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Maturity Models and Cost Justification for PLM: A Case Study in the Plant Engineering Industry

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Abstract. In recent years, there has been a noticeable trend towards a general contractor strategy for plant engineering companies. Multiple disciplines and departments must be administered in a joint project. In the process, different work results are often managed in various systems without any associative relationship. A possible way to address this complexity is to implement a specifically tailored PLM strategy to gain a competitive advantage. Maturity models as well as methods to evaluate possible benefits constitute increasingly applied tools during this journey. Both methods have been theoretically described in previous publications. However, this paper should provide insights in the practical application within machinery industry. Therefore, a medium-sized German plant engineering company serves as an example for determining the scope and value of a multinational overarching Product Lifecycle Management architecture as the central piece of a future digitalization strategy. The company's current maturity levels for several digitalization capabilities are evaluated, prioritized and benchmarked against a set of similar companies. This allows to derive suitable target states in terms of maturity levels as well as the technical specification of digitalization use cases. In order to provide profound data for cost justification the resulting benefits are quantified.

Keywords: Product Lifecycle Management, Maturity Model, Cost Justification, Product Configuration, Layout and Visualization, BOM Management

1 Introduction

Plant engineering companies face big challenges: difficult market environments in a global economy that is volatile, uncertain, complex, and ambiguous (VUCA), China is becoming a cost leader and pushing for more sophisticated plant engineering solutions through massive R&D investment, as well as new dramatically emerging trends towards a general contractor strategy. In order to systematically manage all accruing

product related information and to support engineering processes throughout the lifecycle the concept of product lifecycle management (PLM) raised [1].

PLM could help plant engineering companies to address these challenges and stay competitive. In order to design future PLM architectures maturity models and methods to prepare a cost justification analysis represent proven means [2, 3]. First, we will discuss the trends and requirements in the plant engineering industry and report our approach of how we applied the maturity model to identify relevant use cases as well as their financial benefits to encounter those trends. We validate our approach with support of two companies in the plant engineering industry to provide insights on practical application. Within the scope of this we evaluate, prioritize and benchmark companies' current maturity levels for various digitalization capabilities and derive appropriate goals. The last section describes how to determine the scope and value of a multinational overarching Product Lifecycle Management architecture as the central piece of a future digitalization strategy.

2 State of the Art and Trends for Plant Engineering Companies

Plant Engineering companies may benefit from following emerging trends regarding their customer requirements. As shown in Figure 1, the German Engineering Federation (VDMA) and PwC report that from the plant operator's point of view, the five most important requirements regarding a plant are "*Transparency*", "*High production flexibility*", "*Shorter lead times*", "*Optimized investment costs*" and "*Trust-based relationships*" [4]. The study emphasizes that to be successful, business models need to meet customer needs and that digitalization helps to meet these requirements in a novel way.

A	Transparency – Customers require increased transparency throughout entire project lifecycle in crucial business processes.
B	Production flexibility – Customers require increased transparency in crucial business processes throughout the project lifecycle.
C	Shorter lead times – Customers require shorter project lead times to meet increasing market demand.
D	Optimized investment costs – Customers require a reduction of project costs (through the use of digital tools).
E	Trust-based relationships – With respect of the high investment, customers demand a trust-based relationship.

Fig. 1. The five most relevant plant operators requirements in 2025 [4]

Moreover, PwC/VDMA [4] highlight the trend towards providing individual customer advice, with individualized solutions for each customer. A quantitative analysis re-

vealed that globally Engineering Procurement and Construction (EPC) firms are convinced that the turnkey solutions contract model will play a top priority in the future and many plant engineering companies aim to realize a general contractor business model. Turnkey solutions projects have shown a need for improvement in these ways:

- lack of transparency during project initiation and execution with limited information provided by the contractor
- scoping processes at the project development and tender stage takes too long, especially in lump-sum turnkey projects.

The manufacturing industry is driven by technology advances and emerging trends such as artificial intelligence and machine learning, machines as connected fleets, and increasing involvement of the customer into the manufacturing process [5]. These trends will lead to changes in employment and working conditions [6]. As shown in figure 2, Dispan mentions that new technologies such as additive manufacturing and PLM systems play major roles in collaboration between various disciplines.

Digital technologies that are visible in the company (often still isolated solutions / pilot projects)	Software systems as hidden elements of digital transformation
<ul style="list-style-type: none"> ▪ autonomous transport systems ▪ human robot collaboration ▪ smart glasses ▪ additive manufacturing ▪ digital assistant system 	<ul style="list-style-type: none"> ▪ ERP, MES systems do real time analysis ▪ PLM, CAx (CAD/CAE), digital twin (simulation) ▪ Software bots (Robotic Process Automation RPA) ▪ Artificial intelligence and autonomous software systems

Fig. 2. Digitization of Internal Processes in Mechanical Engineering [6]

According to Wyman [7] “Digitization of plant-engineering processes will provide a third level of efficiency, with building information modeling (BIM) the key driver”. Companies will need to build end-to-end integrated processes that match the requirements of BIM as well as PLM and adjust IT systems accordingly [8]. This will improve design-to-construction, design-to-procure and the reuse of equipment in a modularized plant and product configuration. Companies will see both reductions in product costs and lead time of more than 10 percent” [7].

Addressing these trends, we conducted workshops with two plant engineering companies. We used a maturity model to see how they compared with other companies in the same industry.

3 Application of Maturity Models for PLM

3.1 The Maturity Model

In order to determine maturity levels of an organization, a reference model is needed that allows the classification of capabilities in selected competence fields. We used a maturity model [3] which has been applied more than 200 times in the last four years in Europe and the US.

At the center of the model are 50 capabilities, which in turn are divided into 5 knowledge domains. These describe operational skills and competences of the organization in the fields of product / plant planning (e.g. ideation management, requirements management, etc.), definition of assets (e.g. plant structure & configuration management, product costing, etc.), verification steps (e.g. visualization, simulation, virtual commissioning, etc.), manufacturing / production of equipment (e.g. derivation of manufacturing structures, definition of production processes, production execution, etc.), as well as the operation of plants (e.g. service tasks, plant monitoring, plant safety, etc.).

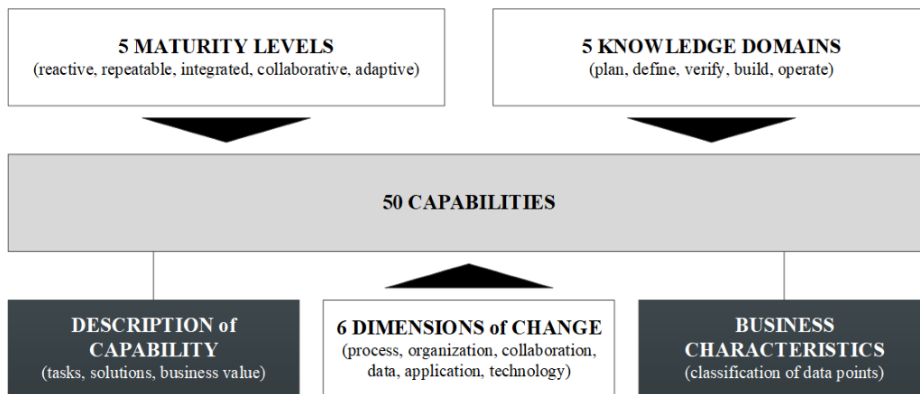


Fig. 3. Elements of the Maturity Model

The model works with 5 maturity levels. Level “reactive” corresponds to a minimal control of data and processes. With level “repeatable” the organization is gaining control of product content and processes. Level “integrated” describes elevation to enterprise Product Lifecycle Management skills. Level “collaborative” indicates demand driven value network product lifecycle management, with a robust horizontal and vertical integration of processes and data managed. Level “adaptive” is characterized by the agility for rapid response to market and technical changes. It also is empowered by leveraging disruptive technologies to enable new ways of collaboration and data exchange. Each capability is additionally viewed from 6 dimensions (process, organization, collaboration, data, applications, technology). This differentiation provides deep insights into the necessary improvements and is the basis for planning the transformation processes.

3.2 Application of the model

The model is a building block of the consulting approach (Fig. 4) and needs accompanying activities to fully unfold its added value. We began by getting a solid overview of the company under consideration. We reviewed the company's history, examined the product and service portfolio, and determined the company's organizational structure and processes, as well as its financial status.

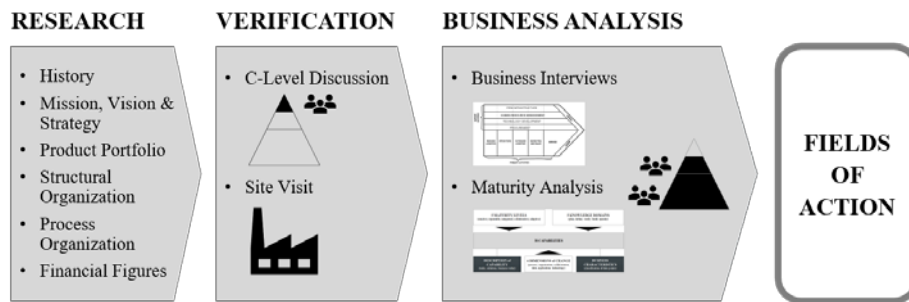


Fig. 4. Elements of the consulting approach

In a second step, the findings were verified in dialog with management. We learned about business strategy of the company as well as the current challenges on the market and ongoing initiatives from a C-level perspective. An inspection of the sites to be considered, in particular regarding production and logistics, completed the picture.

With the preliminary work done, we considered the business units by gathering 2-3 specialists from each area, some managers and some subject matter experts.

Individual workshop helped find out the organizational structure of the area under consideration and the roles of the employees. We identified processes with their inputs and outputs. If a process re-design was planned, appropriate methods were applied (e.g. brown paper analysis). Also, we asked about IT/OT tools, relevant base technologies, as well as internal and external collaboration.

Discussions also concerned current initiatives to optimize workflows, integrate new technologies, as well as known weaknesses. We ended up with a comprehensive understanding of the departments' functions and challenges, plus relationships among the departments. The aim was not only to present problems, but rather to get to the bottom of root causes and immediate effects (e.g. costs, quality, etc.).

The execution of the maturity analysis was the final step in the inventory and did build on the knowledge acquired in advance. In preparation for the maturity workshop, the capabilities to be considered have been preselected, as not all 50 capabilities are usually in focus. The scope could be derived very well from the knowledge gained in the interviews.

In contrast to the interview phase, the maturity analysis did not take place separately with the individual departments but was carried out in one run with all participants of the processes to be considered. Each capability was considered individually and discussed in the team. This procedure created a common understanding of the challenges

and participants did find a consensus on an assessment of maturity of the individual subject areas.

In each case, the joint assessment of the current status and the level of maturity to be aimed for in the medium term were discussed. In addition, the business relevance (prioritization) of each capability was questioned. In order to arrive at usable statements, the workshop participants were called upon to decide for each capability whether it directly supports a core competency of the company, supports direct value creation, or was perceived as a support function [3].

With the conclusion of the maturity workshop, the data collection was complete. The insights gained made it possible to derive the relevant fields of action from the mix of business goals, identified weaknesses, and maturity levels to be achieved in individual capabilities. As a supplementary element, a benchmarking option came into play, which presented the company with its own position in comparison to other market participants.

3.3 Benchmarking

In order for the model with its collected market data to be used for benchmarks, each company under consideration was classified according to a uniform pattern [3]. To ensure this, the model offers a set of standard characteristics (e.g., business strategy, industry, company size, target markets, etc.) which make it possible to take a fingerprint of the respective company characteristics. This classification comes into play when we aim at drawing meaningful data points for comparison with market peers.

The benchmark is therefore based on a comparison of the companies' own perceptions. The top 20% of the peer group are shown as best-in-class. The middle 50% are shown as the industry average. The laggards are the bottom 30% of the comparison data base. This comparative view of the company's competencies is, in addition to the company's own assessment, an important indicator of its position in the market.

A complementary benchmarking option is the comparison of several locations of a company. In our specific case study, the customer used the maturity model to comparatively evaluate several European competence centers and production sites. Thus, the maturity workshop was conducted separately for each plant, resulting in a meaningful comparison. The findings were on the one hand the formal confirmation of a daring gut feeling, but also significantly helped to cast the necessary improvement measures into a meaningful deployment strategy.

3.4 Outcome

One of the companies considered in this case study has a global market share in the logistics industry (warehouse erection and automation). The comprehensive consulting for the European subsidiaries revealed necessary improvement potentials in the following capabilities.

Requirements Management: The planning process of larger warehouses offered by the company as a general contractor can take up to 2 years. At the end of the sales

process, layouts of the plant and the service specifications derived from them are finalized. It became apparent that the various trades (steel construction, mechanical engineering, automation) do not have a transparent view of the contract sections relevant to them and the associated acceptance criteria, neither in the engineering phase, nor in the production phase, nor in the commissioning phase. The tracking of changes to the scope of delivery and their effects on the individual delivery items is also very time consuming and is handled by a large number of project managers. Here, integrated data models on a common PLM platform can create a high degree of transparency.

Asset structure management (later referred to as OBOM): Involvement of different competence centers without common data management for technical aspects and commercial processes prevents creating a common asset structure. Work of companies of different trades are finally brought together during commissioning, which requires tedious coordination and leads to costly errors. A common plant structure could provide transparency on the progress of work among different trades. This would make it easier for engineers from all disciplines to obtain current information about project progress.

Project Management: Another significant benefit for plant engineering lies in the consistent representation of the 4th dimension, time. As in shipbuilding, the successful construction of large-scale plants depends on the efficient and well-thought-out chronological sequence of development, production, delivery, and erection of the plant components. In a common PLM platform, schedules, phase gates and their deliverables could be transparently planned.

Product Configuration: Companies want the ability to provide customer-specific solutions based on standard products, modules, and components. Design automation in the Engineer to Order (ETO) process should make it possible to quickly derive new product variants by defining parametric models and storing sets of business rules. In addition to the engineering of parts and assemblies, the underlying manufacturing processes should also be available as templates. Machines that are fully described with their recurring modules (150% BOM) will be operated from PLM based on configure-to-order (CTO) processes.

Product Cost Management: The automation of customer-specific plant configurations goes hand in hand with accurate cost estimation. Product cost calculations should be stored in the models for both CTO and ETO elements. The goal is to derive a quotation calculation for the configured system (5th dimension).

4 Technical Specification for Interdisciplinary Collaboration within PLM

The capabilities Requirements Management, BOM Management, Project Management, Product Configuration and Product Cost Management are of major relevance to the companies under investigation. This section presents the way to optimize these capabilities. The central component of the concept is a PLM solution that incorporates all locations and allows all technically relevant data, their life cycle and processes to be mapped in a contextualized manner.

As illustrated in figure 5, the PLM system runs not only the development process for standard machines but also the process for customer-specific plant engineering. This allows the already realized standard machines to be used in the overall system. Furthermore, the integration of several plant-specific ERP systems allows an efficient handling of logistic and commercial data and processes. This includes, among other things, the procurement and rough planning of production orders. For this purpose, material masters, parts lists, technical drawings, and routings can be provided to the relevant ERP systems. In addition, a bi-directional integration can also make logistical information accessible to the product designers, such as plant-specific warehouse stocks. Furthermore, downstream processes such as virtual commissioning or clash detections are also feasible, based on available engineering data.

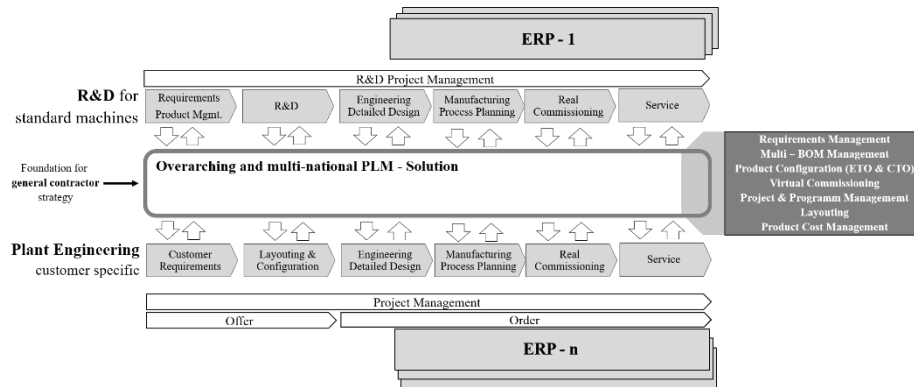


Fig. 5. Overarching and Multi-national PLM Solution to enable general contractor strategy

In the following sub-chapters, an excerpt of relevant use cases is introduced, helping plant engineering companies to realize interdisciplinary collaboration as part of an overarching PLM Solution. This use cases are: Requirements Management, BOM Management, Product Configuration, Layout & Visualization.

4.1 Requirements Management

The first use case in this case study deals with the introduction and improvement of requirements management. So far both companies realized it by managing contract data in documents stored within a central project folder. We propose to handle requirements within a PLM system in order to increase transparency in the development and engineering process. Therefore, a new structure - the *requirement specification* - is established. This structure incorporates all single requirements as separate objects and allows managing the lifecycle as well as the status of each requirement independently and on the other hand to build semantic relationships to other structures via trace links. To minimize the administrating effort the system can import customer requirements either via standardized exchange formats like ReqIF [9] or using structured documents. As figure 6 illustrates, a trace link between a requirement and a part of a bill of material indicates that a specific requirement is *realized by* an assembly or part of the overall

product. Furthermore, a relationship between a requirement and a test case as part of a test specification could be used to express a *verified by* relationship.

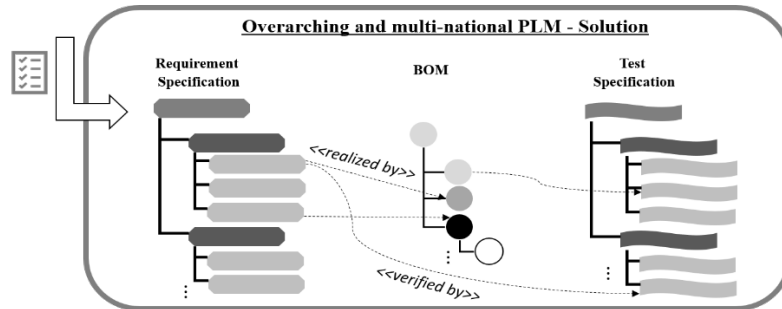


Fig. 6. Requirement structures with a relationship to BOM and Test specification

This supports engineers in the change management process by making the possible impacts of changes visible. Moreover, the approach of handling requirements can be extended on demand to a Model-based Systems Engineering approach following a RFLP process as described in the V-model [10, 11].

4.2 BOM Management

An overarching and multi-national PLM system supports a general contractor strategy by gathering and managing all information in a customer-specific Order-BOM (OBOM) (see figure 7). So far, all information has been stored in domain specific Bill of Materials distributed across several PDM and ERP environments, which in turn has not been integrated to one of the other systems. Administrating interdisciplinary collaboration between the domains involves use cases such as clash detection analysis, collaboration between electrical and mechanical engineers, material flow analysis, virtual commissioning, plant layouts, handling of Building Information Management (BIM) data as well as interdisciplinary processes such as change management.

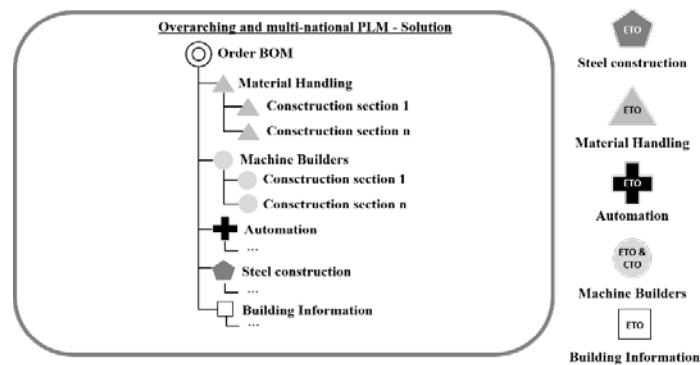


Fig. 7. Order BOM as cross-domain structure within plant engineering

As different as the work results, so are the processes to create product data of the different domains. In steel construction for instance, customer-specific product data is created depending on the boundary conditions provided by the architect's planning. Although standardized profiles are used, the overall planning is always customer-specific and therefore it follows an engineer-to-order (ETO) process. On the other side, many companies focus on standardization of machines following an configure-to-order (CTO) process. This allows to easily configure a machine for a customer project and to install the machine's variant BOM within in the Order BOM. Since such projects can become relatively large and complex, it has proven to be useful to divide the individual domain-specific bill of materials into construction sections. This allows the company to plan the chronological steps and to better plan downstream processes such as the disposition of individual parts and assemblies. Furthermore, one fundamental part for meeting the future requirements of plant engineering companies is the handling and the contextualization of BIM-Models as part of the Order BOM. This allows the company to utilize common use cases for architectural planning and equipment engineering.

Besides the Order BOM, other types of BOMs are essential as well, for instance the Engineering BOM (EBOM) and the Manufacturing BOM (MBOM). Because several publications cover these concepts [11], they are not considered in detail.

4.3 Product Configuration

Different portfolio elements and domains demand various engineering processes. In the case of plant engineering companies, we differentiate between configure-to-order and engineer-to-order processes. As depicted in figure 8 we propose two different configuration mechanisms, which are consolidated in an overarching PLM solution. Whereas a 150% BOM can be used for modularized configure-to-order products, we recommend for engineer-to-order products to utilize design-automation solutions, wherever possible.

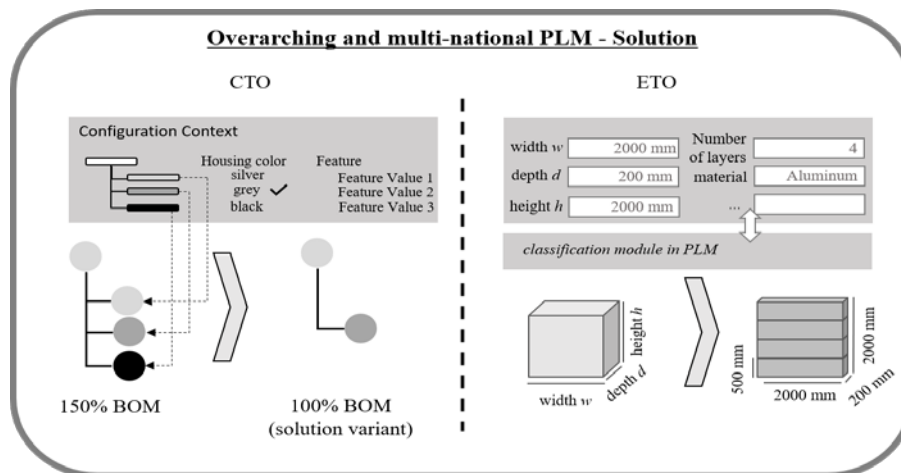


Fig. 8. Configuration mechanisms for CTO & ETO in PLM Solution

On one side configure-to-order processes are used to enable the configuration of pre-conceived standard products as a result of the research and development process. A 150% bill of material is employed, which contains all parts and variants of a specific product type. Moreover, a configuration context is utilized including all configurable features and feature values of a product type. For instance, the color of a housing constitutes a feature, which can be defined during the configuration process. The colors *gray*, *silver* and *black* represent the feature values of the feature *housing color* and comply to one option to be picked during the configuration process. Modern PLM Systems are capable to combine both structures and to define dependency rules. This allows end-users to derive a specific BOM for the configured variant on basis of the introduced 150% BOM. This 100% BOM, also known as a solution variant, can be stored within the PLM system and installed within other structures like the Order BOM.

On the other side, design automation solutions enable engineer-to-order processes. A main characteristic of these processes is that not every variant of the product type must be designed in advance. These solutions enable companies to create customer-specific designs on basis of a predefined set of parameters. As shown in the example, a cube can be defined by its width, depth, height as well as the numbers of layers. By specifying these parameters, a new geometry and dimensional variant can be created. In order to avoid the creation of duplicates, it is essential to integrate a design automation solution with the classification module in the PLM system. If the desired variant already exists, no new design should be created but the existing design should be re-used.

Furthermore, it should be mentioned that completely new products as well as products without any variation can also be part of a plant. However, for this type of products no configuration mechanism is needed as the product data is either available upfront or developed from scratch as part of the customer project.

4.4 Visualization & Layouts

During the different development phases in plant engineering, stakeholders expect various levels of detail. For instance, throughout the proposal phase the customer expects an initial visualization of his entire plant in order to evaluate the suggested solution. However, when looking at detailed engineering and the planning of manufacturing processes the company needs detailed models with tolerances and exact measures to prepare CAM Models and NC Programs based on a CAD models geometry. To meet these requirements, several representations of the part are mapped in the data model by so-called data sets. This mapping is also referred to as CAD-Part-Alignment. Here, all relevant product data is managed and linked via a n:m relationship between document and part.

In addition to the simplified and detailed CAD models, neutral format as JT (Jupiter Tessellation) [12] become increasingly relevant. Developing a whole plant needs further information such as proprietary CAD models, technical drawings or specifications which are also managed as data sets. Furthermore, a PLM System allows to handle revisions via the object type of item revision. As illustrated in figure 9, we have an Item

revision *B* for the Item with the number *125756* defined. The data sets with their own lifecycle and revisioning are always assigned to an item revision.

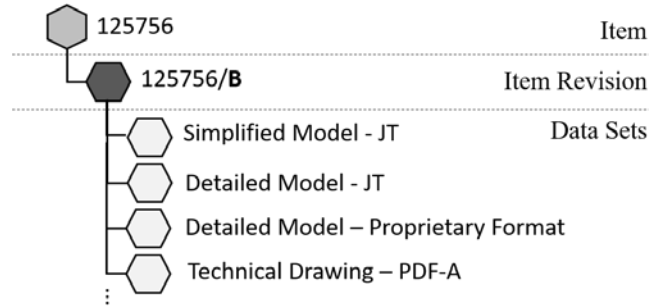


Fig. 9. Several data sets are available as part of item revision object

This flexible data model also supports the creation of layouts. By utilizing the introduced configuration mechanisms, it is possible to position the generated variant in the layout and to install the variant within the Order BOM.

During this process the simplified geometry is applied and visualized. As a result of the positioning within the layout a transformation matrix is generated. By copying the generated transformation matrix of the simplified model to the detailed model, the structure of the layout can be reused in detailed engineering phase, as the simplified models can be substituted by the detailed ones.

5 Cost Justification for PLM Solution

Adopting a central PLM solution may achieve various benefits. While profitability calculations often account for process improvements via the creation of activity profiles [13], other types of benefits such as customer satisfaction or improved hit rates become neglected.

Therefore, we recommend as proposed by Pfenning and Eigner [2], having an additional look at potential benefits other than process efficiency while creating a cost justification document. As depicted in figure 10, we recommend considering all benefits that may be realized for each use case, for example *Visualization and Layout*. As part of this use case a typical cost-based benefit is the reduction of subscription costs for redundant CAD licenses. This occurs as neutral data formats allow viewing and simple operations to CAD Models without the need of CAD licenses.




Visualization and Layout	
	<ul style="list-style-type: none"> • Reduction of processing time for transferring simple into detailed layout • Reduction of processing time needed to gather all CAD Documents for lightweight visualization • Reduction of processing time to convert CAD Data manually
	<ul style="list-style-type: none"> • Reduction of CAD licenses via the usage of neutral data format viewer • Reduction of construction errors due to early validation via profound clash detection analysis
	<ul style="list-style-type: none"> • Improved response times for RfQs • Increased on-time delivery rate • Increased customer satisfaction • Increased Hit-Rate and additional revenue

Fig. 10. Excerpt of potentials to be realized via the visualization and layout use case

In case of qualitative benefits, it is difficult to directly monetized the value added and therefore they are often not included in a profitability calculation. However, we recommend making the qualitative benefits visible during the implementation of the PLM Solution. For this purpose, predefined key performance indicators allow a retrospective evaluation of the positive impact of the PLM introduction. A suitable instrument for that are strategy maps [14], which are based on the balanced scorecard of Kaplan and Norton [15]. A strategy map allows to visualize the relationship between measures of the various perspectives following a linking principle. This allows for instance link *increased customer* satisfaction from the customer perspective to *increased revenue* on the financial perspective.

As part of our case study we analyzed the contribution of several use cases to the overall value of the proposed PLM solution. As depicted in figure 11, we visualized the identified benefits, which has been evaluated together with the customer after presenting the proposed solution concept.

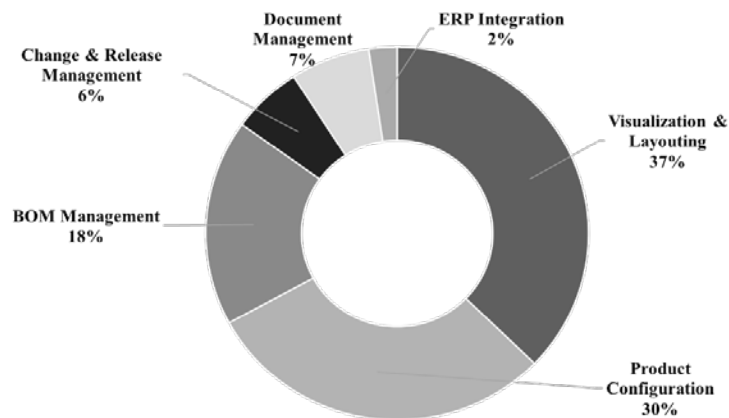


Fig. 11. Use Case contribution to overall identified and monetized value of our case study

While quantifying the potential benefits of an overarching PLM Solution we identified especially three value drivers of the proposed solution. The use cases Visualization & Layout, Product Configuration and BOM Management constitute the most promising use cases and contribute in our case study with 85% to the overall value identified. Although the contribution of percentages is always company specific, it functions as a general guidance while identifying relevant use cases for a future PLM Solution. We therefore see great potential for plant engineering companies, particularly in these use cases.

6 Discussion

Both the application of the maturity model and the preparation of a cost justification analysis assist companies to encounter new trends and requirements with appropriate capabilities and technologies. In the area of plant engineering, especially three use cases have been identified as recommendable - Visualization & Layout, Product Configuration and BOM Management. These use cases will help a company to realize a general contractor strategy by streamlining the collaboration of various disciplines for a common project within the PLM System.

As part of the cost justification we recommend visualizing qualitative benefits via a strategy map. Therefore, we propose to further explore the possibilities in the application of this methodology in order to make the advantages of a PLM System visible.

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