are examples of indirect purchases. The distinction between direct and indirect purchases emphasizes the dual function of procurement in both producing the product and facilitating the business operations that underpin manufacturing.

What are the functions, roles and responsibilities of the purchasing organization?

As described in the previous section, the procurement organization functions as a crucial business unit inside an organization entrusted with the acquisition of products and services. From initial planning to the final use or consumption of the acquired things, the procurement process shown in Fig. 3 encompasses a thorough, systematic approach to obtaining the resources required for organizational operations.

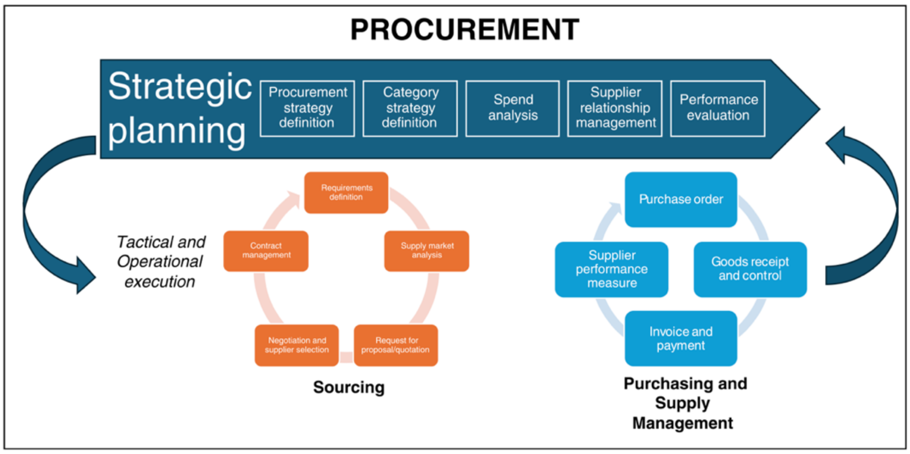

Fig. 3 The procurement process

Strategic planning is the foundation of procurement at the highest level. Developing procurement and category strategies, make-or-buy analyses, expenditure analysis, and managing supplier relationships including performance evaluation are all part of it. The subsequent tactical and operational tasks, which are separated into sourcing, buying, and supply management, are based on these strategic components. Sourcing, which emphasizes supplier selection and contractual engagement, is a crucial stage in the procurement process. It includes requirements definition, supplier market analysis, requesting quotes, and the intricate selection and negotiation procedures that lead to contract management. The operational aspects of the procurement cycle, including the full buy order-delivery-payment sequence, are covered by purchasing (and supply management). At this point, sourcing and strategic planning initiatives become actual procurement transactions.

Future strategic planning is informed and refined by the feedback loop from tactical and operational execution, resulting in a dynamic, iterative process that continuously improves procurement effectiveness. Due to the intricacy of the procurement process in modern firms, a variety of specialist positions are required, each of which offers the procurement department particular knowledge and abilities, usually the following roles are frequently found in a strong procurement organization, ranging from operational execution to strategic supervision.

The CPO (Chief Procurement Officer) is the highest ranking executive in the procurement organization and is in charge of the entire strategy, management, and leadership of procurement operations. They are frequently compared to a Director or VP of Procurement. This position entails directing transformative projects, guaranteeing alignment with corporate goals, and establishing the vision for how procurement can create value throughout the organization. The CPO is in charge of managing risk, advancing the competencies of the procurement team, and promoting procurement's function as a strategic partner to the company. The procurement strategy is essential to accomplishing an organization's larger strategic goals as it serves as the roadmap for how it will acquire products and services. It establishes the aims of the procurement department (e.g., efficiency-focused vs. quality/innovation-focused), coordinating them with the organization's financial and competitive positioning objectives. This approach establishes the tone for procurement operations by influencing risk management, supplier selection, decision-making criteria, and the incorporation of technology and procedures into the procurement function. Grouping similar or related goods and services to take advantage of market conditions and achieve cost savings while guaranteeing quality and supply continuity is a crucial component of procurement strategy [4] (O'Brien, 2019). This approach necessitates a thorough understanding of market dynamics, supplier capabilities, and internal stakeholder needs.

Cross-functional cooperation is encouraged by category management, which frequently results in innovation and ongoing procurement operations improvement.

A customized approach is created for every defined category of products and services. Analyzing the particular spending trends, supplier market environment, and the category's business effect are all part of the definition of category strategies. Strategies take into account factors like cost reduction, quality improvement, risk mitigation, and sustainability in order to optimize the value from each area. Portfolio models are essential for directing this analysis: A key instrument in strategic procurement, the Kraljic Matrix categorizes products and services according to two factors: the significance of purchases and the complexity of the supplier market. This paradigm divides categories into four quadrants non-critical, leverage, bottleneck, and strategic and suggests different approaches to management for each. Procurement experts can prioritize their approach to several categories by adopting this methodology, concentrating on:

- Cost Reduction: The goal is to reduce costs and process complexity for non-critical commodities with minimal supply risk and moderate investment.

- Quality Enhancement: Strategies are developed to promote innovation and quality improvements with major suppliers in categories where quality is a distinguishing factor.

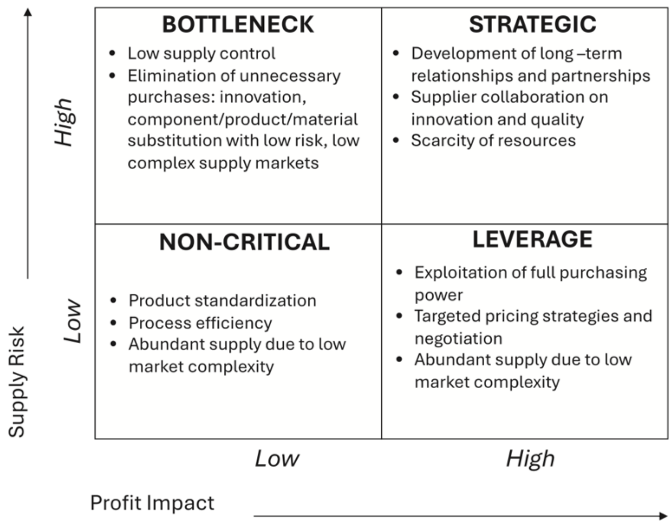

Fig. 4 Kraljic Matrix

Another strategic component of procurement that goes beyond simple price comparison is sourcing. It includes a thorough assessment of elements that are essential to an organization's long-term performance, including cost, quality, dependability, and sustainability. In this situation, procurement specialists play a crucial role in locating and assessing possible suppliers to determine which one best suits the business's operational and strategic needs.

Procurement uses a range of instruments and techniques to guarantee a comprehensive assessment. To comprehend industry trends, supplier capabilities, and threats, they perform supply market analysis. Standard papers that collect comprehensive supplier information, proposals, and competitive bids are called Requests for Information (RFI), Requests for Proposals (RFP), and Requests for Quotation (RFQ). A thorough examination of the collected data in comparison to the sourcing criteria is part of the selection process. The total cost of ownership, which encompasses all expenses related to a product's lifespan in addition to the original purchase price, must be taken into account by procurement teams. Performance, consistency, and adherence to specifications are used to evaluate quality. Assessing a supplier's responsiveness and delivery performance is part of reliability. Sustainability, which affects a supplier's social responsibility, economic practices, and environmental effect, is a factor that is becoming more and more significant. Cross-functional teams are frequently involved in this stage to offer a variety of viewpoints on the suppliers' capacity to satisfy the demands of the company. Additionally taken into account are elements including financial stability, technological prowess, capacity for innovation, and connection with the company's ideals. Contract management and supplier relationships are interconnected procedures that guarantee the continued viability of the supplier partnership. Organizations may establish synergistic connections that propel ongoing value and innovation by writing explicit contracts and cultivating open communication and trust.

To specify the scope of supply, conditions of payment, delivery dates, quality standards, and sanctions for non-compliance, clear contracts are crucial. In order to prevent future disputes and promote a stable supply chain, procurement specialists work to establish conditions that offer value while also being reasonable and manageable for the supplier. Contracts have to contain specific, quantifiable performance indicators that make it possible to track and assess supplier performance. This guarantees adherence to contractual duties and offers information for risk management and improvement. Procedures for handling disputes or performance concerns must also be specified in contracts. This might include official legal procedures as well as organized meetings and mediation. Maintaining the business connection and effectively resolving conflicts are the goals. Procurement is in charge of building and preserving a solid rapport with suppliers once a contract has been signed. Strong supplier relationships are built on contracts. They thought to promote dialogue, teamwork, and trust. Regular meetings, open information sharing, and collaborative planning sessions are examples of effective communication tactics.

However, procurement must take a strategic way that goes beyond contract responsibilities in order to create and maintain strong supplier connections. Regular performance evaluations and cooperative problem-solving initiatives with suppliers should be carried out by procurement. Initiatives for continuous improvement should be supported in order to make sure that the relationships develop and get better in response to shifts in the market and advances in technology.

2.2 Contemporary Approaches to Project Management

Project management has progressively evolved from a predominantly operational discipline focused on planning and control to a strategic organizational capability aimed at delivering value under conditions of uncertainty and complexity. This evolution reflects profound changes in the economic and technological environment, including increased project complexity, globalization of supply chains, technological innovation, and the growing interdependence between organizational functions such as engineering, procurement, and operations. As a consequence, contemporary project management extends well beyond the application of standardized tools and techniques, encompassing governance structures, organizational capabilities, and human factors that collectively influence project outcomes[5] (Rebuglio, 2022). Early project management research was largely grounded in a mechanistic view of projects, where success was primarily assessed through compliance with predefined constraints related to cost, time, and scope. This perspective, often referred to as the "iron triangle," dominated both academic and professional discourse for several decades. However, empirical evidence gradually revealed the limitations of this approach, showing that projects could meet technical constraints while still failing to deliver stakeholder satisfaction or long-term organizational benefits[6] (Cooke-Davies, 2002).

Fig.5 Iron Triangle

This recognition marked a turning point in project management scholarship, leading to a broader and more nuanced understanding of project success and performance. Contemporary research increasingly conceptualizes project management as a socio-technical system, where outcomes are shaped by the interaction of organizational structures, managerial practices, and human behavior [7] (Kerzner, 2017), this work aims to bridge the gap between the just cited functions by introducing a PLM-centered solution that enables functional alignment, data continuity, and informed decision-making across the entire project lifecycle. Within this framework, the identification of critical success factors (CSFs) has emerged as a central analytical approach for understanding why some projects succeed while others fail under similar conditions .

Fig. 6 CSFs (Critical Success Factors)

One of the most influential shifts in the literature concerns the distinction between project success and project management performance. While early studies treated these concepts as largely synonymous, subsequent research has emphasized their conceptual separation: project management performance typically refers to the efficiency of the management process measured through indicators such as schedule adherence, budget compliance, and scope fulfillment whereas project success encompasses broader effectiveness and impact-related dimensions [8] (Cooke-Davies, 2002).

Contributions in this area introduced multidimensional models of project success, incorporating criteria such as customer satisfaction, business impact, and future organizational benefits, these models challenged the dominance of efficiency-based metrics and highlighted the importance of aligning project outcomes with strategic objectives. As a result, project management research increasingly shifted its focus from isolated project metrics to organizational and portfolio-level considerations. This evolution is particularly relevant for engineering and procurement-oriented projects, where technical excellence alone is insufficient to guarantee success. In such contexts, project outcomes depend not only on technical performance but also on effective coordination between engineering design, supplier management, contractual arrangements, and stakeholder expectations[9] (Zwikael and Globerson, 2000). The concept of critical success factors provides a unifying lens through which the complexity of contemporary project management can be analyzed. Originally introduced in management research to identify key areas requiring managerial attention, the CSF approach was subsequently adopted in project management to explain variations in project outcomes across different contexts [10] (Shenhar *et al.*, 2001). Rather than prescribing universal best practices, the CSF framework acknowledges that project success is contingent upon a limited number of context-dependent factors. These factors may relate to organizational conditions, managerial processes, or human capabilities, and their relative importance may vary across industries, project types, and life-cycle phases.

Empirical studies consistently demonstrate that projects characterized by strong top management support, clear objectives, competent project teams, and effective communication mechanisms exhibit superior performance outcomes [11] (Belassi and Tukel, 1996). At the same time, the literature emphasizes that the absence or weakness of even a single critical factor can significantly compromise project performance, underscoring the systemic nature of project management.

A prominent theme in contemporary project management research is the increasing emphasis on organizational context and governance. Traditional project management approaches often treated projects as temporary and largely autonomous entities. In contrast, recent studies highlight the embeddedness of projects within permanent organizational structures and strategic frameworks.

Governance mechanisms such as decision-making structures, accountability systems, and performance monitoring processes play a central role in aligning project objectives with organizational strategy. This alignment is particularly critical in environments characterized by multiple concurrent projects and complex procurement networks, where resource allocation and prioritization decisions have far-reaching implications.

Research on organizational project management maturity further reinforces this perspective, suggesting that organizations with higher maturity levels exhibit more consistent project performance due to standardized processes, institutionalized learning mechanisms, and stronger governance capabilities. These findings support the view of project management as a strategic organizational competence rather than a purely technical function.

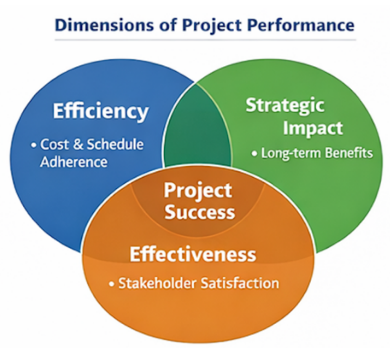

Fig. 7 Dimesions of Project Performance

In parallel with organizational perspectives, contemporary research increasingly acknowledges the importance of human and behavioral factors in shaping project outcomes. Leadership style, team competence, motivation, and interpersonal communication are widely recognized as critical determinants of project management performance.

Transformational and participative leadership approaches are frequently associated with higher levels of team engagement and adaptability, particularly in complex and uncertain project environments. This is especially relevant for engineering projects involving multidisciplinary teams and external suppliers, where effective leadership is required to manage functional diversity and conflicting objectives The growing emphasis on behavioral dimensions reflects a broader shift in project management research toward interpretive and contingency-based approaches. Rather than assuming that standardized methodologies guarantee success, contemporary studies stress the need for project managers to adapt practices to situational demands, balancing formal controls with flexibility and relational competence[12] (Müller and Turner, 2004). The increasing diversity of research perspectives has led to a proliferation of empirical studies employing different theoretical frameworks, methodologies, and performance measures. While this diversity has enriched the field, it has also generated conceptual fragmentation. They also play a crucial role in identifying research gaps and guiding future investigations, particularly in application-oriented domains such as engineering and procurement project management.

A core focus of contemporary project management research concerns the identification and analysis of critical success factors (CSFs) and their relationship with project management performance. As highlighted by multiple studies, project outcomes cannot be attributed to isolated managerial actions or technical tools, but rather to a configuration of interrelated organizational, procedural, and human factors whose relevance varies according to project context. The literature reviewed in recent state-of-the-art analyses converges on the idea that CSFs provide a structured and effective framework for understanding project performance variability across industries and project types. Rather than prescribing universal best practices, the CSF approach emphasizes contextual alignment and managerial prioritization, making it particularly suitable for complex engineering and procurement-oriented projects. Despite differences in terminology and analytical focus, contemporary project management literature shows a significant degree of convergence around a limited number of CSF categories. One of the most prominent categories concerns organizational and governance-related factors. These include top management support, strategic alignment, organizational structure, and the existence of formal governance mechanisms. Top management support is consistently identified as a decisive success factor, as it directly influences resource availability, decision-making authority, and organizational commitment to project objectives[13] (Project Management Institute, 2021). In engineering and procurement-intensive projects, where decisions often involve trade-offs between technical requirements, cost constraints, and supplier capabilities, strong executive sponsorship is essential to ensure timely and coherent decision-making.

Governance structures also play a critical role in managing interfaces between projects and permanent organizational units, clear accountability mechanisms, escalation paths, and performance monitoring systems contribute to improved coordination between engineering, procurement, and project management functions. Conversely, weak governance has been associated with fragmented decision-making and misalignment between project and organizational priorities and a second major category of critical success factors relates to project management processes and practices. These include planning quality, scheduling accuracy, risk management, change control, and performance monitoring. Contemporary research, however, increasingly emphasizes the adaptive nature of these practices. Effective planning is no longer understood as the creation of static baseline plans, but as a continuous and iterative process that supports decision-making under uncertainty[14] (Kerzner, 2017). Risk management emerges as one of the most frequently cited process-related success factors. Studies consistently highlight the importance of early risk identification, systematic assessment, and proactive mitigation strategies. In engineering projects characterized by technological complexity and long supply chains, integrated risk management practices are particularly critical to anticipate disruptions related to design changes, supplier performance, and regulatory constraints.

A third category focuses on human and relational factors, which have gained increasing attention in recent decades: leadership capability, team competence, communication effectiveness, and stakeholder engagement are widely recognized as fundamental enablers of project success[15] (Jugdev and Müller, 2005). This shift reflects a broader recognition of the behavioral and social dimensions of project management, especially in knowledge-intensive and multidisciplinary project environments. Leadership style is frequently identified as a moderating factor influencing the effectiveness of technical and procedural practices. Transformational and participative leadership approaches are associated with higher levels of team commitment, trust, and adaptability, in procurement-related projects, effective leadership also facilitates collaboration with external stakeholders, such as suppliers and contractors, thereby reducing conflicts and improving coordination. In parallel with the refinement of success factor classifications, contemporary research has significantly expanded the conceptualization of project management performance. Traditional efficiency-oriented metrics such as cost variance, schedule adherence, and scope compliance remain central to performance assessment, particularly in engineering contexts[16] (Cooke-Davies, 2002). However, these indicators are increasingly complemented by broader dimensions reflecting effectiveness and long-term impact. The literature commonly distinguishes between efficiency, effectiveness, and strategic or organizational impact as three complementary dimensions of project management performance. Efficiency-oriented performance focuses on the degree to which project outputs are delivered within predefined constraints. Effectiveness-related performance evaluates the extent to which project outcomes meet stakeholder expectations and deliver intended benefits. Strategic impact refers to longer-term contributions to organizational learning, capability development, and competitive advantage. This multidimensional perspective challenges the traditional assumption that adherence to cost and schedule baselines is sufficient to define project success. Empirical evidence suggests that projects may be considered successful despite deviations from initial plans, provided that they generate value for key stakeholders and support organizational objectives[17] (Belassi and Tukel, 1996). This insight is particularly relevant for engineering and procurement projects involving innovation or high levels of uncertainty. A central theme in contemporary project management research is the examination of how critical success factors influence different performance dimensions. Rather than establishing simple linear relationships, recent studies increasingly adopt a contingency-oriented perspective, recognizing that the impact of specific CSFs depends on project characteristics, organizational maturity, and environmental conditions.

For example, planning quality and risk management are consistently associated with improved efficiency-related performance, but their influence on stakeholder satisfaction and strategic impact is often mediated by leadership effectiveness and communication quality. Similarly, top management support exerts both direct effects such as resource allocation and indirect effects, including enhanced organizational commitment and cross-functional collaboration[18] (Müller and Turner, 2004) .

Human-related success factors frequently play a moderating role in the relationship between procedural practices and performance outcomes. Competent and cohesive project teams are better able to adapt standardized tools to situational demands, manage stakeholder expectations, and respond effectively to unforeseen challenges, these findings reinforce the view that project management performance emerges from the interaction of technical, organizational, and behavioral capabilities rather than from isolated managerial actions.

The literature synthesized in contemporary state-of-the-art reviews highlights several dominant research streams shaping the field:

1. One prominent stream focuses on the contextualization of project management practices, examining how industry characteristics, project complexity, and organizational settings influence the relevance of specific success factors. Engineering and procurement projects are frequently cited as contexts requiring tailored approaches due to their technical interdependencies and contractual complexity.
2. Another significant stream addresses the integration of project management with organizational strategy and governance. Studies in this area explore how portfolio management, governance frameworks, and maturity models contribute to improved performance across multiple projects. This line of research supports the conceptualization of project management as a strategic organizational capability rather than a purely operational function, as this work wants to describe.

Overall, contemporary research shows increasing convergence around the idea that effective project management requires a balanced integration of structured processes, supportive organizational contexts, and strong human capabilities. This convergence provides a robust theoretical foundation for analyzing the implementation of project management practices in engineering and procurement-oriented environment despite the extensive body of literature on project management success factors and performance, several limitations remain.

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1. Longitudinal studies are scarce, restricting the understanding of how critical success factors (CSFs) and performance outcomes evolve across the project lifecycle. Most empirical studies adopt cross-sectional designs, providing only snapshots rather than dynamic insights.
2. Research focusing on portfolio or organizational-level perspectives is limited. While single-project analyses are common, engineering organizations often manage multiple, interconnected projects. The influence of governance mechanisms, resource allocation, and strategic alignment across projects remains insufficiently explored[19] (Crawford, 2006).
3. The procurement dimension in project management is underrepresented. Although procurement is acknowledged as a critical component of project success, few studies systematically examine how procurement integration impacts overall project performance, particularly in engineering-intensive environments. This gap is critical given the complexity of supplier networks, contractual obligations, and coordination challenges.
4. Conceptual inconsistencies remain in both CSFs and performance measures. Studies often use heterogeneous definitions and metrics, reducing comparability and hindering cumulative knowledge development. This underscores the need for standardized processes in flexible frameworks (work orders approach) that accommodate contextual variability.

Research Gaps & Practical Implications

Research Gaps	Practical Implications
• Longitudinal Studies	• Understand Lifecycle Dynamics
• Portfolio-Level Analysis	• Manage Interconnected Projects
• Procurement Focus	• Enhance Supplier Integration

Fig.8 Gap and Implication Analysis

These gaps have direct managerial and practical implications. In engineering and procurement-oriented projects, effective project management requires:

1. Robust governance structures that align PLM, procurement, and project management functions, ensuring coherent decision-making and accountability.
2. Expanded performance assessment, encompassing not only efficiency metrics (cost, schedule, scope) but also effectiveness (stakeholder satisfaction) and strategic impact (organizational learning and capability development).
3. Leadership and team competency development, particularly to manage multidisciplinary teams and coordinate external suppliers and contractors.
4. Adaptive project management approaches, balancing standardized procedures with flexibility to respond to uncertainties and evolving project conditions.

Engineering firms can improve overall project performance, lower procurement and technical complexity risks, and better integrate project operations with strategic objectives by addressing these areas. The current effort has been driven by the operational objectives of Podium Engineering, which is now pursuing precisely this route. With the explicit goal of structurally integrating project management, procurement, and engineering operations inside the organization, the thesis focuses on the creation and application of a PLM-centered methodology to assist this change.

2.3 PLM in Engineering Organizations

Product Lifecycle Management (PLM) has progressively emerged as a central paradigm in contemporary engineering organizations, driven by the increasing complexity of products, accelerated innovation cycles, and the need to manage vast amounts of technical information across extended time horizons. The literature consistently positions PLM as a response to the structural limitations of traditional engineering data management approaches, which were primarily focused on isolated lifecycle phases and departmental boundaries [20] (Stark, 2011).

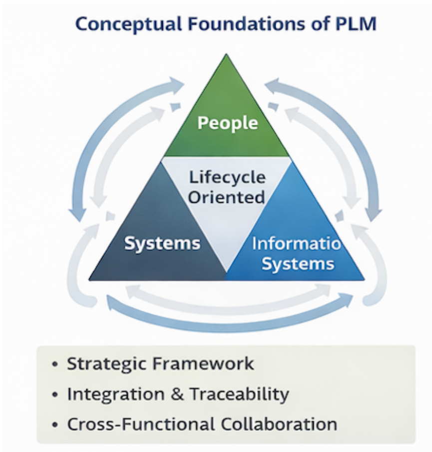

Fig. 9 Conceptual foundation of PLM

In engineering-intensive industries, products are no longer static artifacts but dynamic systems subject to continuous evolution due to technological advances, regulatory changes, and market demands. As a result, managing product-related information over time has become a strategic challenge. PLM addresses this challenge by providing an integrated framework that supports the creation, management, and dissemination of product information throughout all lifecycle phases, from initial concept development to end-of-life [21] (Abramovici, 2007).

The state-of-the-art literature emphasizes that PLM should not be interpreted merely as a software solution, but rather as an organizational approach that integrates people, processes, and technologies around a lifecycle-oriented view of the product[22] (Grieves, 2006). This holistic perspective is particularly relevant for engineering companies, where product knowledge is distributed across multiple disciplines and organizational units. PLM is commonly defined as a systematic approach to managing product-related data and processes across the entire lifecycle. Early definitions focused on technical data management, particularly in the context of computer-aided design (CAD) and product data management (PDM) systems[23] (Saaksvuori and Immonen, 2008). Over time, the concept has evolved to encompass a broader set of managerial and organizational dimensions.

Contemporary definitions highlight PLM as a strategic framework that enables lifecycle integration, traceability, and collaboration[20] (Stark, 2011).

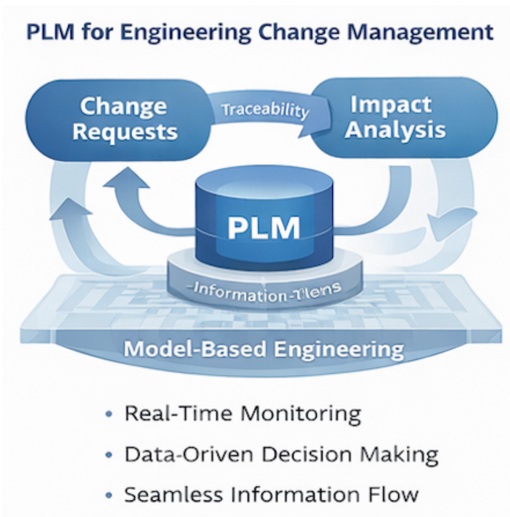

Fig. 10 Role of PLM in engineering change management

This evolution reflects the recognition that product upstream activities like procurement cannot be effectively managed in isolation from downstream phases such as manufacturing, operation, and maintenance. The literature underscores that lifecycle fragmentation leads to inefficiencies, rework, and loss of knowledge, particularly in complex engineering environments. A key conceptual distinction introduced by PLM is the shift from a project-centric or function-centric view to a product-centric view. While projects and functions remain essential organizational constructs, PLM positions the product as the primary integrative element around which information and processes are structured[24] (Eigner *et al.*, 2014). This orientation facilitates continuity across successive engineering initiatives and supports the reuse of product knowledge.

The PLM literature commonly structures the product lifecycle into three macro phases: Beginning of Life (BOL)**,** Middle of Life (MOL)**,** and End of Life (EOL)[25] (Terzi *et al.*, 2010). Each phase presents distinct managerial and technical challenges, which PLM seeks to address in an integrated manner.

The BOL phase encompasses activities related to product conception, requirements definition, design, and development. In engineering companies, this phase is characterized by high uncertainty and intensive knowledge creation. PLM supports BOL activities by enabling requirements traceability, configuration management, and collaborative design across disciplines[26] (Schuh *et al.*, 2010), this work is focuses in this part of the lifecycle.

Engineering change management is consistently identified as one of the most critical and complex processes in engineering organizations. Frequent design changes, driven by evolving requirements or technical issues, introduce significant coordination challenges. The literature emphasizes that ineffective change management leads to errors, delays, and cost overruns[28] (Rouibah and Caskey, 2003).

PLM plays a central role in structuring and formalizing engineering change processes. By linking change requests to product structures and lifecycle data, PLM enables systematic impact analysis and traceability[29] (Eigner and Dickopf, 2009). This capability is particularly important in environments characterized by high product complexity and long lifecycle durations.

Studies indicate that organizations with mature PLM-based change management processes achieve improved control over design evolution and reduced rework[20] (Stark, 2011), moreover, PLM facilitates communication of changes across organizational boundaries, ensuring that downstream stakeholders are informed in a timely and consistent manner.

Another dominant theme in the PLM literature is the role of it in supporting knowledge management since engineering knowledge is often tacit, context-dependent, and embedded in design decisions and artifacts. Without structured mechanisms for capturing and organizing this knowledge, organizations risk losing critical expertise over time[30] (Nonaka and Takeuchi, 1995).

PLM systems support knowledge retention by linking technical documentation, design rational, and historical data to product structures, this enables engineers to access previous solutions, understand design trade-offs, and build upon existing knowledge, the literature highlights that this capability is particularly valuable in engineering organizations with long product lifecycles and low product turnover.

From a strategic perspective, PLM contributes to organizational learning by enabling feedback loops between lifecycle phases. Operational data collected during the MOL phase can be fed back into design processes, supporting continuous improvement and innovation[26] (Schuh *et al.*, 2010). This lifecycle feedback is a defining characteristic of advanced PLM implementations.

Modern engineering products are developed through the interaction of multiple disciplines and organizational units, recent literature highlights the expansion of PLM in response to digitalization trends and concepts such as the digital thread and digital twin are increasingly discussed as extensions of traditional PLM architectures[33] (Boschert and Rosen, 2016). These concepts emphasize continuous data integration across lifecycle phases, enabling real-time monitoring and simulation. The integration of PLM with advanced analytics, simulation tools, and cyber-physical systems further expands its scope. Engineering organizations are increasingly leveraging PLM to support model-based systems engineering and data-driven decision-making[34] (Tao *et al.*, 2018), these developments position PLM as a foundational element of digital engineering strategies.

Fig. 11 PLM as an enabler of knowledge management and organizational learning

Despite its potential benefits, PLM implementation is associated with significant challenges, the literature identifies resistance to change, lack of standardization, and misalignment between organizational processes and system capabilities as common barriers[21] (Abramovici, 2007). Engineering cultures characterized by autonomy and informal practices may perceive PLM as restrictive, its maturity models are frequently used to assess organizational progress and mature implementations are characterized by lifecycle integration, standardized processes, and strategic alignment [35] (Schuh *et al.*, 2010). In contrast, low-maturity implementations often focus narrowly on data management, failing to exploit the full potential of PLM. The literature consistently emphasizes that PLM facilitates cross-functional integration by providing a shared information environment and standardized data structures[21] (Abramovici, 2007), this integration reduces misunderstandings, improves coordination, and supports concurrent engineering practices, the goal of this work is to demonstrate that through an operational integration engineering, procurement and project management can operate together enhancing quality, performance and cost efficiency. However, the literature also highlights that technological integration alone is insufficient, effective collaboration requires alignment of processes, incentives, and organizational culture. PLM implementation therefore entails significant organizational change, which must be carefully managed to realize its potential benefits[32] (Kerzner, 2015).

3. Problem Statement and Current limitations

3.1 Structural Limitations of the Current Software Landscape

Examining the organization's distinctive operational traits and the information systems that support its primary operations might help to clarify the mismatch covered in previous sections. Product definitions and related data are intrinsically unstable in highly technical engineering firms like Podium Engineering, whose operations are primarily concentrated on prototype development and small series manufacturing. The loosely coupled systems between project management, procurement, and Product Lifecycle Management (PLM) responsibilities is greatly exacerbated by this operational context, which is marked by unpredictability and constant change, the presence of a dynamic, or "living," Bill of Materials (BOM) is a fundamental feature of prototype-oriented workplaces.

Fig. 12 Fragmented Software Landscape in Engineering Project Execution

Prototype and small series projects are distinguished by ongoing design improvement, in contrast to large production settings where product structures often solidify early in the development phase. Before reaching a final configuration, components frequently go through several revisions, and engineering adjustments are not unusual occurrences but rather a typical and anticipated part of project execution. Because of this, the BOM constantly changes throughout the course of the project, emerging as a crucial but extremely erratic component of coordination. In theoretical terms, PLM systems are made to handle this changing product structure by guaranteeing version control, configuration control, and traceability. Nevertheless, Manufacturing Bills of Materials (MBOMs) do not yet reflect a completely industrialized and procurement-oriented view of the product in the current organizational structure. Rather, MBOMs and Engineering Bills of Materials (EBOMs) are still quite similar, with the major differences being in form rather than substance. This lack of distinction limits PLM's capacity to assist downstream operations and lessens its usefulness as a common point of reference for various activities. This restriction's effects are most noticeable in the procurement area. In order to determine purchasing needs, supplier involvement, and material requirements, procurement planning activities rely on the extraction of MBOM data. Procurement is compelled to use information that is intrinsically unstable because MBOMs are often modified and primarily represent an engineering viewpoint, this makes it more difficult to create trustworthy procurement strategies ahead of time, raises unpredictability, and complicates sourcing selections. In the current setup, ERP system is used to oversee the execution of purchasing operations, while Microsoft Excel is mostly used to construct procurement plans, Excel lacks built-in procedures for data integrity, version control, and integration, despite its flexibility in managing changing requirements. Similar to this, ERP functions independently of both the PLM environment and project management tools, even though it offers crucial features for transactional execution, supplier management, and administrative control. Because there are no automated data flows between these systems, procurement staff must manually reconcile data, which raises the possibility of mistakes and misalignment. The usage of Microsoft Project as a stand-alone scheduling tool highlights these issues from a project management standpoint, Microsoft Project does not offer visibility into product maturity, configuration state, or procurement execution, but it does allow activity planning and milestone monitoring. Because of this, project timetables are frequently predicated on hypotheses that could no longer hold true in the event of engineering modifications or delays in procurement. As a result, the project manager must constantly modify plans in light of incomplete and delayed information. The project manager's capacity to collaborate with other stakeholders is severely hampered by this lack of integration. Purchasing operations are carried out in the ERP system, engineering upgrades handled by the PLM system, and procurement plans kept in Excel all change asynchronously. In a highly iterative and time-constrained engineering setting, coordination mostly depends on meetings, informal communication, and manual data aggregation, all of which are inadequate. The ensuing lack of synchronization raises project risk and decreases the efficacy of decision-making. Fundamentally, different perspectives of reality are reflected in the incompatibility of project management, procurement, and PLM systems. PLM systems use configurations, revisions, and lifecycle stages to model the product. Excel-based procurement plans represent purchasing needs as static lists detached from configuration logic, while project management software models operate in terms of tasks, dependencies, and schedules, ERP systems like Mago concentrate on transactional execution and cost control. These representations perpetuate functional silos and remain disjointed in the absence of a single lifecycle reference or shared data backbone. This fragmentation becomes especially important in the creation of prototypes and small series, when change is inherent and frequently non-linear.

Reduced responsiveness and misaligned judgments result from design changes spreading across systems with incomplete visibility and delays. The organization's capacity to keep control over changing configurations and foresee the effects of change is compromised by the lack of a single, reliable source of truth for product, procurement, and project information. PLM stands out as the only solution that may theoretically serve as an integration backbone in this disjointed information ecosystem. PLM is intended to manage product definition and evolution over the whole lifetime, in contrast to project management and ERP solutions, which are intrinsically focused on execution and control. However, PLM's integrative potential cannot be fully realized as long as it is only loosely linked to project scheduling, ERP execution, and procurement planning. This structural constraint explains why the organization's project management, procurement, and PLM are still out of alignment despite the availability of sophisticated tools and potent technological capabilities.

3.2 A PLM-Centered Framework for Cross-Functional Integration

The research in Section 3.1 shows that the misalignment between procurement, project management, and Product Lifecycle Management (PLM) is a structural problem that results from disconnected information systems and fragmented processes rather than just a collection of individual inefficiencies. Small adjustments to specific tools or processes are unlikely to address the root reasons in such a situation, rather a methodical approach is needed to guarantee uniformity and cross-functional integration. The particular contextual factors that define the development environment further support the use of PLM as the primary integration tool. In the high-innovation engineering environment in which Podium ngineering operates, procurement engages in more comprehensive sourcing efforts rather than just buying commodities as in more traditional businesses, there is a constant need to restart the procurement process and build new supplier connections because every project has different sourcing requirements. As a result, a solid, standardized approach that can handle the intricacy of frequent project modifications is needed. Furthermore, the high level of cooperation between engineering and procurement increases the need for a robust system that can guarantee dependable information transmission and enforce uniform processes. A system that can handle changing product topologies, ensure traceability over several revisions, and facilitate quick information exchange among stakeholders is necessary due to the dynamic nature of product development in prototype and small-series contexts and because of its capacity to handle product definition and evolution throughout the lifecycle, PLM stands out as the best enterprise technology to act as the integration backbone.

The goal of a PLM-centered framework is to supplement current project management and ERP systems by offering a cohesive and authoritative representation of product-related data, rather than to quickly replace them, an operational shift is required. In this architecture, downstream systems are synchronized through regulated and uniform data flows, with PLM acting as the single source of truth for product structure, configuration status, and change management. The suggested architecture is built on three primary PLM-based technologies that are intended to mitigate particular parts of the misalignment between engineering, procurement, and project management responsibilities in order to address the problems mentioned in the preceding sections.

- The **Assembly Plan** tool bridges the gap between engineering definition and downstream operations by offering an organized, mBOM-focused perspective of the product assembly. This tool facilitates a more robust management of changing manufacturing Bills of Materials in iterative contexts and promotes a clearer distinction between engineering and manufacturing viewpoints by formalizing the link between components, configurations, and assembly logic.

- The **Sourcing Summary** tool gives a consolidated, PLM-native view of sourcing related data. This solution improves visibility and traceability for engineering and procurement stakeholders by directly linking supplier information, sourcing tactics, and procurement restrictions with product components. By doing this, it lessens the need for external spreadsheets and promotes more consistent and well-informed decision-making across the course of the project.
- The **Order Plan** tool links the fully developed product to the procurement execution. This technology makes order management more proactive and coordinated by linking BOM evolution with scheduled buying actions, this lessens the impact of late design modifications and eliminates the need for manual data reconciliation between systems. These three technologies together constitute the foundation of the suggested PLM-centered architecture and are necessary to realign engineering, procurement, and project management operations in a iterative development environment. These solutions make it possible for stakeholders to coordinate more consistently by creating an organized and shared representation of product specification, sourcing choices, and ordering logic. In Chapter 3, the suggested implementation strategy is provided and thoroughly detailed, along with a step-by-step description of their setup, underlying data structures, and mutual interactions. To further improve control, transparency, and decision support throughout the product lifecycle, a number of sophisticated PLM capabilities are added to the suggested architecture in addition to these essential tools. A Problem Reporting System (PRS), cost analysis tools, and organized release planning procedures are a few of these characteristics. These components greatly enhance governance, traceability, and well-informed decision-making, even though they are not essential to the structural realignment covered in this chapter. In Chapter 5, their

contribution to strengthening the overall efficacy and resilience of the suggested solution is thoroughly explored.

4. Implementation of a PLM-Centered Framework

This chapter operationalizes the PLM-centered paradigm presented in Section 3.3 in the particular context of Podium Engineering, a company with a strongly engineering-driven operating approach. The firm works mostly on a project-based basis, producing small-series and prototypes that are characterized by numerous design iterations, high technical complexity, and changing product configurations. Podium Engineering is a particularly relevant case for the examination of cross-functional integration difficulties involving engineering, procurement, and project management because of its project-oriented and innovative environment. Throughout the development phases, the DMU team, the project chiefs, and project buyers actively participated in the design of requirements, functional validation, and progressive solution refinement to guarantee conformity with actual operational demands. In this regard, the thesis's author actively took part in the development process during the internship, witnessing and assisting with the suggested tools' gradual implementation and learning firsthand about the organizational and technical dynamics that underlie their adoption. The suggested strategy attempts to overcome the inadequate integration between these tasks mentioned in the preceding chapter by using Product Lifecycle Management as an integration backbone. The Assembly Plan, the Sourcing Summary, and the Order Plan are the three main PLM tools that form the framework of the implementation. Each tool helps create an organized, lifecycle-oriented representation of product, sourcing, and ordering data while focusing on a particular facet of cross-functional coordination. When combined, these solutions provide better stakeholder collaboration, increased traceability between product updates, and a more uniform alignment between engineering requirements and procurement execution. The suggested architecture uses a PLM-centered data model to encourage synchronization and coherence across tools and organizational functions rather than replacing current enterprise systems. The following sections provide a detailed description of each tool's goals, extent, and function within the larger framework. Working with a specialist software house, the tools were created as completely customized PLM extensions using a methodical, incremental design and deployment process, close and ongoing communication between technical and commercial parties drove this approach.

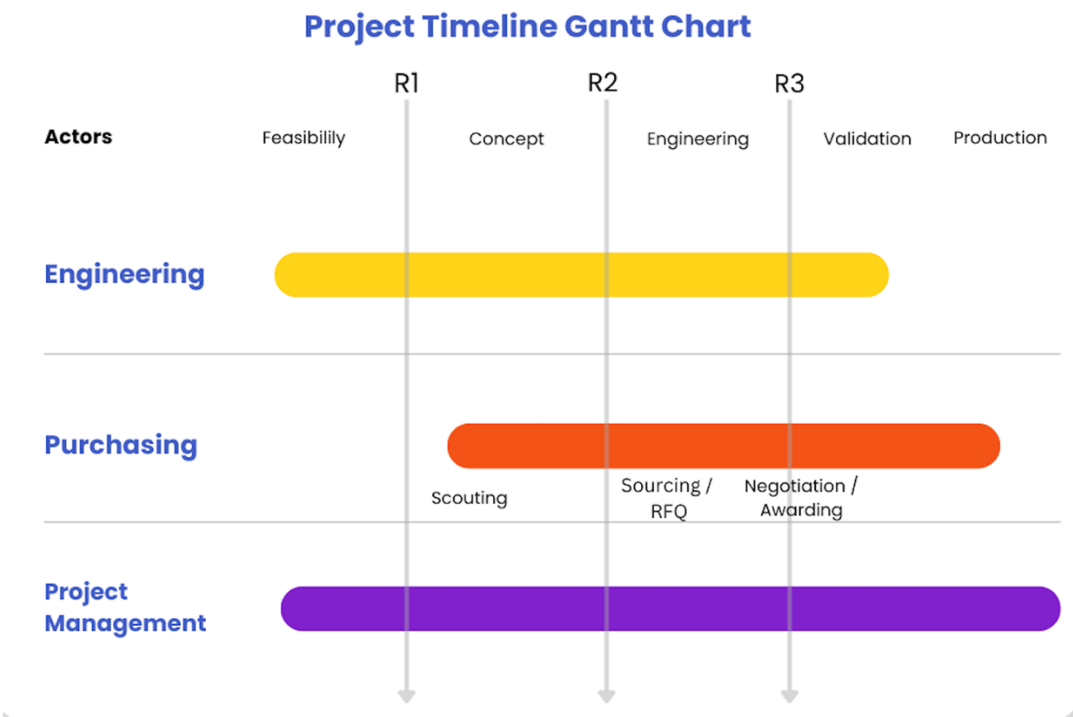

Fig. 13 Project timeline in the PLM frame

Acronyms found in figure 13 and in Chapter 4:

R1: Release where are evaluated technologies and open technical risks, occurs the timeline definition.

R2: This Release defines preliminary E-BOM & CAD product structure, preliminary manufacturing process and definition of costs based on preliminary suppliers' quotation.

R3: In this phase complete E-BOM & CAD product structure with geometrical integration are released, the performances are assessed and confirmed by CAE simulation and manufacturing requirement are integrated.

TD: Technical Director

Head of PC: Head of Project Chiefs

PC: Project Chief

TL: Team Leader

DMU: Digital Mock Up

4.1 Assembly Plan Tool

A key component of the PLM-based Project Management system, the Assembly Plan tool facilitates the integrated planning, scheduling, and traceability of tasks associated with the Manufacturing Bill of Materials (M-BOM). Its main goal is to convert the product structure into a logical and cohesive temporal representation so that engineering, procurement, and assembly departments can coordinate early on in the project.

The Assembly Plan offers a systematic way to match technical definition with operational planning in prototype and small series development environments where product configurations are constantly changing. The solution helps to improve cross-functional synchronization, lower uncertainty, and boost overall planning dependability by creating a direct link between the M-BOM and project scheduling. The M-BOM, which is automatically created using pre-made templates suited to peculiar business departments (such as automotive, battery, and motorsport), is the foundation of the Assembly Plan. By filling the M-BOM with all part numbers categorized as Assembly, these templates enable the physical structure of the product to be specified from the outset of the project. Starting on "day zero" of the project lifecycle, this method makes it possible to create a uniform and standardized product structure. While lower-level components and subassemblies are implicitly included within the lead time of their parent assembly, second-level assemblies serve as the foundation for the Gantt chart produced by the Assembly Plan. By doing this, the system guarantees that lower-level components are finished before higher-level assemblies while maintaining the M-BOM's hierarchical logic. This system facilitates a planning strategy that is in line with the actual assembly schedule and architecturally consistent. The level of the M-BOM that the Assembly Plan relates to, such as level 2 or level 3, can be specified by the user and changed while the project is being carried out. The system creates a parametric Gantt chart based on this setup, where each activity represents an assembly and dependencies show the parent-child connections specified in the M-BOM. Every part number in the system is linked to a required commodity category that was established at the time of creation, in order to anticipate procurement durations during the early planning phases, each category has a predetermined lead time and the system automatically substitutes the actual lead time for the estimated one when the procurement department enters an actual lead time based on supplier quotes or proposals. This change enables the Assembly Plan to go from a phase of predictive planning to one of dynamic, data-driven execution. Instead than using absolute calendar dates, the Gantt chart produced by the Assembly Plan only uses relative time, represented in days. The timetable shows the total amount of time needed to finish assembly and procurement tasks. Without sacrificing logical coherence or structural dependencies, this relative method allows for efficient scenario modeling, impact evaluation of delays, and real-time plan modifications.

While tasks related to separate levels must be completed sequentially, tasks related to the same hierarchical level can be carried out concurrently. By creating parametric linkages between each activity's start and finish dates, the system makes sure that any changes made to a parent assembly automatically influence its dependent pieces.

Furthermore, both positive and negative adjustable offsets between consecutive tasks are supported by the Assembly Plan, in order to meet particular industrial, logistical, or organizational needs, these offsets enable the construction of tailored gaps or overlaps between jobs, because strict schedule restrictions are sometimes incompatible with iterative development methods, this flexibility is especially important in prototype settings.

The integrated management of tooling, including molds, fixtures, and manufacturing equipment, is a crucial component of the Assembly Plan. There are two types of tooling elements:

- Tooling associated with a part number, directly linked to a specific production component;
- Independent tooling, such as assembly fixtures or testing equipment, associated with a specific assembly rather than a single component.

Tooling lead times are automatically included into the Gantt chart and are always maintained in sequence with regard to the component or assembly to which they are connected. The system asks the user to indicate if the project is a first-time setup when an Assembly Plan is created. If verified, all necessary tooling is automatically inserted; if not, tooling can be manually added for each part number. This reasoning guarantees coherence among planning assumptions, production preparedness, and product description. Through the Assembly Plan's graphical user interface, users may add, edit, and display activities by giving them titles, codes, and references. For every component, users may specify commodity categories, assembly schedules, and supplier lead times. The Gantt chart shows each second-level assembly as a separate row, and the system automatically configures all serial and parallel dependencies.

Different stakeholders may engage with the tool in accordance with their roles and responsibilities thanks to this interface, which provides both high-level supervision and specific operational control.

To improve responsiveness and collaboration, the Assembly Plan includes automatic notification logic:

- Weekly summary emails are generated to highlight upcoming deadlines;
- The Project Manager receives a consolidated overview of all pending activities;
- Team Leaders from Procurement, Engineering, and Assembly receive targeted reminders related to their specific domains;
- As deadlines approach, the system issues dedicated alerts indicating required actions such as releases, orders, or assembly activities.

These systems facilitate proactive project management and lessen the need of manual follow-ups.

The Assembly Plan is tightly integrated with other PLM modules, including:

- Release Agenda, for planned release milestones (e.g., R2, R3);
- Problem Reporting System (PRS), for monitoring part status and anomalies;
- Sourcing Summary and Procurement Summary, for supplier management, cost comparison, and variance analysis;
- Order Plan, for managing production volumes, requirements, and deliveries.

A two-way planning approach is made possible by this integrated design. While the Order Plan allows for forward planning from procurement execution to manufacturing, the Assembly Plan facilitates backward planning from the finished product to its components. When combined, these perspectives provide a cohesive and lifecycle-focused planning paradigm. The Assembly Plan-related activities start at the beginning of the project. The EBOM and MBOM, which are necessary for the Assembly Plan to function properly, must be created by the Digital Mock-Up (DMU) team upon project

clearance and the DMU Manager is responsible for organizing the transfer of design studies to finalized part numbers. Prior to each release, it is the responsibility of the DMU Manager to ensure that all components contain the information required for the proper functioning of the PLM-based procurement modules. The Assembly department is in charge of the Assembly Plan's operational administration, which includes its compilation and ongoing updates. While the DMU Manager guarantees the accuracy and comprehensiveness of the information structure, the Chief Engineer confirms adherence to project deadlines. The Assembly Engineer notifies all relevant parties, especially the procurement department of the first iteration's completion after the initial compilation. Early supplier assessments and the formulation of first negotiating tactics for crucial components are made possible by this. Although the Assembly Plan tool offers a methodical and technically strong way to integrate planning logic, procurement lead times, and product structure, its successful implementation depends on the organization's roles and responsibilities being clearly defined. To guarantee consistency, data quality, and long-term use, a formal distribution of ownership, responsibility, and operational duties is necessary due to the cross-functional nature of the suggested solution. Because of this, a RACI-based responsibility structure is introduced, which links the Assembly Plan activities to the pertinent organizational responsibilities participating in the process.

ACTIVITY	TD	HEAD OF PC	PROJECT CHIEF	TL	ENG	PURCHASING	ASSEMBLY	DMU
Ebom and Mbom generation	A		I		C			R
Data related to material, supplier, sourcing type, manufacturer				A	R	C		
Verification of completeness of item master data								R
Compilation and management of the Assembly Plan			A				R	
Verification of compliance with project requirements		A	R					

Table 1 RACI Matrix for the Assembly Plan Tool

4.2 Sourcing Summary Tool

A key element of the PLM Project Management module, the Sourcing Summary tool was created especially to assist with the management, oversight, and control of sourcing operations during the course of the project. It functions as the main technical procurement coordination platform inside the suggested framework, essentially acting as the control room where all temporal and economic data pertaining to project components comes together. The Sourcing Summary's main goal is to ensure that sourcing operations are completely managed, digitalized, and traceable inside the PLM environment by facilitating procurement-related decision-making with transparency, correctness, and speed. The Sourcing Summary resolves the fragmentation concerns mentioned in Chapter 3, where procurement data were previously maintained through disjointed spreadsheets and non-integrated systems, by combining cost, lead-time, supplier, and ordering information into a single PLM-native application. A specific Sourcing Summary is connected to the related Manufacturing Bill of Materials (M-BOM) for every project or vehicle configuration. A continuous and reciprocal relationship between engineering definition and procurement execution is established by automatically importing all acquired part numbers from the M-BOM, because of this connection, sourcing operations may change concurrently with product development, giving early insight into prices and lead times while staying in line with the rapid design modifications that are common in prototype and small series settings. From an architecture standpoint, the Sourcing Summary serves as the project database's ordered visualization layer and input interface for all sourcing-related data. It is achieved using a table-based, PLM-native user interface that enables continuous updates and organized data entry. A single item number is represented by each row, while columns show the essential sourcing characteristics needed for technical procurement, such as contractual references, logistical specifications, and economic data. This tool facilitates the management of tooling costs and the association of procurement-specific features, such fixtures or temporary part numbers, that were not initially included in the M-BOM, in addition to component-related data. The Sourcing Summary's support for multi-supplier management is one of its unique features. Multiple possible suppliers can be linked to each part number, enabling the evaluation of different sourcing choices within the same digital context. The tool allows for direct cost and lead-time comparisons as well as the generation of optimization scenarios, such as minimum-cost or minimum-lead-time configurations, to aid in decision-making. In order to maintain human control over final sourcing decisions and to take organizational, technological, and strategic factors into account, these scenarios are meant to be analytical tools rather than automated choices. Another key component of the Sourcing Summary is cost management: the program provides the computation of aggregated sourcing costs at the project level and makes it possible to handle both recurring and non-recurring expenses, including tooling investments. As sourcing efforts develop, updated supplier bids are gradually compared to an initial cost baseline that is created based on early estimates obtained from the M-BOM. This method allows for the early identification and mitigation of procurement risks by highlighting variations in lead time and cost using dynamic variance studies. Mechanisms for controlling data maturity and confidence are also included in the Sourcing Summary, each part number moves through predetermined confidence stages as sourcing data develops from first estimates to verified quotes and purchase orders. This process gives quick insight into the degree of procurement activity maturity while ensuring consistency between the assumptions used for project planning and the dependability of sourcing data. A thorough logging system automatically records every action taken inside the Sourcing Summary, and to provide complete auditability of sourcing decisions and compliance with governance standards, every alteration is tracked with reference to the user, timestamp, modified field, and previous and updated values. In highly regulated or technologically sophisticated situations, where procurement choices need to be justified and evaluated over time, this traceability is very important. Ensuring data consistency, accountability, and decision dependability across the procurement lifecycle is made possible in large part by the Sourcing Summary tool's governance. The tool is regulated by well defined roles and access regulations, which are intended to strike a balance between centralized control and cross-functional cooperation, given its role as the authoritative source for sourcing-related information. The procurement department, which is in charge of the ongoing upkeep and verification of all sourcing-related data, is given primary ownership of the sourcing summary. This covers sourcing tactics, lead times, cost structures, ordering status, and supplier information management. The framework prevents the discrepancies that usually result from dispersing data management by centralizing responsibilities within the purchasing function, ensuring that procurement data stays current, coherent, and in line with contractual and commercial realities.

The Sourcing Summary is primarily available in visual form to other organizational departments, such as Engineering, Assembly, and Project Management. This design decision represents the requirement to avoid uncontrolled changes that can threat data integrity while offering complete transparency on sourcing status, cost evolution, and delivery schedules. All stakeholders may evaluate how sourcing decisions affect their own operations thanks to this shared view, which facilitates well-informed and coordinated decision-making throughout the company. Simultaneously, the governance model permits regulated exceptions, wherein specified roles the Project Chief and the Assembly function, in particular are permitted to alter specific subsets of data as necessary for operations. While maintaining the procurement department's overall accountability for sourcing choices and data integrity, these restricted editing privileges allow for prompt alterations in response to project-specific requirements, such as timetable modifications or assembly limitations. The intrinsic traceability measures built into the Sourcing Summary further strengthen governance. Every update to the data is automatically recorded, together with the user's details, the timestamp, and the type of change, this facilitates both internal evaluations and post-project studies and guarantees complete auditability of sourcing decisions. Furthermore, the usage of data maturity phases and confidence levels gives a clear indicator of the dependability of source information at various project stages, coordinating governance with both data ownership and data quality. Because the Sourcing Summary's data directly influences downstream procedures like order planning, procurement execution, and project control, its governance goes beyond the tool itself within the larger PLM ecosystem. To ensure consistency among linked tools and to support the broader goal of realigning engineering, procurement, and project management processes into a unified digital framework, it is crucial to establish a clear governance structure.

ACTIVITY	PROJECT CHIEF	PURCHASING	ENGINEERING	ASSEMBLY	DMU
Sourcing summary filling	A	R	R	R	

Table 2 RACI Matrix for the Sourcing Summary Tool

4.3 Order Plan Tool

The suggested PLM-centered framework's execution-oriented layer is represented by the Order Plan tool, which converts sourcing choices and project specifications into tangible, traceable, and timely procurement activities. The Order Plan controls the scheduling, sequencing, and prioritizing of purchase orders, while the Assembly Plan specifies what needs to be produced and when, and the Sourcing Summary establishes how and from whom components should be procured. As a result, it is essential for bridging the gap between planning and practical execution. The Order Plan serves as the main conduit between engineering-driven planning data and procurement execution procedures inside the larger PLM system. Its goal is to maintain complete alignment with the project timeline and growing product definition while ensuring that buying operations are completed at the right time, in the right amounts, and with the right degree of priority. The suggested method eliminates the conventional division between engineering tools and procurement execution systems by integrating the Order Plan into the PLM environment, allowing a continuous digital thread throughout the project lifetime. The data included in the Assembly Plan and the Sourcing Summary is used directly to create the Order Plan. Together with their verified sourcing attributes such as the chosen supplier, the agreed-upon lead time, the cost details, and the degree of confidence all acquired components that are part of the Manufacturing Bill of Materials are moved to the Order Plan. By eliminating manual duplication, this automated data propagation guarantees complete consistency throughout engineering, sourcing, and ordering processes. Functionally speaking, the Order Plan is implemented as a structured, PLM-native table that offers a thorough and current summary of all procurement actions necessary for a particular project. A purchasable component or procurement batch is represented by each row, and the important ordering parameters such as the necessary quantity, the target delivery date, the calculated order release date, the supplier reference, the priority level, and the order status are recorded in the columns. In order to encourage user adoption and maintain natural integration of all data within the PLM system, the tabular format is purposefully made to mimic conventional procurement planning spreadsheets. The automated computation of scheduled order dates based on component lead times and project milestones is a key feature of the Order Plan, the system does a backward scheduling operation to find the latest possible order release date, beginning with the necessary delivery date specified in the Assembly Plan. Proactive procurement planning is made possible by this technique, which also identifies components whose lead times might jeopardize project timelines. Any delay in order release or sourcing validation is instantly apparent, enabling remedial action to be made before it affects downstream operations. In settings where design changes and needs are constantly changing, the Order Plan is essential to organizing procurement processes. In order to keep procurement activities in line with the most recent product specification, changes to the Assembly Plan or the Manufacturing Bill of Materials immediately cause a reevaluation of the related Order Plan entries, since component designs frequently go through several iterations before stabilizing, this functionality is especially important in prototype and pre-series development situations. The Order Plan facilitates efficient change management and lowers the possibility of buying out-of-date or wrong components by clearly connecting procurement activities to particular BOM revisions and project milestones. The Order Plan offers substantial benefits in multi-project and high-complexity settings in addition to managing individual projects. Procurement resources and supplier capacities are often shared in businesses that carry out various development initiatives concurrently, which can result in conflicting priorities and possible disputes. The Order Plan makes delivery criteria, order release dates, and priority levels clear and comparative, allowing for a unified picture of procurement operations across concurrent projects. Instead of responding to problems after the fact, procurement teams may foresee bottlenecks, plan order sequencing, and match procurement priorities with overall portfolio-level goals thanks to this visibility. Another unique aspect of the Order Plan is priority management: considering variables including lead time, cost effect, component criticality, and reliance on upstream engineering tasks, each procurement line may be given a priority level that represents its importance for project execution. The Order Plan facilitates more efficient job distribution within the procurement function and improves responsiveness in settings with limited resources by formalizing priorities within the PLM system, also prototype and small series manufacturing situations, where procurement decisions must strike a balance between flexibility, cost management, and risk reduction, are also especially supported by the tool. In these situations, components are frequently purchased in batches that correspond to various stages of development, including functional builds, validation series, and early prototypes. By enabling the autonomous management of several batches, each connected to distinct delivery criteria and milestones, the Order Plan facilitates this incremental procurement approach, this strategy lowers the financial risk related to design uncertainty and avoids placing excessive or early orders. The Order Plan's incorporation into the PLM framework enhances cash-flow management and cost control from an economic standpoint and this technology lessens the possibility of allocating funds prior to design stabilization by tying order release choices to verified engineering data and established project milestones. For expensive or long-lead-time components, where improper timing can lead to large cost overruns or the buildup of outdated inventory, this feature is especially important. The Order Plan facilitates a more effective use of financial resources by allowing procurement expenditures to be more closely matched with real project demands. Early identification of procurement-critical products improves risk minimization even further, and proactive mitigation measures can be made possible by clearly highlighting components in the Order Plan that exhibit extended lead times, immature designs, or a significant reliance on supplier capacity. This visibility facilitates well-informed decision-making and lessens the possibility of schedule interruptions or downstream delays, which are especially harmful in prototype and small series situations. Consistency between sourcing choices and procurement execution is ensured by the Order Plan's strong interaction with the Sourcing Summary: the Order Plan is automatically updated as sourcing factors change, including supplier selection, lead time changes, and cost modifications and on the other hand, the sourcing layer receives input from order execution, such as order confirmations, delivery updates, or delays. The PLM system's position as the exclusive source of truth for procurement-related data is strengthened by this two-way information flow. The Order Plan is essential for synchronizing PLM and ERP functions from the standpoint of systems integration. Purchase order issuance and financial accounting are examples of transactional tasks that are usually handled by ERP systems, while the PLM system is the official setting for procurement planning, coordination, and decision support. While enabling other systems to manage execution, the Order Plan preserves the engineering and project context of procurement choices by maintaining a synchronized representation of procurement planning within the PLM environment. In addition to preventing the loss of contextual information that frequently happens in ERP-centric techniques, this division between planning and execution guarantees consistency between technical and commercial dimensions. The same guidelines that apply to the Sourcing Summary also govern the Order Plan. Purchase orders are released and their progress is tracked, and the procurement department is primarily in charge of maintaining and updating the order plan. Ordering progress, delivery projections, and important procurement concerns are visible to other corporate units including Project Management, Engineering, and Assembly, when project-level modifications to priorities or delivery dates are necessary, some roles, like the Project Chief, may be granted controlled editing access. However, the procurement department is still ultimately responsible for data accuracy and purchase implementation and the Order Plan's inherent characteristics include traceability and auditability. Changes to quantities, dates, priority, statuses, and other order-related data are all automatically recorded. This thorough change history helps supplier performance evaluation, allows procurement decisions to be evaluated and justified throughout time, and offers a solid foundation for post-project evaluations and continuous improvement programs. The benefits of the Order Plan integrated within the PLM environment are clear when contrasted with conventional procurement planning techniques based on disjointed spreadsheets and ERP-centric execution models. ERP systems are not made to deal with the unpredictability and iterative nature of early-stage development, and spreadsheet-based tools lack native connection with product structures and change management procedures. In contrast, the this tool offers a cohesive planning layer that synchronizes procurement execution with project goals, permits dynamic updates in response to design changes, and maintains complete traceability to engineering data. In conclusion, the suggested PLM-centered procurement framework's execution-oriented cornerstone is the Order Plan tool: it guarantees that ordering operations are consistently in line with engineering intent, project goals, and organizational restrictions by converting sourcing choices and project timelines into organized, traceable, and coordinated procurement actions. A cogent and comprehensive approach to project-driven procurement management is made possible by the Order Plan, which, when combined with the Assembly Plan and the Sourcing Summary, completes the digital thread linking product description, procurement planning, and operational execution.

ACTIVITY	HEAD OF PC	PROJECT CHIEF	PURCHASING	ASSEMBLY	DMU
Perimeter definition	A	R			
Work order implementation in PLM system		A			R
Assembly upload with associated deadline	A	R			

Table 3 RACI Matrix for the Order Plan Tool

5. Supporting Tools and Key Performance Indicators

The background, difficulties, and structural solution for enhancing the alignment of project management, procurement, and engineering activities through a PLM-centered framework were presented in the preceding chapters: while Chapter 3 outlined the essential operational tools intended to restore coherence, traceability, and control throughout the product development and procurement lifecycle, Chapter 3 focused on the crucial problems resulting from the fragmentation of processes, tools, and responsibilities across organizational functions. However, defining essential planning and coordinating tools is not enough for such a framework to be implemented successfully, additional procedures are needed to provide governance, transparency, and ongoing performance monitoring in complex engineering environments that are marked by rapid design modifications, changing bills of materials, and strict cost and schedule limitations. Because of this, this chapter introduces a set of performance measuring tools and supporting tools that are used in conjunction with the suggested PLM-based solution. By addressing transversal elements that span several roles and lifecycle stages, the supporting tools covered in this chapter aim to improve the framework's resilience and operational efficacy. These technologies strengthen the PLM system as the primary source of truth for technical, organizational, and financial data by enabling organized problem management, methodical cost control, and disciplined release and configuration management. They serve as facilitators that assist decision-making, lessen ambiguity, and enhance coordination among stakeholders engaged in engineering, procurement, and project execution rather than establishing new planning frameworks.

This chapter presents a collection of Key Performance Indicators (KPIs) in addition to these auxiliary tools, which are intended to assess the efficacy of the suggested solution and measure the gains made in comparison to the original state. The KPIs are designed to offer objective, quantifiable insights into crucial aspects including procurement dependability, bill of materials stability, cost management, and schedule adherence. They are directly generated from the data structures and procedures presented in the preceding chapters. The suggested KPIs facilitate evidence-based decision-making and allow for ongoing development over time by connecting performance measurement to the PLM-centered framework. As a result, this chapter is organized as follows. The supporting tools that strengthen process governance and supplement the fundamental PLM features are first presented in Section 5.1. The chosen KPIs are then presented in Section 5.2, together with its description, justification, and connection to the instruments and procedures covered in Chapter 5, by offering both operational assistance and quantitative methods for evaluating its impact within an engineering-oriented organizational setting, these components together complete the suggested framework.

5.1 Supporting PLM Governance Tools for Time and Cost Control

The structural mechanisms by which engineering, procurement, and project management activities are coordinated within a PLM-centered framework are defined by the fundamental tools discussed in Chapter 4. However, structural alignment by itself is insufficient to ensure successful execution in engineering contexts with high levels of uncertainty, numerous design iterations, and progressive decision-making. To handle the economic and temporal ramifications of changing product definitions, more operational control and governance levels are needed, the supporting tools discussed in this part are specifically designed to strengthen the framework's resilience by providing systematic control over release schedule and cost evolution without the need for parallel planning structures. Supporting tools are native PLM features that act on the same data base as the main tools, rather than being separate systems, they make use of the data that the Assembly Plan, the Sourcing Summary, and the Order Plan have already produced, turning it into useful information that helps with day-to-day operational choices and in this way, they complement each other: the supporting tools make sure that execution is regulated, traceable, and economically viable over time, while the core tools specify what has to be done and how. The Release Planning Tool and the Cost Analysis Tool are two of the supporting tools used in the framework that are especially important. These technologies deal with schedule instability and cost uncertainty, two factors that are frequently found to be significant drivers of risk in prototype-driven and small-series engineering projects. By formalizing the planning of component releases inside the PLM environment, the Release Planning Tool also known as the Forward Release Planning Agenda is intended to control the temporal evolution of product maturity. Its main goal is to make sure that the design maturity development is clearly planned, tracked, and in line with downstream production and procurement restrictions, the tool encourages a proactive strategy where release timing becomes an explicit design and management decision, as opposed to accepting release dates as implicit implications of project deadlines. The Engineering Bill of Materials and the Release Planning Tool are closely related from an operational perspective, a scheduled release date that corresponds to a certain maturity level can be assigned to each system, subassembly, or component included in the EBOM. Because of this link, release planning may be carried out at various granularities, enabling project teams to concentrate on important elements while keeping an overall timetable that makes sense, maintaining the hierarchical link between assemblies and components, inconsistencies are prevented and release dependencies are met. A forward-planning logic that captures the iterative nature of engineering development is supported by the Release Planning Tool, in the early stages of a project, planned release dates are first established based on broad assumptions about design work, resource availability, and project milestones. These dates are being improved as the project moves forward and data becomes more trustworthy. The technology expressly supports this iterative refining process by keeping track of all intended and actual release dates, allowing temporal differences to be examined rather than hidden. The Release Planning Tool's connection with procurement-related data is a crucial feature, The Sourcing Summary and the Order Plan give supplier lead times and order emission limits that are used to regularly assess planned release dates. Through this assessment, the system may determine whether a scheduled release date conflicts with needs downstream. Coordination between engineering, procurement, and project management is prompted by the automated flagging of such disputes, this system avoids schedule overruns and procurement delays from resulting from late design freezes. The collaborative nature of release choices is reflected in the Release Planning Tool's operating procedure. Planned release dates are established and updated by engineering teams in accordance with design developments and technical preparedness. Project management is in charge of ensuring that release planning and overall project milestones are in line, while procurement offers feedback about lead times and sourcing constraints. The PLM system eliminates ambiguity and unnecessary planning artifacts by ensuring that a single, authoritative release plan is maintained despite the involvement of several stakeholders in the planning process.

Another crucial feature of the Release Planning Tool is baseline management. The release plan can be explicitly baselined at certain project milestones, such phase gates or design freeze reviews. The plan becomes unchangeable after it is baselined and is used as a benchmark for measuring any further deviations. After the baseline is created, all changes to the release dates are automatically monitored, allowing for clear documentation of schedule modifications and the reasons behind them, by enabling teams to examine recurrent causes of project delays, this capacity promotes both responsibility and continuous improvement. Another key component of the Release Planning Tool's usefulness is visualization: calendar-based representations give stakeholders an easy-to-understand summary of release schedules and dependencies, allowing them to promptly spot periods of congestion or subsystem misalignments. During coordination meetings, interactive rescheduling features facilitate scenario analysis, enabling teams to assess the effects of different planning choices prior to making adjustments, the tool promotes mutual understanding and well-informed bargaining among stakeholders through these graphical elements.

ACTIVITY	HEAD OF ENGINEERING	TL	PC	PURCHASING	ASSEMBLY	DMU
Realease calendar definition and update	A	R	R			

Table 4 RACI Matrix for the Release Planning Tool

The Cost Analysis Tool deals with the financial aspect of project execution, whereas the Release Planning Tool controls the temporal aspect of product development. Cost data is constantly changing in engineering projects with increasing design maturity as estimates are improved, quotes are obtained, and orders are placed. By offering a systematic and verifiable depiction of project costs inside the PLM environment, the Cost Analysis Tool is intended to control this progression, the Cost Analysis Tool functions as an analytical layer that compiles cost-related information from many sources, such as the Order Plan, the Sourcing Summary, the Engineering and Manufacturing Bills of Materials, and the Procurement Summary. The tool creates a single cost model by combining these inputs, which is nevertheless closely related to the technical specification of the product. Cost assessments are always contextualized within the present product configuration and project scope thanks to this relationship. An initial cost baseline is established at the start of the project using preliminary estimations based on historical data or early supplier indications. This baseline is being updated to reflect more trustworthy data as the research moves forward. By clearly differentiating between quoted, verified, and projected prices, the Cost Analysis Tool enables stakeholders to evaluate the maturity and dependability of the underlying data in addition to the absolute cost level. In prototype and small-series settings, where decisions are frequently made based on incomplete knowledge, this difference is especially crucial, early deviation identification is made possible by the tool's continual computation of cost variances in relation to the baseline. Different degrees of detail, from the overall project cost to specific components or commodity categories, can be used to investigate variances, this multi-level analysis facilitates the identification and prompt resolution of cost drivers, supporting both strategic decision-making and operational problem-solving. From a workflow standpoint, the procurement function, which is in charge of updating bids, negotiated prices, and order values, is principally responsible for maintaining cost data. Cost information is accessible to engineering and project management departments in read-only or controlled-edit modes, guaranteeing openness while maintaining data governance. The Cost Analysis Tool instantly updates when the product structure or sourcing strategy is altered, guaranteeing that the financial effects are immediately apparent. Temporal cost analysis, which supports assessments of cash-flow evolution and financial vulnerability over time, is made possible by the integration of the Cost Analysis Tool with the Order Plan. The tool enables businesses to predict financial obligations and evaluate the financial effects of schedule modifications by connecting expenses to anticipated order dates and quantities. In small-series settings, when procurement choices have a disproportionate effect on project economics, this capacity is very helpful, the Cost Analysis Tool provides notable benefits in terms of consistency, traceability, and scalability when compared to conventional spreadsheet-based cost monitoring methods. The danger of mistakes and misalignment is decreased by doing away with the need for manual reconciliation between engineering data, procurement plans, and cost spreadsheets. Additionally, a more proactive approach to cost control is supported by the close interaction with the PLM system, which guarantees that cost evaluations stay in sync with design modifications, demonstrating that when combined, the Release Planning Tool and the Cost Analysis Tool greatly improve the suggested PLM-centered framework's operational efficacy. They allow stakeholders to manage uncertainty in a transparent and regulated way by offering structured time and expense management techniques. The supporting tools presented in this part guarantee that the structural alignment of processes is maintained during execution, whereas the core tools discussed in Chapter 4 determine this alignment. Their incorporation into the PLM environment establishes the framework for methodical performance assessment, which is covered in the part that follows by defining Key Performance Indicators.

ACTIVITY	HEAD OF PC	PROJECT CHIEF	ENGINEERING	PURCHASING	ASSEMBLY	DMU
Baseline Implementation	A	R				
Target cost evaluation		A	R	R		
Target cost update		A	R	R		

Table 5 RACI Matrix for the Cost Analysis Tool

5.2 Key Performance Indicators for Economic Control and Decision Support

A systematic and well defined collection of Key Performance Indicators (KPIs) facilitates economic monitoring and decision support within the suggested PLM-centered framework. In order to ensure complete consistency between operational data, procurement operations, and performance assessment, these indicators are directly produced from data handled within the PLM system using the Cost Analysis Tool outlined in Section 5.1. An iterative procedure incorporating internal project needs, literature references, and validation with industry experts in engineering, procurement, and project management was used to determine the chosen KPIs. Finding indicators that are not only theoretically significant but also operationally observable, automatically calculable, and immediately relevant in project-driven engineering contexts with small-series manufacturing and prototype development was the goal.

The KPIs' concept, calculation methodology, and function in project performance evaluation are explained in an organized, engineering-focused way below.

Cost Forecasting and Variance Indicators

- **Estimate at Completion (EAC)**

Definition*:* Forecasted total cost of the project at completion.

$$\text{EAC} = \text{Ordered Parts Costs} + \text{Quoted Parts Costs} + \text{Estimated Remaining Costs}$$

The EAC offers a dynamic estimate of the total project cost that is updated on a regular basis when engineering and procurement data change. It serves as the main metric for long-term cost management.

- **Cost Variance (VAC)**

Definition: Deviation between the initial project budget and the forecasted final cost.

$$\text{VAC} = \text{Budget at Completion (BAC)} - \text{EAC}$$

It helps identify financial variations from the baseline plan early on and quantifies possible budget overruns or underruns.

- **Estimate to Complete (ETC)**

Definition: Portion of the project cost that has not yet been ordered or validated.

$$\text{ETC} = \text{EAC} - \text{Ordered Costs}$$

The ETC helps to indicate regions where uncertainty and procurement effort are still concentrated and draws attention to the remaining economic vulnerability.

Cost Efficiency Indicator

- **Cost Performance Index (CPI)**

Definition: Normalized indicator of cost efficiency relative to planned targets.

$$\text{CPI} = \frac{\text{Budgeted Cost}}{\text{Actual or Forecasted Cost}}$$

The goal of the CPI is to provide a standardized measure of economic efficiency by enabling performance comparisons between projects of varying sizes and levels of complexity.

Procurement Commitment and Cost Consolidation Indicators

- **Ordered Ratio**

Definition: Percentage of total project cost already covered by issued purchase orders.

$$\text{Ordered Ratio} = \frac{\text{Ordered Costs}}{\text{EAC}}$$

It measures the degree of transition from planning to execution, indicating how much of the project cost is contractually committed.

- **Quoted Coverage**

Definition: Percentage of total project cost supported by supplier quotations or offers.

$$\text{Quoted Coverage} = \frac{\text{Quoted Costs}}{\text{EAC}}$$

This KPI evaluates the degree of external validation of cost projections, which is especially important in the early stages of a project.

- **Commitment Index**

Definition: Overall level of economic commitment assumed by the organization.

$$\text{Commitment Index} = \frac{\text{Ordered Costs} + \text{Quoted Costs}}{\text{EAC}}$$

Commitment index supports risk assessment and procurement maturity evaluation by merging verified orders and validated quotes to provide a consolidated view of financial exposure.

Data Reliability and Confidence Indicators

- **Confidence Index**

Definition: Measure of the average reliability of the project cost forecast. The index is computed by weighting cost components based on their maturity level (e.g. ordered, quoted,estimated). Makes the level of uncertainty explicit, distinguishing between well-consolidated costs and preliminary estimates.

- **Confidence × Performance Indicator (CCI)**

Definition: Composite indicator combining cost performance and data reliability.

$$\text{CCI} = \text{CPI} \times \text{CI}$$

CCI assists with decision-making at the management level by pointing out instances where strong performance is backed by trustworthy data or where apparent cost performance may be compromised by poor data confidence.

Each KPI is linked to a qualitative state based on predetermined threshold values in order to improve interpretability and facilitate quick decision-making. A color-coded approach (green, yellow, orange, and red) is used to present indicators, indicating their acceptability in relation to project objectives. The KPIs are appropriate for dashboards, review meetings, and management reporting because of this depiction, which enables stakeholders to promptly detect key situations without the need for in-depth numerical research.

6. Conclusions and Key Findings

The problem of cross-functional misalignment between engineering, procurement, and project management activities in engineering-driven companies functioning in project-based settings was the focus of this thesis. Such misalignment is mostly caused by the fragmentation of information systems and processes rather than by individual inefficiencies, as is covered throughout the work, and PLM-centered integration framework was suggested as a solution to this problem. It is intended to serve as a unifying framework that may facilitate decision-making, traceability, and coherent data management throughout the project lifetime. At Podium Engineering, the suggested framework has been put into practice and is presently undergoing preliminary operational validation. The initial findings show that the integration strategy is providing noticeable advantages, especially in terms of economic control, data consistency, and cross-functional coordination, even if it is still in the early stages of implementation.

The creation of a high-performance racing battery system and a restomod car project are two separate project typologies from various business lines to which the solution has been applied. These two examples provide a useful foundation for assessing the resilience and flexibility of the suggested method as they reflect radically different technical and procurement environments. The PLM-centered approach allowed for a more organized aggregation of procurement data in the early stages of the racing battery project, which was marked by quick design iterations, significant technical uncertainty, and brief decision cycles. Cost Variance (VAC) decreased significantly compared to previous project, indicating a progressive stability of cost projections brought by the implementation of the Sourcing Summary and Cost Analysis tools. Concurrently, as procurement maturity improved, the Confidence Index (CI) rose from an initial value of about 0.55 to values over 0.75, demonstrating a notable improvement in the accuracy of economic projections. Similar to this, the framework facilitated better coordination between technical modifications and procurement execution in the restomod vehicle project, which was marked by longer development cycles, larger levels of customization, and a greater focus on aesthetic and integration limitations. A more controlled shift from projected to committed expenses was the outcome of the synchronization between engineering releases and buying operations made possible by the Assembly Plan and Order Plan tools. In contrast to earlier projects managed without the integrated framework, the Estimate at Completion (EAC) showed less volatility in this instance, and the Ordered Ratio climbed more gradually over project milestones. During advanced project phases, Cost Variance values stabilized range, demonstrating the PLM-centered data model's capacity to enable economic predictability. The use of confidence-oriented indicators was very beneficial for both project types. Stakeholders were able to contextualize cost performance within the maturity level of available data by using the Confidence Index and the Confidence × Performance Indicator (CCI) together, which decreased the possibility of incorrect or premature judgments. Project stakeholders repeatedly emphasized this feature as a significant advancement above conventional spreadsheet-based offline monitoring techniques. These findings offer preliminary proof that the suggested framework may serve various business lines without necessitating significant structural modifications, even though they should be evaluated in the context of an ongoing implementation. Comparable benefits were shown in projects with significantly varied organizational and technological features, indicating that the technique may be used to a wider variety of engineering-driven projects rather than just one application domain. From a methodological standpoint, this work shows that separate tool improvements are insufficient to provide successful integration between engineering, procurement, and project management. Rather, it calls for performance metrics that are directly generated from operational data, a lifecycle-oriented data format, and transparent governance procedures. Instead of suggesting disruptive alternatives, the PLM-centered strategy described in this thesis leverages current systems and extends them through focused, tailored solutions. It is important to recognize some of the study's shortcomings, corporate involvement and user adoption have an impact on the reported gains, and the validation offered is based on a small number of initiatives inside a specific corporate setting. This thesis concludes by demonstrating that, in complex, project-driven engineering contexts, a PLM-centered integration framework is a practical and successful approach to enhancing alignment, transparency, and economic control. The study offers a methodological contribution as well as a useful basis for future development and industry adoption by firmly establishing the suggested solution in actual industrial practice and validating it through preliminary implementations across several business lines making, introducing predictive analytics, and greater interaction with ERP systems.

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