DIGITALNA TRANSFORMACIJA KROZ PDM/PLM SISTEME: OKVIR ZA UPRAVLJANJE INFORMACIJAMA U PROIZVODNIM PREDUZEĆIMA

DIGITAL TRANSFORMATION THROUGH PDM/PLM SYSTEMS: A FRAMEWORK FOR INFORMATION MANAGEMENT IN MANUFACTURING ENTERPRISES

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REZIME

U modernom konkurentnom okruženju mala i srednja proizvodna preduzeća (MSP) nastoje skratiti vrijeme razvoja i isporuke proizvoda uz istovremeno poboljšanje kvaliteta i smanjenje troškova. Upravljanje informacijama o proizvodu postaje ključno za efikasnost – od ideje i dizajna, preko proizvodnje, do isporuke. U radu se analizira trenutno stanje sistema za upravljanje podacima o proizvodu u tipičnom proizvodnom MSP, te predlaže strategija za unapređenje putem uvođenja naprednih PDM/PLM (upravljanje podacima o proizvodu / upravljanje životnim ciklusom proizvoda) rješenja. Identificirane su slabosti postojećeg pristupa gdje je tehnička dokumentacija centralizovana u tehničkom odjelu, a druge funkcije (planiranje, nabava, proizvodnja, kontrola kvaliteta) kasno i parcijalno uključene u proces. Predložene su mjere poboljšanja: migracija na savremeniju CAD/PDM platformu, automatska generacija CNC kodova, implementacija integrisanog PLM softvera radi bolje koordinacije svih učesnika. Očekivani rezultati su brži protok informacija, smanjenje grešaka i troškova, kraće vrijeme lansiranja novih proizvoda na tržište te poboljšana saradnja među odjelima. Zaključeno je da digitalna transformacija kroz PDM/PLM sisteme predstavlja ključni korak ka povećanju konkurentnosti proizvodnih MSP.

Stručni rad

SUMMARY

In the modern competitive environment, small and medium-sized manufacturing enterprises (SMEs) strive to shorten product development and delivery time while improving quality and reducing costs. Product information management becomes key to efficiency – from idea and design, through production, to delivery. This paper analyzes the current state of product data management systems in a typical manufacturing SME, and proposes a strategy for improvement through the introduction of advanced PDM/PLM (product data management/product lifecycle management) solutions. Weaknesses of the existing approach have been identified where technical documentation is centralized in the technical department, and other functions (planning, procurement, production, quality control) are late and partially included in the process. Improvement measures have been proposed: migration to a more modern CAD/PDM platform, automatic generation of CNC codes, implementation of integrated PLM software for better coordination of all participants. The expected results are a faster flow of information, reduced errors and costs, shorter time to market for new products, and improved collaboration between departments. It was concluded that digital transformation through PDM/PLM systems is a key step towards increasing the competitiveness of manufacturing SMEs.

1. INTRODUCTION

The modern market imposes an increasingly rapid growth of demands, forcing manufacturers to shorten the time of development and marketing of products. This means that, in addition to the production itself, the entire process necessary to achieve the ultimate goal – the delivery of a quality product within the set deadline – needs to be accelerated and improved. The emphasis must be on all phases of the business process, from marketing, planning, design, production, quality control, maintenance, product delivery, all the way to end-of-life disposal of products. In a broader sense, it is also necessary to take into account the impact on the environment by placing products that are recyclable and environmentally friendly. In order for the entire process – from the initial idea to the delivered product – to function efficiently while respecting quality standards and deadlines, it is unthinkable without modern technologies and information systems. Technological automation (machines, robots) has already significantly accelerated production, reduced errors and labor costs. However, production itself is only one part of the overall system. Managing the information that accompanies a product is equally important: the more connected, accessible and organized this data is, the easier it is to manage all aspects of product development and implementation. Numerous standards, software tools and systems have been developed for this purpose; In this paper, the focus is on PDM/PLM systems as a support to the complete product information management process.

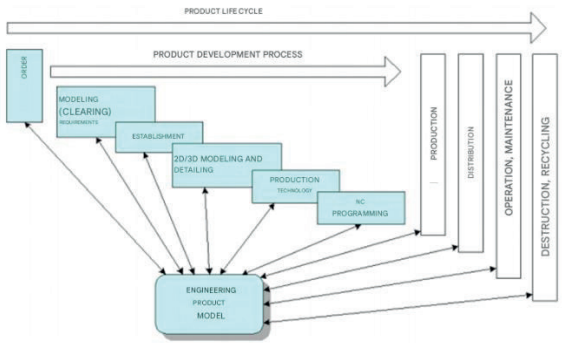

Figure 1. Product life cycle and related business functions in a manufacturing enterprise

As a representative example, the situation in a small manufacturing company is analyzed – from the product design phase to the sharing of information between departments. The paper examines the current state of the technical information system in this context. The main contribution is to define the necessary new functionalities and strategies for their implementation, with an assessment of the benefits that would be achieved for the company.

2. THEORETICAL FRAMEWORK OF THE PRODUCT DATA MANAGEMENT SYSTEM

2.1 Product Information Management Concept

Successful product development involves a series of activities from market research, through design and production, to sales and distribution. Key indicators of development success are product quality, development costs and time, and the ability of the team to effectively implement ideas. In order for a manufacturer to remain competitive, the product must be continuously improved after launch – in order to reduce production costs, apply faster and simpler technologies, bring improvements to market faster, and maintain quality that retains customers and conquers new markets.

Product information permeates all business functions and is the backbone of the business system. The competitiveness of a company directly depends on timely and accurate information in all sectors. It is the duty of management to ensure that all departments (from development, through marketing and sales, to procurement, production and service) have access to relevant product data for the quality performance of their tasks. Different departments generate and use different product information. For example:

- The engineering department creates technical documentation: 3D models, drawings, material components (BOM), calculations, analysis results, etc.
- Marketing and sales prepare catalogs, brochures and sales offers, for which they need information about product characteristics, available variants, delivery times, etc.
- Planning and production use information such as workshop drawings, operation sheets, NC programs, and data on the necessary resources and capacities for the production of products.
- Quality control needs design criteria and specifications (e.g., tolerances, materials) to verify the compliance of the finished product with the requirements.

From these examples, it can be seen that the information about the product is diverse and distributed throughout the company. If they are not centrally coordinated, mismatches can occur – e.g. sales promise something that production cannot deliver due to outdated capacity information. That is why integrated information systems are being introduced in practice, which enable unified management of product data through all phases and functions.

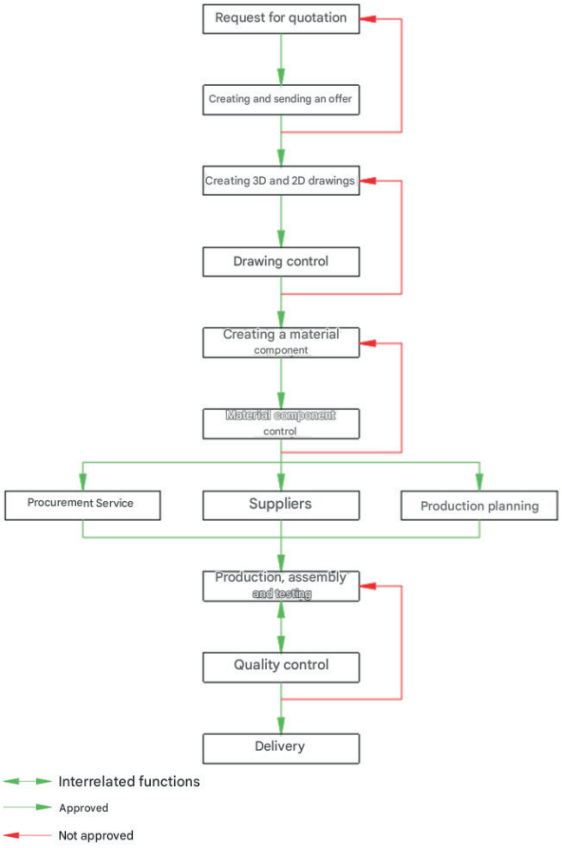

Figure 2. The flow of information between different departments in the company

2.2 Overview of PDM, PLM and ERP systems

Product data management is carried out through the application of specialized software solutions. A product data management (PDM) system is a central repository and tool for managing technical data about a product during the development phase. By definition, PDM implies the use of software and other tools to find, store and manage all data related to the product (CAD models, drawings, BOMs, specifications, etc.). PDM focuses on engineering activities and versioning design files, serving as an electronic vault of technical documentation. The basic functions of a PDM system typically include: controlled storage and versioning of files, management of meta-data (attributes such as part names, descriptions, suppliers, prices), management of relationships between objects (linking drawings and corresponding BOM items, tracking changes and approvals), and support for searching and classifying components. Over time, PDM systems have evolved and often offer additional features such as workflow management, notifications, integration with CAD tools, etc.

PLM (Product Lifecycle Management) encompasses a broader concept – management of the entire product life cycle from idea to recycling. PLM can be thought of as a superset that includes PDM, but also extends to processes beyond the design itself. One common definition describes PLM as the "digital backbone of the product" that integrates all information and processes through all stages of the life cycle: from the initial concept, through design and manufacturing, to use, maintenance, and final disposal of the product. The goal of a PLM system is to provide a single platform on which all internal and external stakeholders (development team, suppliers, production, service, customers) collaborate, so that everyone has access to up-to-date and relevant data. A properly implemented PLM should manage information about all phases of the life cycle: requirements and concepts, design and engineering, testing and simulation, manufacturing and assembly, quality control, logistics, and all the way to servicing and recycling. In this way, PLM connects different disciplines and makes it possible to track every change in the product over time, with full traceability.

It is important to emphasize that PLM is not a replacement for ERP, but a complement to it. Enterprise Resource Planning (ERP) systems integrate key business functions (finance, procurement, sales, human resources, manufacturing, etc.) into a single information framework. Typical modules of an ERP system include: Customer Relationship Management (CRM), Supply Chain Management (SCM), Materials and Inventory Management (Procurement), Production, Sales, and Logistics Management, Financial Management, Human Resources, etc. Within the ERP environment, there is often a segment for production data management, which links design information to procurement and production. Still, traditional ERP mainly handles transactional data (e.g., orders, invoices, inventory) and may have

limitations in handling complex technical product data. This is where PDM/PLM comes in: by integrating the PDM/PLM system with ERP, the flow of information from the development phase to the execution phase is achieved. An example of such integration is that a BOM created in PDM/PLM directly becomes an input to the ERP for procurement and production. This eliminates duplicate data entry and reduces errors. Modern trends are moving towards the convergence of PLM and ERP solutions, where data flows smoothly: e.g. PLM manages product configuration and versions, while ERP uses this data for resource planning and performance monitoring.

For small and medium-sized businesses, the introduction of such systems has become more accessible with the development of cloud solutions. Smaller businesses have traditionally procrastinated, due to the complexity and cost of implementing these comprehensive systems, but modern PLM trends show an increase in adoption in SMEs as well. For example, in 2023, SMEs accounted for about 30% of all cloud PLM deployments, up from ~22% compared to 2021. This growth has been driven by subscription models that reduce initial investment, as well as the "democratization" of advanced features – now even smaller businesses can access tools for collaborative design, analytics, etc., alongside large systems. However, challenges remain, which will be discussed in the continuation of the paper through the analysis of the current situation and possible improvements of PDM/PLM practices in SMEs.

Table 1. Comparative overview of the functionality of PDM, PLM and ERP systems

Options	**PDM** (Product Data Management)	**PLM** (Product Lifecycle Management)	**ERP** (Enterprise Resource Planning)
Primary Focus	Management of technical documentation and product data (design, engineering).	Holistic management of the entire product life cycle – from concept to recycling.	Management of the company's business resources and processes (procurement, production, finance, etc.).
Phase Coverage	Product development (mainly the design and production preparation phase).	All phases of the product life cycle (development, production, distribution, use, maintenance, disposal).	Operational operations (planning of materials, production, sales; warehousing; finance; HR; etc.).
Typical data	CAD models and drawings, product structure (BOM), technical specifications, document versions and revisions, engineering modifications.	All product data: include PDM data + marketing requirements, service information, quality data, configurations, project plans, etc.	Business data: orders, materials and inventory, price lists, customers and suppliers, financial transactions, employee records, etc.
Key features	Data vault (secure central storage of documents); version control and revision; approving engineering changes; search and reuse of parts; integration with CAD tools; basic collaborative functions (notifications, reviews).	Portfolio and product configuration management; management of project tasks and processes (workflow) through the organization; collaboration between multiple departments; change management at the level of the entire product; Integration with CRM/SCM. Life cycle analytics.	Production planning and scheduling; MRP (Material Requirements Planning); keeping stock records; Order tracking and delivery; invoicing and accounting; personnel records and payroll; reporting to management.
Users / Domain	Engineers, designers, technical preparation – focus on **the engineering** domain within the development/construction department.	A wide range of users from different departments (R&D, production, quality, logistics, management) – **cross-functional** and often inter-company (suppliers, partners).	Operational personnel and management in **all business functions** (purchasing, sales, warehouse, finance, administration); mainly internal use within the company.
Goals	Increase the productivity of engineers by eliminating data searches, prevent conflicts in drawing versions, reduce construction errors.	Reduce the overall time and cost of product development, improve product quality and compliance, accelerate market entry, enable rapid product changes and adaptations to market needs.	Increase the efficiency and integration of business processes, reduce redundancy and errors in data entry, provide a single source of truth for business transactions, facilitate decision-making based on up-to-date data.

3. CURRENT STATE OF PDM/PLM IMPLEMENTATION IN SMES

This section analyzes how a typical product information management system works in a small manufacturing company, prior to the introduction of advanced PDM/PLM solutions. The analysis includes the architecture of the existing information system, the flow of data through the company's departments, and the roles of different participants in the data management process.

3.1. Information System Architecture

SMEs generally have limited IT infrastructure to manage production data. The engineering

department uses CAD software to create 3D models and 2D drawings. In this particular case, an outdated CAD platform (e.g. PTC Pro/ENGINEER) is used, and all drawings and models are stored on a local server or file-system that has access to the technical department. There is no separate PDM software – versioning and control of documentation is done manually or through the basic functionalities of the CAD software itself. BOMs (components) are created in the form of tables (e.g. in Excel or in an ERP module), based on the final drawings.

Other functions in the enterprise, such as production planning, procurement, and warehouses, use separate applications or an ERP module for their own needs, but integration with technical data is minimal. For example, an ERP solution (based on an outdated platform) is used to record inventory and issue work orders, but is not directly related to CAD documentation. Data such as codes and names of new parts are entered manually into the ERP when the structure issues drawings and BOMs. This architecture, therefore, has an information island in the technical department and a separate business data island in the ERP, with the occasional exchange of information through the export/import of files or printed documents.

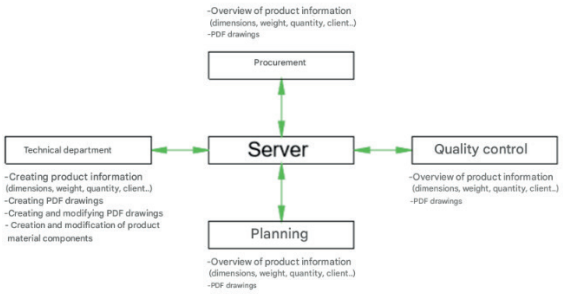

Figure 3. Information System Architecture in a Typical Small Manufacturing Company

The advantage of such a simple system is its low cost and simplicity – a small number of users in the technical department can directly control all changes to the design. However, the disadvantage is that other departments have limited insight into design information during product development. There is no central repository that the purchasing department or quality control can access for verification or early involvement in development. It all comes down to the fact that the technical department finalizes the documentation, and then "forwards" it further through the organization.

3.2. Data flow and process management

The current flow of product information in an enterprise occurs linearly, mostly sequentially from the technical department to the others. The process begins when a company contracts a new job, i.e. when a customer accepts an offer for a product. Then the construction proceeds to the creation of technical documentation – 3D models are created, 2D drawings are drawn from them, and a list of materials is compiled. When the drawings and BOM are completed and checked internally, the technical department approves the documentation as official and publishes it for the other departments. Publishing to the current system means that files are placed in an accessible location (e.g., a network location) or printed and forwarded.

Subsequently, the planning service uses this data to plan the production process. Planning, based on the BOM and drawings, checks whether the necessary materials and capacities are available. The purchasing department also only takes action when it receives this final data – materials and components are ordered on the basis of the BOM. Often, procurement has only drawings of individual parts and BOM, without a broader picture of the product, which increases the risk of misinterpretation of needs. When the materials arrive and everything is ready, planning launches the work order into production. Production performs the task according to the documentation; During production, quality control conducts product inspection. If it notices a non-conformity of the product with the drawing or some defect, quality control can stop the delivery: the product is returned for finishing or declared a waste before delivery.

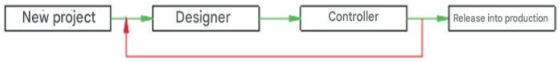

Figure 4. Linear flow of data through the departments of the company

This "cascade" flow of information means that quality control comes to the end of the chain – it only gets full information for the first time after the product is practically finished. The role of control is reactive (checking and eventually rejecting the finished product), rather than proactive (involvement during design). Similarly, neither procurement nor production have an impact on development decisions; They perform tasks according to already completed specifications. Reliance on such a linear flow

can only work if the technical department is extremely efficient and errors are minimized. Otherwise, problems are noticed late (e.g. only during inspection or installation), which causes last-minute changes, additional costs and delays. It should also be noted that feedback is limited: if a design change occurs after the documentation has been approved, the technical department will make the change and record it (typically through drawing revision or minutes). Other departments will not necessarily be immediately informed about the details of the change, except through a formal channel (new version of the drawing, etc.). Thus, it may happen that the procurement or production is not aware of the reason for the change or the potential impact on its part of the business. Such fragmentation of information leads to the underutilization of knowledge within the company – e.g. the experiences of people in production and quality do not contribute to the improvement of design because they are not integrated into the early stages of the process.

3.3. Roles of participants and decision-making processes

As described, in the existing system, the technical department plays a central role. Design engineers and project managers within the technical department are the ones who make all the important decisions about the product – from the choice of materials and components, through construction solutions, to the final documentation. They are the only ones who have the right to modify the technical data on the server, while the other departments are primarily the users of that information. In other words, the authority to change is hierarchically set: the construct creates and modifies, the others use the data.

This leads to a situation where the knowledge and perspective of other departments are not included in the decisions. Quality control, which has insight into the problems of production and use of the product, currently reacts only after the product is created – there is no mechanism for their suggestions on design improvement to be integrated during development. Similarly, the production planning department could provide valuable information about how a design affects capacity or deadline planning, but in the current system, it plans after the design is complete. The warehouse has an overview of the stock of standard parts or semi-finished products that may be used, but this information was not considered during the design of the new product. The consequence of this approach is the underutilization of the collective knowledge of the company. Although the technical department can be very professional, the lack of a multidisciplinary approach means that some errors or sub-optimalities are not noticed in time. For example, quality control is currently "last in the hierarchy of data use" – it performs inspections based on drawings and BOMs, but did not participate in their creation. This is a major disadvantage, as quality control has insight into manufacturing problems and errors that occur and could suggest design changes to prevent them from occurring. All responsibility for corrections falls on the technical department, which eventually corrects the documentation and initiates changes after the established facts.

In short, the current situation is characterized by: centralized decision-making in construction, poor communication between departments during development, and feedback delays. While such a system can be operated in SMEs with simpler products and a small team, it becomes a constraint on growth and innovation.

Based on the analysis, the key needs for change were identified: to involve other departments in the early stages of development, to provide them with access to information in a timely manner, and to establish a single platform where all relevant product information will be available to everyone with appropriate rights.

4. PDM/PLM SYSTEM DEVELOPMENT STRATEGIES

Based on the identified shortcomings, concrete strategies are proposed for the development of product data management systems in SMEs. These strategies include improving the software tools used, making better use of existing design data to automate processes, and introducing an integrated PLM solution that will connect all the functions of the company into a single information system. In our example, the focus is on three main initiatives:

1) Migrating from an outdated CAD/PDM platform to a more modern one.
2) integration of automatic generation of NC codes directly from the CAD model, and
3) Implementation of comprehensive PLM software that brings together all product information.

4.1. Software Platform Migration

The first step towards improvement is to modernize the basic tools used by the technical department. In the observed case, this means upgrading the existing CAD system (Pro/ENGINEER) to a more modern version – e.g. PTC Creo Parametric. Newer CAD platforms offer better support, compatibility with modern operating systems, as well as integration with PDM modules. Software vendors often allow for cost-effective migration; specifically, PTC offered a free upgrade to Creo for licensed users of Pro/ENGINEER.

The migration to the new CAD is not only an aesthetic change, but brings new functionalities crucial for PDM. For example, Creo Parametric comes with built-in PDM/PLM connectivity (such as PTC Windchill or Creo Vault), supports larger datasets, better manages versions and variants, and has enhanced collaborative tools. This means that engineers would get more powerful design tools, but also the ability to share information with others more easily. The new CAD format would be fully compatible with modern model viewers – PTC Creo View Lite, for example, allows any user (e.g. from sales or management) to open a 3D model and view it with the addition of comments, without the need for professional CAD software. Such availability of visual information to all participants would improve communication: customers can be presented with 3D models during deal negotiations, production can check complex assemblies before starting a series, etc.

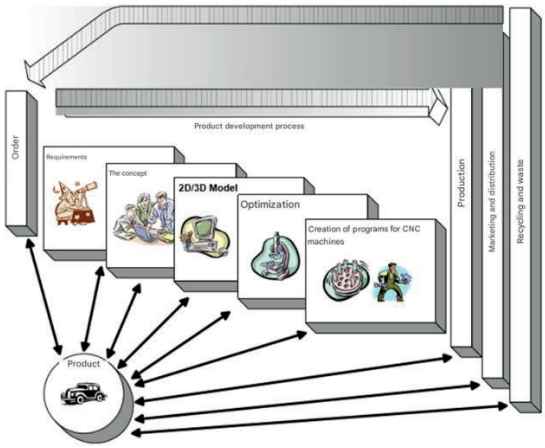

Figure 5. Migrating from an outdated CAD/PDM platform to a more modern solution

In addition, by switching to modern tools, the company ensures the support and upgradability of its system. Old software loses support over time, while new ones enable compliance with current standards (e.g. import/export of formats, integration with BIM or IoT platforms as part of Industry 4.0). In short, the migration of the CAD/PDM platform creates a solid foundation for further digitization of processes and removes technical barriers to the implementation of more complex PLM solutions.

4.2. Integration of automatic code generation

The second recommended strategy relates to improving the CNC programming process. In its current state, CNC machine operators manually program tool paths to process parts. This bottleneck increases production times and raises costs. For example, for processing pipes with a diameter of 60 mm on a lathe, the calculated times are: machine operation 3.6 min, operator work 3.6 min, plus preparation time ~1 hour. This preparation (which includes programming and adjustment) directly affects the cost of the product and productivity. The solution is to introduce automatic generation of NC (G-codes) from the finished 3D model. Already when creating models in CAD, the engineer can take advantage of CAM modules or integrated tools for the program to generate code for the required operations. This drastically shortens the preparation time – each work order starts with the creation of a 3D model anyway, followed by 2D documentation, so adding CAM steps does not represent much additional effort.

The implementation of this initiative in practice requires a certain organization: it is necessary to establish a repository (folder) on the central server for generated CNC codes by work orders. The procedure would be as follows: the design engineer and the project manager, after completing a 3D model that has passed all internal checks, start generating the NC program for the relevant processing and save these files to the intended folder. A limited number of people will have access to these folders – e.g. the technical department and an authorized production representative (CNC programmer or craftsman). This production representative will use the generated codes to set up the machines. The right to modify the codes would be retained by the technical department and the design engineer's coordinator, by mutual consent.

This system ensures that each CNC program is based on up-to-date design data, eliminates the possibility of the operator translating the drawing into error code, and speeds up the flow of information. Initially, of course, time should

be invested in training staff to use the new tools and procedures. But after the learning curve, the company would have a standardized library of NC programs available immediately after the design is completed, which means that the time to prepare for the production of a new product drops drastically. One of the results would be more consistent quality – each time we would use proven, optimized code instead of having several different operators write each of their own programs. In the long run, this contributes to reducing costs and responding faster to orders, as routine tasks are automated. The integration of automatic code generation into the PDM/PLM framework also means that these codes can be versioned, linked to the appropriate version of the drawing, which further enhances control over the process.

4.3. Implementation of a comprehensive PLM solution

The third and most important strategy is the introduction of a centralized PLM system in the enterprise. It is a software solution that would connect all departments and allow them to work on a single platform for all product information. The fragmented approach (CAD files separately, Excel BOM, ERP data separately) would be replaced by an integrated environment. One of the leading examples of PLM platforms is PTC Windchill – an industry-recognized PLM package that was originally recommended for the observed company. In the following, we will use Windchill as a paradigm of a possible solution.

A PLM system like Windchill makes it possible to break down organizational barriers and create a consolidated knowledge base about the product. All relevant information – CAD models, drawings, BOMs, test results, customer requirements, quality documentation, etc. – is stored in a central database, with controlled access and powerful search. Windchill uses multi-system databases to provide a unique and accurate view of all product versions and configurations, including associative BOM structures (each modification of the model is reflected in the corresponding item of the material). The architecture of the system is open and allows integration with other software (e.g. ERP, CRM), which means that it can be connected to an existing ERP and automatically exchange data (e.g. stock status, production plan). At the same time, high standards of security and access control ensure that only authorized persons can change or approve certain information.

A key advantage of the introduction of PLM would be the operationalization of that improved flow of information (Figure 6) in practice.

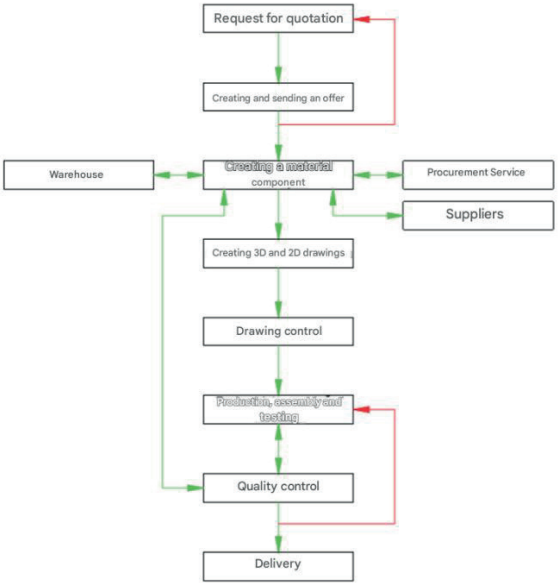

Figure 6. Improved data flow in the enterprise

The software would impose a collaborative process: e.g., quality control would no longer be a passive user of the data, but an active participant. They could enter all their notes on observed manufacturing errors directly into the PLM system (as a record of non-compliance or a suggestion for change). This data would automatically be visible to the design team, which can then avoid repeating the same errors in new iterations of the design. With the new system, quality control becomes integrated: quality gives input to development, and development to quality (e.g. through test plans). Similarly, the production planning department in the PLM environment has insight into every design change in real time – as soon as the construction approves a new version of the drawing or BOM, the planning receives a notification. The warehouse can monitor product structures and suggest the use of existing inventory. Procurement through PLM has the exact specifications and can involve suppliers earlier. All stakeholders have access to the latest product information, which is one of the basic principles of the PLM philosophy.

The implementation of PLM will also affect the speed of change: PTC Windchill, for example, allows design changes to occur dynamically but controlled, through change management mechanisms. Each change goes through a

defined flow from request to approval, with the assignment of responsible persons and recording of decisions. This guarantees traceability and reduces the chances of unauthorized or unnoticed modifications. The company thus achieves the ability to react more quickly to market pressures – whether it is the need to adapt the product to new customer requirements or the correction of an observed problem, PLM ensures that all relevant teams implement the change in a coordinated manner. With full traceability throughout the product lifecycle, management can track the status of each project, identify bottlenecks, and make data-driven decisions.

It should be emphasized that the choice of a specific PLM solution depends on many factors: the size of the company, the budget, the existing systems, the type of product, etc. PTC Windchill is just one example; there are other solutions on the market (Siemens Teamcenter, Dassault Systèmes 3DEXPERIENCE, and even open-source variants). For SMEs, cloud PLM is increasingly attractive due to lower upfront costs and scalability. Regardless of the platform, the goal remains the same – to integrate all processes and data related to the product, which is a prerequisite for the digital transformation of the company.

5. PRACTICAL FRAMEWORK IMPLEMENTATIONS

Successful implementation of these strategies requires a well-thought-out implementation methodology, a realistic assessment of the expected benefits, as well as the identification of risks with a plan for their reduction. Below are recommended approaches that can serve as a framework for small and medium-sized enterprises when implementing PDM/PLM systems.

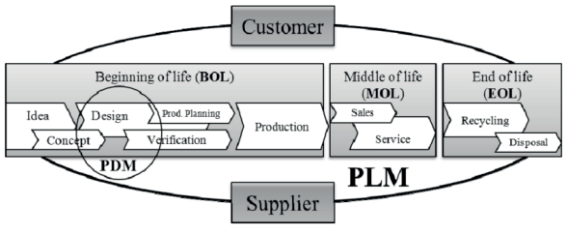

Figure 7. Phases of PDM/PLM system implementation in small and medium-sized manufacturing companies

5.1. Implementation methodology

The deployment of PDM/PLM solutions should be carried out in phases and with an inclusive approach. For SMEs, it is not recommended to implement all changes abruptly, simultaneously, but to gradually integrate through pilot projects. An example of such an approach would be to first migrate the CAD software and establish a basic PDM module within the technical department, and only after this comes to life, expand the application to other departments. Experience shows that small-scale piloting is effective: e.g. starting with a single production program or one sector (design or quality control) and testing new processes there. After the benefits are shown (faster development, fewer errors, satisfaction of the system users), we move on to the next phase and include other departments (production, procurement, logistics) and connect with the ERP system.

At the same time, it is extremely important to form a project team that includes representatives of all key functions: engineers, production technologists, quality controllers, planners, IT experts, and even commercial users. A PLM project is not just an IT endeavor – it is an organizational change and gives the best results if all stakeholders contribute to defining requirements and solutions. Regular team meetings, joint decision-making on the configuration of the system (e.g. defining the flow of approval of changes, rules for naming documents, access levels) will ensure that the implemented system really meets the needs of the business. In an SME environment, where resources are limited, this kind of cross-functional collaboration helps to avoid conflicts and for everyone to understand the value of the system from the start.

Training and documentation of procedures is another important element of the methodology. The learning curve of a new system is often underestimated – in order for users (especially those outside the technical department) to accept PDM/PLM, they need to understand how it makes their job easier. It is recommended to organize workshops and trainings tailored to each user group (e.g. specifically for designers, especially for procurement people, etc.), where it will be shown specifically how to use the new software in everyday tasks. Within the team, it is useful to identify the "champions" of change – people who will enthusiastically advocate for the system and help colleagues overcome it. This can be a young software engineer or a planner open to new technologies. Such internal promoters and mentoring support accelerate the adoption of a digital data management culture.

Methodologically, success metrics should also be defined before the implementation begins. For example, monitoring the number of errors in documentation before and after, the time required from design to commissioning, the duration of changes, the level of customer satisfaction (in terms of met deadlines and quality) and the like. These metrics will later serve to quantify the effects of the project.

5.2. Assessment of benefits

The implementation of the proposed solutions is expected to bring multiple benefits to the company. Most of these benefits have a direct impact on competitiveness and financial performance, while some are indirect but significant in the long run. We will list the most important expected benefits:

- Shorter product development and delivery times: The accelerated flow of information and the parallel operation of multiple departments shortens the overall time-to-market of the product. For example, generating NC programs in advance and starting component procurement early can save days or weeks in the production cycle.
- Increase product quality: Through better version control and the involvement of quality control from the beginning, design and manufacturing errors are reduced. Products are more robust and reliable, as feedback from production is incorporated into improvements more quickly.
- Reduction of development and prototyping costs: Digital validation (simulations, virtual prototypes) within the PLM environment, as well as the ability to reuse existing data, lead to fewer physical prototypes and tests that are expensive. Also, the knowledge from previous projects (stored in the PLM database) avoids previous mistakes, which brings savings in material and time.
- Process optimization and increase productivity: By introducing standardized procedures through PDM/PLM, streamlining the workflow is achieved. Less time is spent searching for information or waiting for approval, and more time is spent on actual engineering and manufacturing. Efforts focus on adding value instead of administration.
- Reduction of production waste: Better coordination of design and production means that problems in production are spotted digitally (in the preparation phase) instead of on the shop floor. This reduces the amount of defective or semi-finished products that end up as waste due to design flaws.
- Savings on materials and inventory: Integration with warehouse and procurement allows for more efficient use of existing components and materials. Designers can more easily check if there is already a specific part in stock to meet the need, rather than specifying a new one – which reduces excess inventory.
- Improved collaboration and employee satisfaction: Although more difficult to measure, this benefit is real – people in different departments who previously worked "blindly" will now be involved and informed. This raises morale and creates a culture of joint problem-solving. Information transparency often leads to better management decisions, as relevant data is available to them in real time for analysis.

All these benefits are reflected in the ultimate goal: to improve the company's market position. Faster release of new or improved products with high quality and better competitiveness. More satisfied customers (getting the right product on time) bring repetitive jobs and a positive reputation. Internally, more efficient processes with less waste and waiting lower costs per unit of product, improving profitability. Literature and case studies from the industry confirm these trends – companies that have adopted PLM platforms record an acceleration of development cycles by up to 20–30%, a reduction in errors in modifications, and a significant improvement in product configuration management, which is especially important if products appear in multiple variants.

Of course, the precise quantification of the benefits depends on the baseline values and the specifics of the company. It is advisable to monitor the defined metrics after implementation in order to document the progress made, which can serve as internal feedback and justification for the investment in PDM/PLM.

5.3. Risk analysis and mitigating measures

Every significant change carries certain risks. The introduction of PDM/PLM systems in SMEs can face a number of challenges that need to be identified and mitigated by a risk management

plan. The basic risks and recommended measures to reduce them will be listed here:

- **High upfront implementation costs:** Acquiring software licenses, investing in new equipment, and training employees require significant financial resources. For SMEs, this can be a burden, so there is a risk of abandoning or shortening the project due to chaos in the versions until everything is sorted out. Mitigation: Thorough preparation of data before migration – clean up incomplete and outdated records, standardize ciphers, resolve duplicates. Plan the integration modularly: first connect the most critical points (e.g. transfer the BOM to ERP), test on a pilot project, and only then go wider. Ensure the support of software vendors or experienced consultants during the integration, in order to quickly overcome any problems. Also, keep the parallel operation of the old systems during the run-in period – e.g. keep records in both the old and the new system for a certain period of time, until it is confirmed that the new one is working properly, thus avoiding data loss.
- **Resilience to change among employees:** The introduction of a new system often encounters cultural resistance – people are used to the current ways of working and may perceive PLM as an additional bureaucracy or threat (fear of losing their job due to automation, discomfort when learning new software). Mitigation: Apply strong change management – clearly communicate the vision and benefits of the new system to each department. Involve users from the beginning to feel the ownership of the system. Organize trainings that are not dry, but practically aimed at facilitating their work. Celebrate "quick wins" – e.g. when a new system prevents a mistake or speeds up the process for the first time, promote it internally so that people can see a concrete result. Identified internal "champions" of the system (enthusiasts) can positively influence colleagues by their example.
- **Technical problems of data integration and migration:** There is a risk that the integration of PLM with existing ERP or other applications will not go smoothly. Legacy data may not be compatible with the new formats, migration can lead to temporary chaos in versions until everything is sorted out. Mitigation: It is implemented in the same way as stated for the high cost of implementation.
- **Vaguely defined processes in the new system:** PLM software is highly customizable, which is a strength, but it can also be a source of risk if clear rules are not set (who does what, who approves, how the change goes, etc.). Without this, users may be confused or different departments will have different expectations from the system. Mitigation: Document and standardize processes before or during implementation. Use the opportunity to optimize existing procedures and then map them into the PLM workflow. Involve users in defining these processes so that they are accepted. Clearly describe common scenarios in step-by-step manuals (e.g. "how to propose a drawing change in PLM" or "new product release process"). This will reduce uncertainty and variation in the use of the system.
- **Possible implementation failure due to lack of support or overestimation of capabilities:** Studies show that a significant percentage of PLM projects do not meet expectations – and rates of ~50% of partially failed implementations are also mentioned. The reasons are often organizational (lack of support from management, conflict between departments) or unrealistic expectations (PLM is seen as a silver bullet). Mitigation: Top management support from start to finish is key. Management should make it clear that the implementation of PDM/PLM is a strategic priority and free up sufficient resources for implementation. Regular monitoring of the progress of the project by the management and the removal of any obstacles (e.g. additional investment if necessary, mediation in conflict of priorities between departments) increases the chance of success. Also, set realistic expectations – PLM will not solve all problems overnight. It takes time for the benefits to be fully realized, which requires communication with all stakeholders to avoid disappointment.

Risk management is an integral part of the implementation strategy. The experience of SMEs that have successfully implemented digital transformation shows that with the right approach, risks can be controlled. It is especially important to continuously measure the results and collect feedback during implementation, and adjust the plan if necessary. Flexibility and

agility in project management will help turn potential problems into lessons and minimize failures to local incidents instead of jeopardizing the entire project.

6. CONCLUSION

Small and medium-sized manufacturing companies that want to be competitive in the market face major challenges in achieving this goal. In addition to ensuring product quality and speeding up production, a critical factor in their success is the effective management of product information that connects all parts of the organization. This paper shows that the availability and sharing of accurate product information at the right time is the key to good business planning and execution in all departments of the company. Information silos and discontinuities lead to errors (e.g. incorrect material orders or subsequent structural changes), which slows down delivery and increases costs.

The proposed measures – modernization of CAD/PDM tools, automation of production data generation and implementation of an integrated PLM system – have a common goal: to improve the flow of information and collaboration within the company, while relying on digital technologies. With their implementation, each employee would receive timely and accurate information necessary for their work, and feedback from the "field" would be immediately available to others. Such transparency and connectivity enables the reduction of errors, faster response to changes in customer requirements and continuous improvement of products and processes. In other words, the quality of business becomes a shared responsibility of all functions, not just management or one department.

We can conclude that digital transformation through PDM/PLM systems is increasingly recognized as essential for ensuring long-term competitiveness of manufacturing SMEs that strive for long-term sustainable competitiveness. Although implementation brings challenges, it has been shown that with an adequate strategy, these challenges can be overcome and significant benefits can be achieved. Companies that turn to modern principles of product data management will ensure faster, more coordinated and better business, which directly contributes to a better market position in an increasingly demanding industrial environment.

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