YÖNETİM BİLİŞİM SİSTEMLERİ DERGİSİ
http://dergipark.org.tr/ybs

Yayın Geliş Tarihi: 19.11.2025
Yayına Kabul Tarihi: 26.04.2026
Online Yayın Tarihi: 25.06.2026

Cilt: 12, Sayı: 1, Yıl: 2026, Sayfa: 24-36
ISSN: 2630-550X

DIGITALIZATION-ORIENTED BOM MANAGEMENT IN THE AUTOMOTIVE INDUSTRY

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ABSTRACT

Today, the automotive industry is rapidly evolving due to technological advancements, increased competition and changing consumer expectations, necessitating enhanced innovation and optimized manufacturing processes. Effective Bill of Materials (BOM) management plays a crucial role in improving product development efficiency and expediting market introduction of innovations. As vehicle systems become more complex, especially with the integration of software and electronics in electric and autonomous vehicles, the role of synchronized BOMs with digital twins will become increasingly critical. Effective BOM management will facilitate not only the mechanical and physical aspects but also the integration and testing of software systems that control vehicle operations. This narrative review examines the role of BOM management in accelerating product development processes and maintaining competitive advantages in the context of digitalization in the automotive industry, and it analyzes the advantages of synchronizing engineering and production BOMs with digital twin through PLM systems.

Keywords: Bill of Materials (BOM) Management, Product Lifecycle Management (PLM), Digital Twin, Automotive Industry

OTOMOTİV ENDÜSTRİSİNDE DİJİTALLEŞME ODAKLI BOM YÖNETİMİ

ÖZET

Otomotiv endüstrisi, teknolojik gelişmeler, artan rekabet ve değişen tüketici beklentileri nedeniyle hızla gelişmekte ve bu durum gelişmiş inovasyon ve optimize edilmiş üretim süreçlerini gerektirmektedir. Etkin Ürün Ağacı (BOM) yönetimi, ürün geliştirme verimliliğini artırmada ve yeniliklerin pazara sunulmasını hızlandırmada önemli bir rol oynamaktadır. Araç sistemleri, özellikle elektrikli ve otonom araçlarda yazılım ve elektroniğin entegrasyonu ile daha karmaşık hale geldikçe, dijital ikizlerle senkronize BOM'ların rolü giderek daha kritik hale gelecektir. Ürün ağacının etkili yönetimi sadece mekanik ve fiziksel unsurları değil, aynı zamanda araç operasyonlarını kontrol eden yazılım sistemlerinin entegrasyonu ve test edilmesini de kolaylaştıracaktır. Anlatısal derleme olarak hazırlanan çalışmada, BOM yönetiminin otomotiv endüstrisinde dijitalleşme bağlamında ürün geliştirme süreçlerini hızlandırmada ve rekabet avantajını korumadaki rolü incelenmiş ve PLM sistemleri aracılığıyla mühendislik ve üretim BOM'larının dijital ikizlerle senkronize edilmesinin avantajları analiz edilmiştir.

Anahtar Kelimeler: Malzeme Listesi (BOM) Yönetimi, Ürün Yaşam Döngüsü Yönetimi (PLM), Dijital İkiz, Otomotiv Endüstrisi

1. INTRODUCTION

1.1 Industry Overview

The automotive industry is undergoing a significant transformation driven by rapid technological advancements, increasing global competition and evolving consumer expectations. This shift compels companies to accelerate innovation cycles while revisiting and optimizing their manufacturing processes. However, the transformation also presents challenges such as economic constraints, declining sales and reputational risks, requiring automotive firms to develop efficient and sustainable solutions to remain competitive (Karabulut and Akyüz, 2023). In this context, effective Bill of Materials (BOM) management is crucial to optimizing processes from product design to production and ensuring the seamless integration of engineering data (Lopez-Vega and Moodysson, 2023).

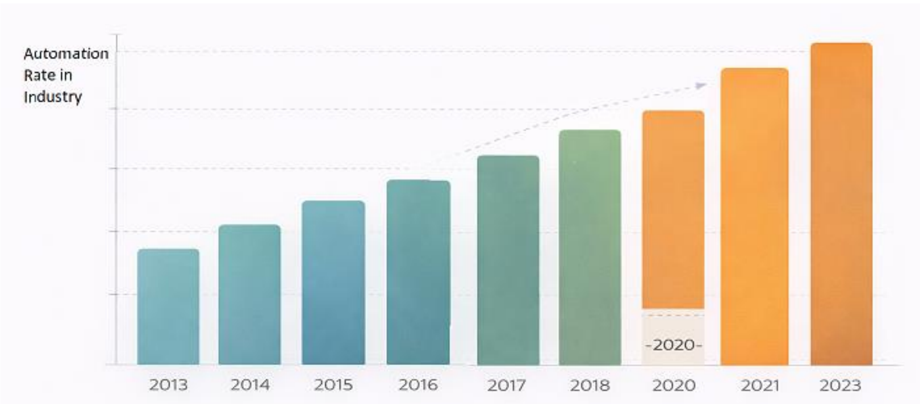
1.2 Purpose and Scope

BOM management plays a fundamental role in the automotive industry by both in controlling costs and enabling the rapid introduction of innovative products to the market. Tools such as Engineering Bill of Materials (eBOM) and Manufacturing Bill of Materials (mBOM) make these processes more transparent and efficient, while Product Lifecycle Management (PLM) systems support the integration of engineering, manufacturing and aftermarket data, ensuring a smooth flow of information across departments. In doing so, automotive companies not only accelerate product development but also enhance manufacturing efficiency, securing a competitive advantage in the market. This narrative review aims to examine the role of BOM management in accelerating product development processes in the automotive industry, specifically analyzing how the synchronization of eBOM and mBOM within PLM systems enables digital twin implementation. The study explores the theoretical foundations of this integration and provides practical implications for industry practitioners.

The literature for this review was selected based on relevance to BOM management, PLM systems, and digital twin technologies in manufacturing contexts. Sources were identified through academic databases including Web of Science, Scopus, and Google Scholar, using keywords such as "Bill of Materials," "PLM," "digital twin," and "automotive manufacturing." Priority was given to peer-reviewed journal articles and conference proceedings published between 2010 and 2024, supplemented by industry reports where academic sources were limited.

In addition to these advantages of utilization in the automotive industry, there will be further implications for implementing a well-structured BOM in the future. Factories and industry are undergoing significant changes due to the rapid pace of technological development. As illustrated in Figure 1, automation in factories has increased exponentially. One of the crucial outcomes is the emergence of technical requirements for system implementation. These requirements encompass hardware, software and communication-network infrastructure. The technical requirements for hardware and software mentioned above are not merely administrative tools; they constitute the foundation for the Product Configuration & Description System that enables the transition from a 26-character build code to a physical vehicle. Accordingly, a synchronized BOM structure can be regarded as a fundamental enabler for supporting digital twin applications in automotive manufacturing.

Figure 1. Automation in Factories (ST Endüstri)



Several software systems support BOM-production integration. PLM systems, for instance, require direct integration with production processes. PLM is typically part of the ERP system, with SAP being a prominent vendor. While PLM manages the design, production and maintenance stages, automation systems transform this data into production accurately, quickly and without errors. Having all product, historical and real-time data in a single system is strongly required, according to Gehrke et al. (2020), PLM provides the capabilities needed to be implemented as the foundation for digital twin solution implementation, but even before considering digital twin implementation, the PLM system concept and adoption of its functionality must be considered.

2. DEFINITION AND TYPES OF BOM IN AUTOMOTIVE INDUSTRY

2.1 BOM Management & Importance in Automotive Industry

Automotive companies must adapt to rapid transformation due to technological advancements, increasing competition and evolving customer expectations to remain competitive. However, this adaptation process often comes with significant challenges, including economic constraints, declining sales figures and potential reputational risks. In such a dynamic landscape, companies need to accelerate their innovation cycles while maintaining efficiency and cost-effectiveness (Lopez-Vega and Moodysson, 2023).

One of the key enablers for achieving this agility is effective Bill of Materials (BOM) management. A well-structured BOM system enhances product development efficiency and ensures integration of new technologies into production (Cinelli et al., 2017). By optimizing BOM management, automotive companies can reduce lead times, improve resource utilization and enhance product configurability, ultimately delivering innovative products to the market faster and more efficiently.

Beyond the challenges of technological adaptation, another critical issue for automotive companies is the complexity and diversity of engineering data. As modern vehicles combine a wide range of components including mechanical, electrical and hydraulic systems, the diversity of engineering data expands accordingly. Furthermore, global companies require cooperation and communication among their subsidiaries worldwide, which presents significant challenges given the volume of engineering data involved. Effectively organizing and structuring engineering data becomes essential for development and production processes (Capistrano Burgos et al., 2022). To achieve operational efficiency, engineering data must be well-structured, systematically organized and easily accessible throughout the product lifecycle.

2.2 BOM Types and eBOM-mBOM Relationship

The Bill of Materials (BOM) outlines the hierarchical relationship between a vehicle and its individual components. It serves as a valuable tool for organizing and managing vehicle data consistently throughout its lifecycle. Essentially, the BOM maps out how different parts fit together within a structured system. For example, a vehicle is made up of large units which are further divided into assembly blocks containing smaller parts and materials. This structure not only reflects the physical makeup of the vehicle but also provides a comprehensive inventory of all components required for its construction.

At the early stages of the product lifecycle, after the completion of the design phase, the product tree is generated to represent the hierarchical structure of the product. This tree serves as a critical reference throughout the design, engineering changes, production, service, purchasing and aftersales. Since Manufacturing Bill of Materials (mBOM) takes eBOM as a reference, eBOM has a critical role in the production stage. Product trees are developed from an engineering perspective and facilitate the transfer of engineering data to manufacturing for efficient processes. Through eBOM implementation, engineering changes (EC) can be executed efficiently, and all relevant departments are informed immediately.

In production planning, a BOM is tied to production orders, describing the relationship between components and semi-finished or raw materials, either in stock or to be purchased (parts). The structure required for manufacturing differs significantly from the engineering perspective. To meet production requirements, companies utilize the Manufacturing Bill of Materials (mBOM) (Chen et al., 2023).

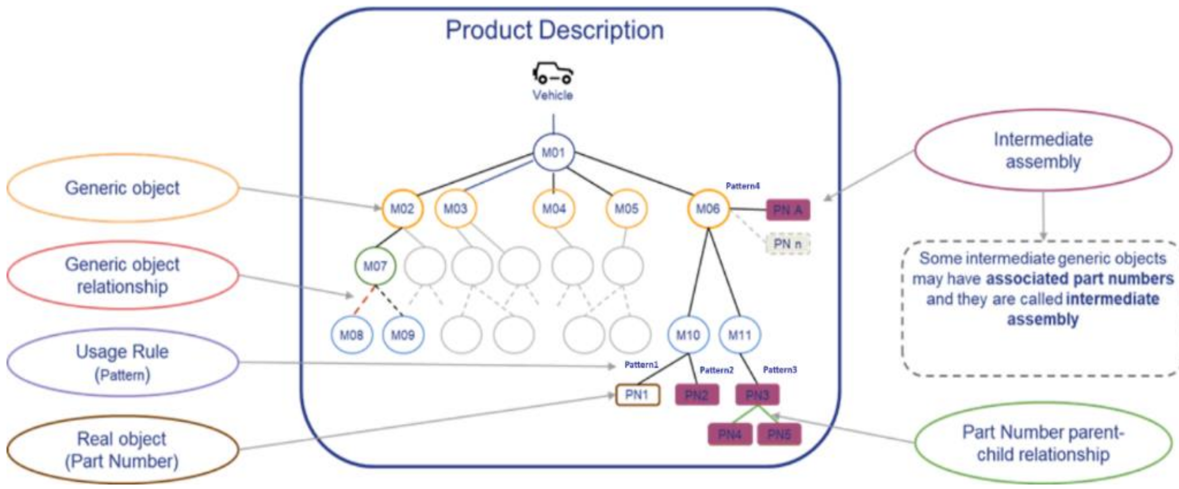
Unlike the eBOM, which is centered on design intent, the mBOM is tailored to support manufacturing processes, including assembly sequences, logistics and supply chain management. The transformation from eBOM to mBOM is a crucial step in ensuring that design specifications are efficiently translated into manufacturable products while optimizing production workflows.

One of the fundamental tools for managing engineering data is the Engineering Bill of Materials (eBOM). The eBOM provides a hierarchical representation of a product, reflecting its design from an engineering perspective. It captures the relationships between various subsystems, each containing domain-specific information that differentiates them from one another. Industrial data structures could be represented as networks and analysed through the related measures. A bill of materials (BoM) is a diagram that lists all the components and parts required to produce one unit of a finished product or end part and it is often presented as a structure made of hierarchical relationships among different components and materials (Cinelli et al., 2017).

The structure of a BOM can be single-level or multi-level, depending on the complexity of the product and the requirements of the production process. For instance, electrical, hydraulic and mechanical subsystems require distinct data structures, reflecting their unique characteristics and dependencies. The eBOM plays a crucial role in product development by ensuring that all engineering data is accurately defined, linked and traceable throughout the design phase.

Figure 2 illustrates the hierarchical structure of a product BOM using a tree model, which is essential for product lifecycle management. At the top level, Generic Objects represent configurable product variants. These are linked to Real Objects (actual part numbers) that implement the generic specifications according to production standards. Usage Rules define the conditional logic that determines which components are included in each vehicle configuration. The figure further depicts Intermediate Assemblies, representing subassemblies with their own unique identifiers and component relationships. This multi-level structure enables efficient management of complex automotive products, from high-level vehicle variants down to individual components.

Figure 2. Automotive Product Structure & BOM Hierarchy (Prepared by Authors)

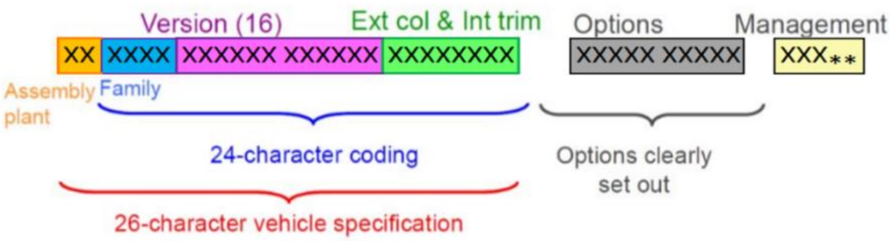


BOM systems are prepared and organized with intelligent numerical systems. Intelligent numerical systems assign a unique number to every part, assembly, subassembly. Such a numbering system not only simplifies the identification of parts but also improves efficiency in areas such as production, procurement, inventory and maintenance. It enables faster and more accurate operations, including classification, traceability, and reuse of components. Grouping similar parts under standard classifications also facilitates standardization and supports the analysis of engineering changes. This system enables authorized users to access part specifications and information efficiently. Furthermore, product components, such as raw materials, should be clearly defined and classified as either Buy or Make in line with the supply and production strategy. Proper planning for raw material procurement, material cost calculation, inventory control and monitoring of material requirements followed by planning based on these needs will ultimately help reduce waste and increase operational efficiency.

All the BOM types must be integrated with each other and should be up to date. Connections between different types of BOMs are achieved by using some specialized tools. Such as software interfaces or data integration platforms or applications that utilize programming languages to synchronize BOM data across different systems.

Figure 3. demonstrates the vehicle build code structure, illustrating how unique vehicle specifications are generated through a systematic coding approach. The code comprises several segments: the assembly plant identifier, vehicle family designation, version number, and optional equipment codes selected by the customer. Management codes containing information about the vehicle's intended market and usage are also integrated into this specification. The complete build code serves as a unique identifier that links directly to the BOM, enabling the decomposition of the product structure for a specific vehicle configuration. This association with a production date is critical, as it determines which version of each component is applicable at the time of manufacture. This specification must be associated with a production date to allow the extension / decomposition of the Bill of Material.

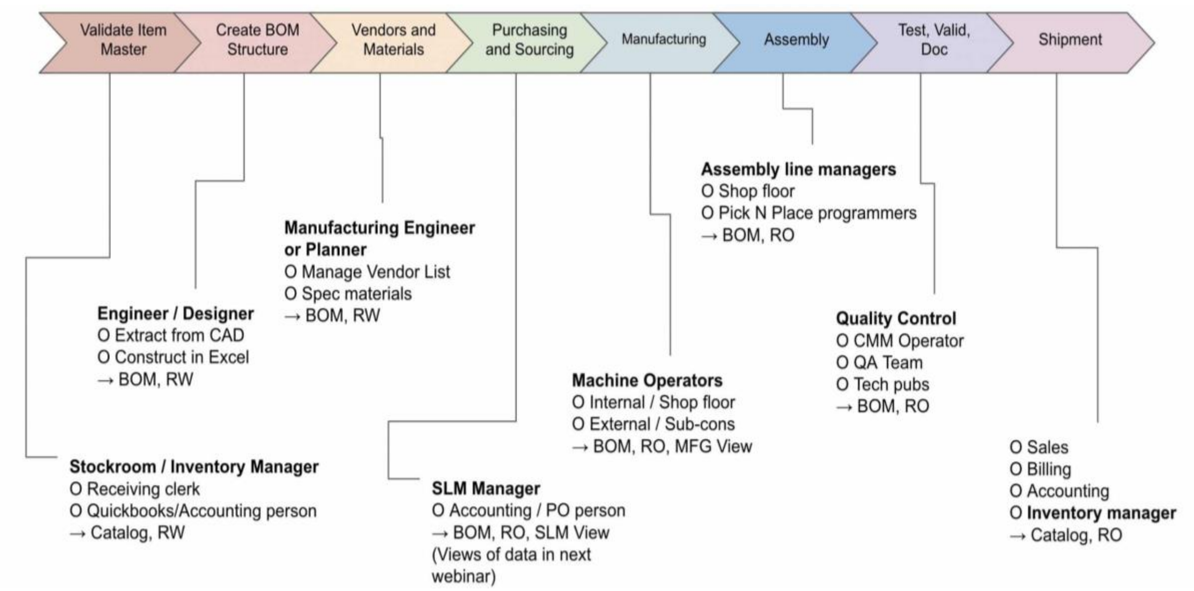
Figure 3. Vehicle Configuration & Build Code Structure (Prepared by Authors)



2.3 BOM in Project Management and Engineering Changes

The process of creating a BOM begins at the design stage, where product concepts are transformed into structured assemblies and subassemblies. In the context of vehicle manufacturing, this typically corresponds to the early phases of project management, where the initial idea of the vehicle is translated into a functional architecture. At this stage, project teams define major systems such as the powertrain, chassis, interior and electrical modules and begin decomposing them into assemblies and components that will later be documented in the Engineering Bill of Materials (eBOM) (Tchana et al., 2019). As illustrated in Figure 4, BOM processes begin at the start of the project timeline and form the backbone of the project. Every step of the project affects the BOM structure and interacts dynamically with it.

Figure 4. BOM Processes in Project Timeline (OpenBOM, t.y.)



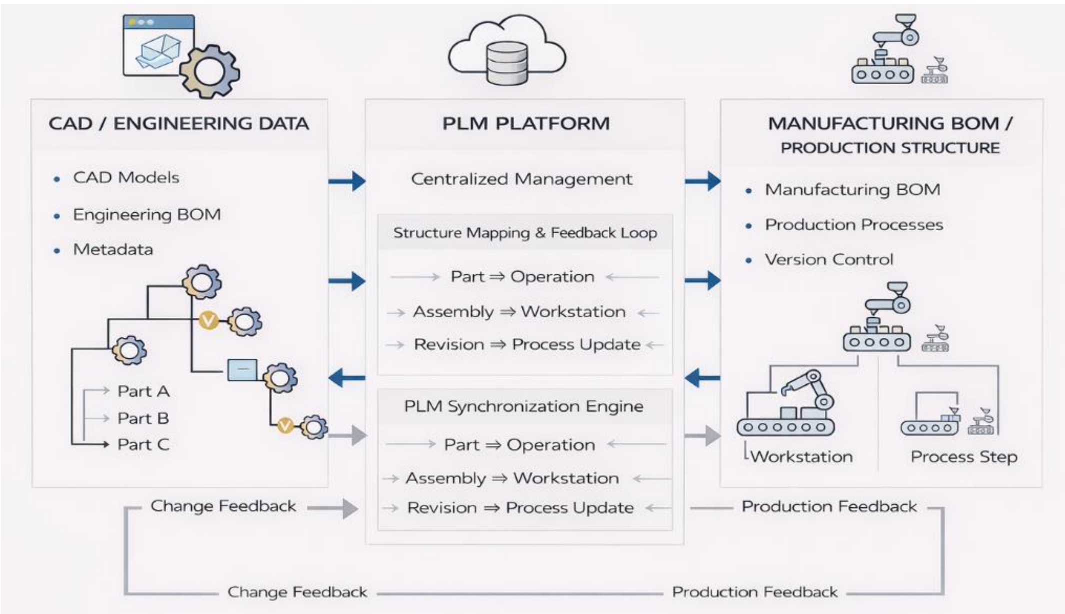
For example, in a mid-size electric vehicle development project, the project plan may begin with a Concept Phase, followed by Design, Prototyping and Validation phases. During the Design Phase, engineers use CAD tools to model each component such as the battery housing, control units or frame sections and define how they fit together in the overall structure. As each component is created, it is added to the BOM, with detailed metadata like part numbers, material types and quantity per vehicle (Aydin and Güngör, 2005). This step is closely monitored by project managers through tools such as PLM systems to ensure deadlines and data consistency across teams.

3. TOOLS FOR MANAGING eBOM AND mBOM

Specific tools exist to accomplish various BOM management tasks. Product Lifecycle Management (PLM) systems like Siemens Teamcenter, PTC Windchill and Autodesk Fusion Lifecycle are central to managing eBOMs, offering capabilities for collaboration, version control and change tracking. Computer-Aided Design (CAD) software, including AutoCAD, SolidWorks and CATIA, enables engineers to create the designs from which the eBOM is derived. Additionally, Product Data Management (PDM) systems, such as Autodesk Vault and SOLIDWORKS PDM, ensure secure management of design data and version control, while simulation tools like ANSYS and Altair HyperWorks validate product performance before production begins.

In another aspect, the mBOM focuses on the materials, components and assembly instructions required for manufacturing. Enterprise Resource Planning (ERP) systems such as SAP ERP, Oracle NetSuite and Microsoft Dynamics 365 manage procurement, inventory and production planning based on mBOM data. Manufacturing Execution Systems (MES) like Siemens Opcenter and Rockwell FactoryTalk enable real-time tracking and monitoring of manufacturing processes. Supply Chain Management (SCM) tools, including Kinaxis RapidResponse and Infor Supply Chain, ensure alignment of material flow and inventory with mBOM requirements. Specialized BOM management tools like OpenBOM and Arena PLM further support communication between design and manufacturing teams. As illustrated in Figure 5, the relationship between CAD/engineering assembly structures and manufacturing BOM is fundamental to this integration.

Figure 5. Relationship Between CAD/Engineering Assembly And Manufacturing Structure (Gunasekaran et al., 2005)



4. BOM AND PLM SYNCHRONIZATION

4.1 Definition of PLM Systems and Relation with BOM Management

Factories require the direct integration of PLM systems with production processes. PLM is part of the ERP system and its vendor is SAP. While PLM manages the design, production and maintenance stages, automation systems transform this data into production accurately, quickly and without errors.

Since the data is first created in PLM, it appears natural that the PLM system should be the "master data" source (Saratech, 2024). PLM is a comprehensive platform used not only for BOM management but also for various key functions across the product lifecycle. It enables efficient product data management (PDM) by handling CAD file versions and technical documentation. PLM supports collaboration and project management, allowing cross-functional teams to coordinate tasks and track project timelines. It eases change management through controlled engineering change processes and ensures compliance with industry regulations by managing quality and audit trails. The platform also manages supplier information, part approvals and alternative materials. Additionally, PLM supports configuration management for complex product structures and offers global collaboration tools for teams working across multiple locations.

Having all product, historical and real-time data in a single system is strongly required, according to Gehrke et al. (2020), PLM systems provide the capabilities needed to be implemented as the basis for digital twin solution implementation. However, even before considering digital twin implementation, it is important to understand what a PLM system is and start using its functions. These systems serve as the foundation for centralized product data management, ensuring that both design and manufacturing teams always have access to the most up-to-date and accurate BOM information.

A primary benefit of PLM systems is their ability to synchronize eBOM and mBOM, ensuring a seamless transition from design to production. PLM systems act as a bridge between engineering and manufacturing by linking CAD models directly to BOM. As design changes occur, whether due to new features, updates in materials, or cost optimizations, PLM tools automatically update both the eBOM and mBOM in real-time. This reduces the risk of errors due to outdated data, ensuring that manufacturing teams always work with the correct and current BOM information. Version control is another key aspect of PLM systems. As product designs evolve, multiple versions of the BOM are generated. PLM tools track these revisions and maintain historical data, providing full traceability of changes over time. This is particularly important in industries where compliance and regulatory standards must be met, as it ensures that the correct versions of components and assemblies are used in production, thereby maintaining product quality and meeting industry standards.

4.2 Advantages of PLM Systems and Globalization Effect

PLM systems support collaborative workflows between cross-functional teams. Engineers, designers, procurement specialists and manufacturers can collaborate on the same platform, with real-time access to the latest BOM data. This reduces communication barriers and allows for more efficient decision-making, as teams can identify and resolve issues early in the design or production process. PLM platforms help to ensure that any modifications to the BOM, whether driven by design changes, supplier updates or manufacturing constraints, are properly reviewed and approved before being implemented.

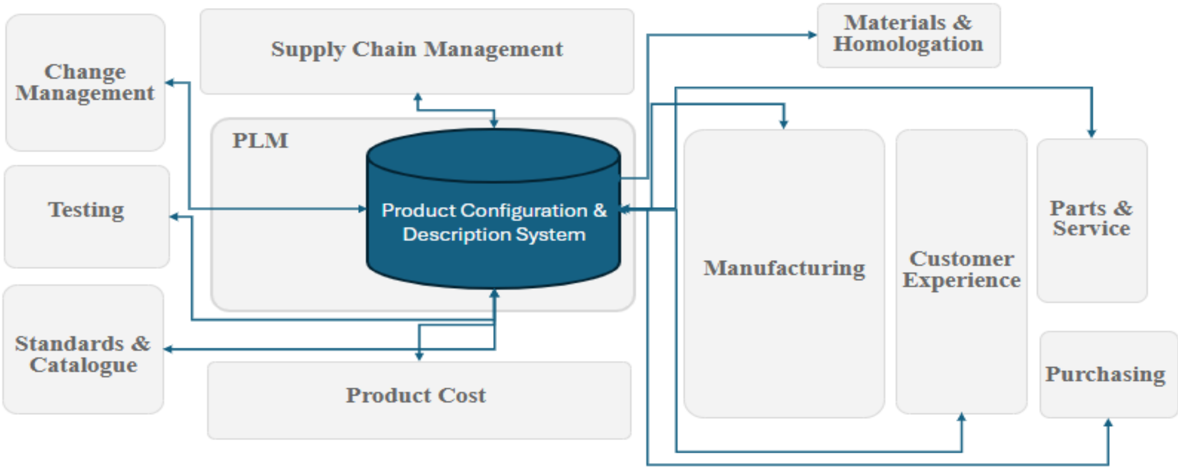
In addition to other advantages, PLM systems provide material traceability. By linking the BOM to product data and supplier information, PLM tools offer visibility into the source and status of every component used in manufacturing. This is especially useful for quality control and for ensuring that the right materials are sourced to avoid production delays. Furthermore, PLM tools can track the lifecycle of each component and provide information on when parts may require updates or replacements and ensure a consistent flow of high-quality materials throughout production. Integration with other systems is also a significant advantage of PLM. PLM systems integrate with ERP and MES platforms, enabling real-time data exchange between design and production systems. This integration ensures that the information obtained in the eBOM is accurately reflected in the mBOM, which can then be used for production planning, procurement and scheduling.

By centralizing the creation, management and synchronization of eBOM and mBOM, PLM systems help improve material flow, optimize inventory management and production efficiency. As a result, companies can avoid common production delays caused by mismatched or outdated BOM data, reduce waste due to overproduction or material shortages and improve overall operational performance. As companies continue to innovate and develop increasingly complex products, the ability to effectively manage BOMs through PLM systems is essential for maintaining quality, reducing costs and ensuring on-time product delivery. In the scope of global manufacturing, managing heterogeneous and scattered information is a vital point for product lifecycle management. Through PLM, the BOM conveys crucial product information that directs development at different phases of a product lifecycle (Luh et al., 2010).

5. MANUFACTURING IMPACT

BOM management plays a central role in connecting all phases of the automotive manufacturing ecosystem. As illustrated in Figure 6, BOM management serves as a foundational data hub linking engineering design, production planning, manufacturing execution and aftersales processes, enabling seamless information flow across the entire product lifecycle.

Figure 6. The Place of BOM Management in the Entire Ecosystem for Automotive Industry (Prepared by Authors)



CNC machines and robots in automated production lines perform operations using product data design files and BOM data from PLM. In addition, sensors and IoT devices collect real-time data during the production process and feed this information back to the PLM system, allowing for product improvements. Integration with Manufacturing Execution Systems (MES) determines the specific materials, processes, and machinery required for production, thereby systematizing the entire workflow. The primary benefits of this integration include faster production, reduced error rates and real-time optimization. While production processes are continuously improved with data received from IoT and sensors, the production line can rapidly adapt to new products through PLM data integration. Consequently, a flexible and customizable production structure is created and the efficiency of industrial processes is increased (Kritzinger et al., 2018).

Digital twin technologies represent another emerging aspect of PLM capabilities. These technologies create a virtual copy of physical production processes, enabling virtual and physical environments to operate synchronously. In this way, potential problems can be detected in advance and processes can be optimized instantly. In the context of lifecycle integration, PLM systems play a critical role in ensuring the consistency and continuity of product data across different stages of the lifecycle (Vieira et al., 2016).

6. FUTURE DIRECTIONS AND TECHNOLOGICAL TRENDS: THE IMPACT OF BOM MANAGEMENT ON DIGITAL TWIN IMPLEMENTATION IN MANUFACTURING

The definition of digital twins, considered as the basis of this research, establishes a clear primary goal which is closely to monitor the physical product throughout its manufacturing and operational phases. By conducting virtual simulations of these processes, the resulting data is utilized to optimize the product's deployment in the real world (Moyne et al., 2020). The digital twin concept, originally introduced by Dr. Michael Grieves at the University of Michigan in 2002, has evolved from a theoretical construct within product lifecycle management (PLM) to become one of the most transformative technologies underpinning Industry 4.0 (Son et al., 2022; Grieves and Vickers, 2017). A digital twin acts as a virtual equivalent of a physical vehicle, mirroring its design, behavior and performance in real time. According to Tao et al. (2018), the digital twin paradigm comprises five key dimensions: physical entities, virtual models, services, data, and connections between them—with the Bill of Materials serving as the structural backbone that defines product composition and enables mapping between physical components and their virtual representations.

As automotive manufacturers aim to enhance their product development strategies, integrating market demands, customer expectations and real-world feedback into the design process has become essential. However, traditional engineering and manufacturing approaches often fail to include this critical information, restricting the ability to create customer-oriented products (Syreyshchikova et al., 2020). Recent systematic literature reviews confirm that digital twins across the product lifecycle enable different stakeholders—designers, manufacturers, and users—to communicate around a common digital object, acquire and share information, and manage products more precisely during every phase of their lifecycles (Pronost et al., 2023). Investigation on the effects of digital twin integration on product quality and compliance within PLM systems highlights that real time insights from digital twins allow for continuous quality monitoring throughout the product lifecycle. Findings suggest that companies experienced a 25% decrease in non-conformities and enhanced compliance with regulatory standards after adopting digital twin technology (Zhao et al., 2021).

Digital twin technology is emerging as a game-changing solution, enabling manufacturers to gain deeper insights into market needs both before and throughout the product lifecycle. By integrating PLM systems and BOM structures with digital twin models, companies can create a solid connection between design, production and real-world performance data (Moyne et al., 2020). According to Kritzinger et al. (2018), the successful implementation of digital twins in manufacturing requires a robust data foundation, which is fundamentally provided by well-structured BOM systems. Kritzinger et al. (2018) further categorize digital twins based on their level of data integration: digital models with no automated data flow, digital shadows with one-way data flow from physical to virtual, and true digital twins featuring bidirectional automated data exchange—this taxonomy is essential for understanding how BOM structures must be designed to support varying levels of digital twin maturity. This integration allows for the simulation, analysis and optimization of vehicle performance, ensuring design decisions are informed by data and aligned with customer requirements. In addition, integrating digital twin data with BOM management enhances both Engineering BOM (eBOM) and Manufacturing BOM (mBOM) by offering real-time updates on component performance, failure rates and usage patterns, which can refine product configurations, improve serviceability and support predictive maintenance. Research by Wang et al. (2022) demonstrates that introducing digital twin technology into the BOM reconstruction process enables the construction of consistent reconstruction mechanisms for complex products, ensuring accuracy and traceability across eBOM, process BOM (PBOM), mBOM, and maintenance BOM (WBOM) transformations. Utilizing digital twin technology alongside BOM structures and PLM systems will drive innovation, shorten time-to-market and improve product lifecycle management in the evolving automotive industry.

The theoretical relationship between PLM systems and digital twin technology represents a paradigm shift in manufacturing data management. Son et al. (2022) emphasize that the original concept of digital twins was based on product lifecycle management, making the PLM-BOM-digital twin triad an inseparable theoretical construct for modern manufacturing systems. The most successful PLM systems over the past twenty-five years—including Siemens Teamcenter, PTC Windchill, and Dassault ENOVIA—have positioned BOM management as the foundation of their technological platforms, recognizing that effective product data management requires robust, hierarchically-structured representation of product composition (Voskuil, 2023).

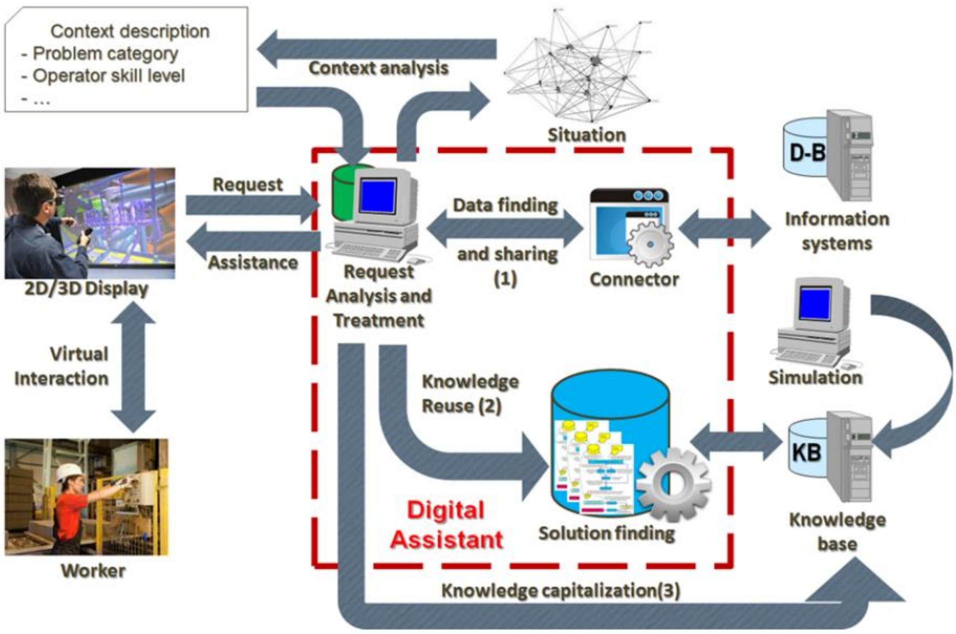
The importance of BOM extends not only to production planning and control but also to the flexibility of virtual enterprises in adapting to market demands. The BOM must be regularly updated to reflect changes in product design or production processes and shared with all partners. This enables quick solutions to be developed in the event of deviations in the production process, maintaining continuity in manufacturing. In today's competitive environment, where product life cycles are shrinking and market demand is increasingly dynamic, maintaining an up-to-date BOM allows enterprises to sustain a competitive advantage by ensuring the right materials, timely production, and efficient logistics planning (Gunasekaran et al., 2005). The proper application and extensive use of the

BOM are essential for the sustainability of both virtual enterprises and traditional manufacturing systems, facilitating the creation of a more efficient and coordinated production network.

Integrating BOM data with digital twins creates a closed-loop system where design changes are instantly reflected in virtual prototypes. This integration transforms vehicle development by enabling engineers to test performance, compliance and manufacturability before physical prototypes exist. The digital thread concept provides continuous data flow across the product lifecycle, enhancing traceability and real-time monitoring, while BOM structures are instrumental in creating both digital twins and digital threads of products (Voskuil, 2024).

Digital twins facilitate understanding of marketing and customer needs at the pre-design stage by representing the real vehicle virtually. As vehicle integration into virtual systems requires additional data, creating a virtual replica of the real vehicle enables engineers and designers to simulate usage scenarios, analyse customer interaction, and evaluate potential design adjustments before physical production begins. This approach not only reduces development costs and time but also enhances product-market fit and improves worker efficiency. Process automation supports the integration of AI systems, thereby reducing errors and enhancing system efficiency (Piroumian, 2021). As illustrated in Figure 7, the functional architecture of a digital factory assistant integrates PLM, IoT and AI-driven components to enable closed-loop manufacturing intelligence.

Figure 7. Functional Architecture of the Digital Factory Assistant (Gehrke et al., 2020)



Virtual engineering technologies have become an emerging field in industry and research. Nowadays, different sectors are using Virtual and Augmented Reality in various phases of their manufacturing process (advanced manufacturing process visualization, assembly tasks, training, etc.). This involves the connections with existing components of the information system in the factory, especially the PLM system used to handle the CAD models (Dhuieb et al., 2014). Liu et al. (2023) further demonstrate that digital thread-driven methods for distributed collaboration among digital twin manufacturing units utilize heterogeneous information networks to model tasks and adjust processes based on quality analyses, with BOM structures serving as the common reference framework across organizational boundaries. Industry analysts predict that half of all large manufacturing companies will utilize digital twins by 2025, with BOM management serving as the foundational data layer enabling this transformation (Gartner, 2020). The advent of modern data management technologies, particularly graph databases and semantic models, paves the way for robust product models that treat the BOM not as a static list but as a multi-view, configuration-controlled product model connecting various stages of the product lifecycle through a digital thread (Voskuil, 2024).

7. CONCLUSION

In conclusion, this narrative review investigates the critical role of effective BOM management in the automotive industry's transformation amid technological advancements, competition and evolving consumer expectations. From a theoretical perspective, this research confirms the foundational necessity of digitalization in modern manufacturing; nevertheless, it distinguishes itself by shifting the focus from individual data silos to an integration strategy. By integrating eBOM and mBOM within PLM systems, automotive companies can enhance product development and manufacturing efficiencies and reduce time-to-market for innovative products. Unlike earlier approaches that often viewed these BOMs as separate systems, this work demonstrates that their seamless synchronization is the critical factor for bridging the gap between design and production. The synchronization of BOMs with digital twin technologies is particularly crucial, providing a virtual representation of vehicles that supports real-time monitoring, simulation and optimization.

The study's unique value lies in its exploration of this specific alignment, proving that a unified BOM structure is not merely an administrative task but the essential backbone for the practical implementation of virtual vehicle representations. While previous studies such as Gehrke et al. (2020) and Vieira et al. (2016) have examined PLM and digital twin concepts separately, this review synthesizes their relationship through the lens of BOM management, demonstrating that eBOM-mBOM synchronization is the critical enabler for digital twin implementation in automotive manufacturing. Regarding practical implications, the findings provide a strategic roadmap for industry practitioners, highlighting that the integration of eBOM and mBOM within PLM systems is a prerequisite for enhancing product development and manufacturing efficiencies and reducing time-to-market for innovative products. As vehicles grow more complex, due to the combination of software and electronics, the ability to manage these components through comprehensive PLM systems becomes essential. Additionally, globalization requires accurate data management across teams, enhancing collaboration, change management and material traceability.

Finally, future research directions should focus on the interoperability standards required for this integration and explore the impact of AI-driven predictive maintenance on dynamic BOM updates. In the future, the integration of BOM management with digital twins and emerging technologies like augmented reality and AI promises to further revolutionize manufacturing processes, reduce errors and improve adaptability, ensuring that the automotive industry remains competitive and responsive to future challenges.

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ABBREVIATION LIST

Abbreviation	Full Form
AI	Artificial Intelligence
APS	Autonomous Production System
BOM	Bill of Materials
CAD	Computer-Aided Design
eBOM	Engineering Bill of Materials
ERP	Enterprise Resource Planning
GBOM	Generic Bill of Materials
IoT	Internet of Things
MES	Manufacturing Execution System
mBOM	Manufacturing Bill of Materials
MPS	Manufacturing Product Structure
PDM	Product Data Management
PLM	Product Lifecycle Management
SAP	Systems, Applications and Products in Data Processing
S4 HANA	SAP Business Suite 4 SAP HANA
SBOM	Service Bill of Materials
SCM	Supply Chain Management
VE	Virtual Enterprise