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John Stark *Editor*

Product Lifecycle Management (Volume 4): The Case Studies

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Preface

This book presents some 20 case studies of Product Lifecycle Management (PLM). With the exception of two of the case studies, all the others were written in the second half of 2018. The case studies show how organisations in different industry sectors and of different sizes are making progress with PLM. Each case study is addressed in a separate chapter and details a different situation, enabling readers to put themselves in the situation and think through different actions and decisions. The case studies are a useful resource for those wishing to learn about PLM and how to implement and apply it in their own organisation.

Geneva, Switzerland John Stark

Contents

How Do Elephants and Ants Tango?

Sami Grönstrand and Helena Gutierrez

Abstract The PLM journey at Outotec covers Plant, Equipment and Service businesses. It started in 2011 in conjunction with a global processes and IT systems harmonization program. This case study focuses on the years 2016–2018 and adjusting the concept—the so-called "making elephants and ants tango" or "one size doesn't fit all"—phase of the PLM journey. It outlines PLM activities for both Equipment Products and Plants, then describes some lessons learned. Finally, next steps are discussed.

Keywords PLM · Journey · Plant · Equipment · Services

1 Outotec

Outotec is headquartered in Espoo, Finland, and has three Business Units: Minerals Processing; Metals, Energy & Water; and Services. In 2018, Outotec had revenues of €1276 million and around 4000 employees.

2 Company Background

Our role at Outotec is to build, maintain and even run entire operations literally from the ground up. Sustainability is at the core of what we do. This means helping our customers create the smartest value from natural resources and working with them to find the most sustainable solutions for water, energy, minerals, and handling the full value chain from ore to metals.

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In minerals processing we cover the full spectrum from pre-feasibility studies to complete plants and life-cycle services, drawing from more than a century of heritage and established R&D resources. Deliveries range from mineral processing equipment, optimized processes (including intelligent automation and control systems), all the way to plants delivered in EPC (Engineer-Procure-Construct) mode or as EPS (Engineer-Procure-Service) with a core technology package while the customer provides the balance of the plant. Technologies cover Grinding, Flotation, Thickening and Filtration plus Automation and Analyzers for each process step and entire production facilities.

For metals processing, we cover process value chains from ores and concentrates to refined metals—Flash smelting and converting, Electric smelting, Electrorefining, and various Hydrometallurgical processes such as Solvent Extraction, to name a few. We have also strong expertise in sulfuric acid processing for metallurgical plants and elemental sulfur. Additionally we also offer technologies and services for renewable and conventional energy production utilizing various fuels such as biomass, coal, sludge, agricultural and industrial by-products as well as sorted waste.

Our Services cover ramp-up support, spare parts, technical services and long-term operation and maintenance contracts. We also modernize existing facilities and equipment, boosting productivity and extending the use life of assets.

Outotec has grown both organically and through acquisitions in past decades. Today it has a wide portfolio for tens of metal and energy applications based on core technologies and knowledge.

3 PLM for Equipment Products

A large program (2011–2016) addressed the processes, applications and operations architecture at Outotec (Fig. 1).

All business processes were harmonized, information architecture aligned and core systems selected and configured. A vast part of the OPAL was the harmonization of delivery processes and ERP systems. Also, PLM systems were compared, and one common system was selected. The PLM deployment was executed as classroom trainings where process, concept and system training were combined in each location.

The focus during this wave of deployment was the early adopters and more repeatable equipment products and businesses, where special effort was directed on migrating and building the first product structures.

4 Adjusting and Focusing

From 2016 onwards, as the program drew to a close and resources were significantly slimmed down, we focused on adjustments and some additional capabilities.

Fig. 1 Starting point of the OPAL programme in 2011

One example of the adjustments was the simplification of roles and user rights. At one point, there were more than 50 roles in the PLM system, which resulted in a high maintenance load and slowness of getting new product and project initiatives started. As a corrective action, a cross-process and cross-functional workshop was arranged to analyze the situation and make necessary decisions to merge and remove roles.

Another example of adjustment was to analyze the initial system configuration. We found that several views and workflows weren't almost used at all, and these were subsequently discontinued to make the UI less cluttered.

5 Plant PLM

Some years after the first PLM deployment, which focused on equipment products, it was time to look at Outotec plants. The challenge? Plant projects are always different.

Large plants require intense collaboration between and among different disciplines, using a variety of different tools. In the design phase, plant data is spread across several applications and there is a need to improve visibility of product data across the lifecycle. In the service business for our installed base, we wanted to improve the findability of information by enabling a functional view of a complete plant, with relevant information connected to the plant's structure (Fig. 2).

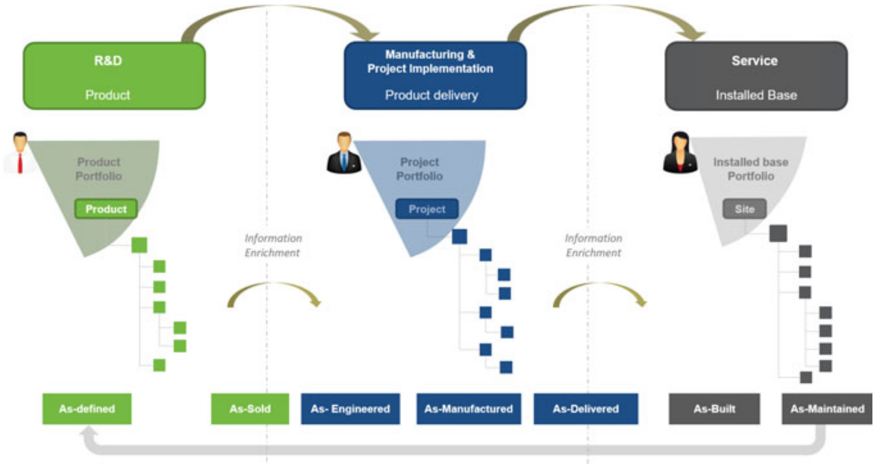
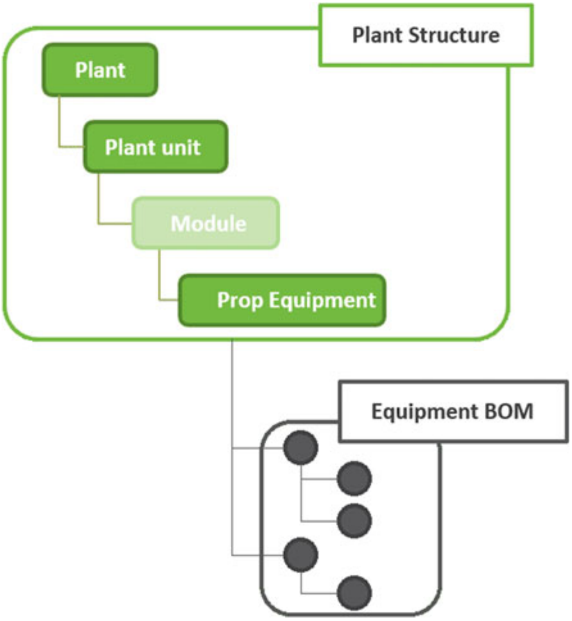


Fig. 2 Collaboration across the lifecycle

Fig. 3 Plant structure and equipment BOM



The plant's production process varies based on raw materials, end-product requirements, energy source, etc. Plant sites are across the planet and, more and more, in harder-to-reach locations. The on-site conditions are always unique, as are the utilities, local services and logistics. Equipment design codes and legal requirements change from one project to the next.

However, there's a common flow of events that must take place to get the project from start to finish, regardless of the size or complexity of the plant.

Plant structures (Fig. 3) are a hierarchical representation of the plant that include plant units, modules and equipment. Equipment in the plant is specified using attributes. Some of these attributes are measured by field instruments, creating a digital feedback loop or, in some cases, a remotely accessible live view of the plant. Equipment products' Bills of Materials are linked to the plant structure. The plant structure in PLM is the master for the installed base.

Developing and implementing Plant PLM was an interesting effort. No available out-of-the-box solution met our needs, so we had to design an information model from scratch and develop a solution to meet our requirements. When deploying this concept, we focused our scarce resources on early adopters who realized the benefits and became advocates. Plant PLM helps proposal teams to create equipment lists quickly and reduce the overall time spent on creating reports. Product lines get a better understanding of the building blocks of the plants and enforce reuse of plant library elements within projects. Overall, PLM enhances visibility and information-sharing throughout the plant's lifecycle.

6 Unlocking Value in the Installed Base

An additional boost and justification for Plant PLM came from the service business. There was a need to get a holistic view of the full installed base of our customer sites organized in a hierarchical, functional structure. At that point, data was maintained by various businesses in different systems and in different ways. From there, it was difficult to consolidate data using analytical tools and proactively drive and focus our sales and service efforts.

This situation formed the background business case for the Installed Base (IB) Project. The main targets of the IB project were to:

- Define a consistent information model and system architecture for the installed base;
- Enable combining the Plant structure with the Product Bill of Material in a hierarchical way; and
- Provide visibility to installed base data to the front-line sales staff through an easy-to-use Installed Base Portal.

Eventually, the development team came up with an information model extension to complement Plant PLM and cover the installed base requirements (Fig. 4).

The integrations and the system information mastering rules were defined and adjusted. In parallel, a modern Installed Base portal was developed to visualize installed base data and create reports and queries (Fig. 5).

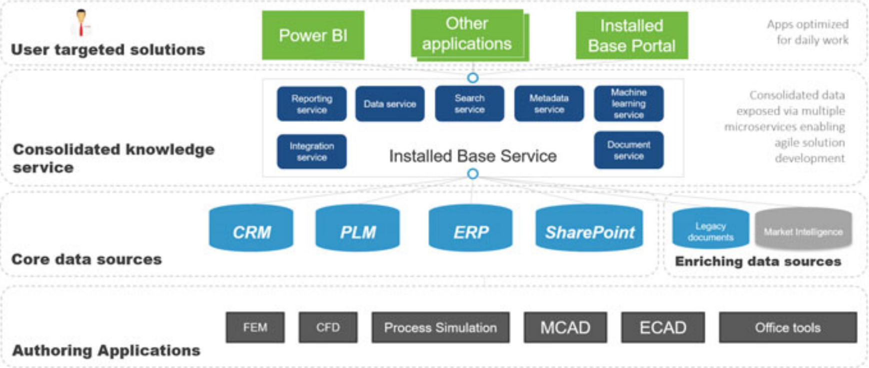
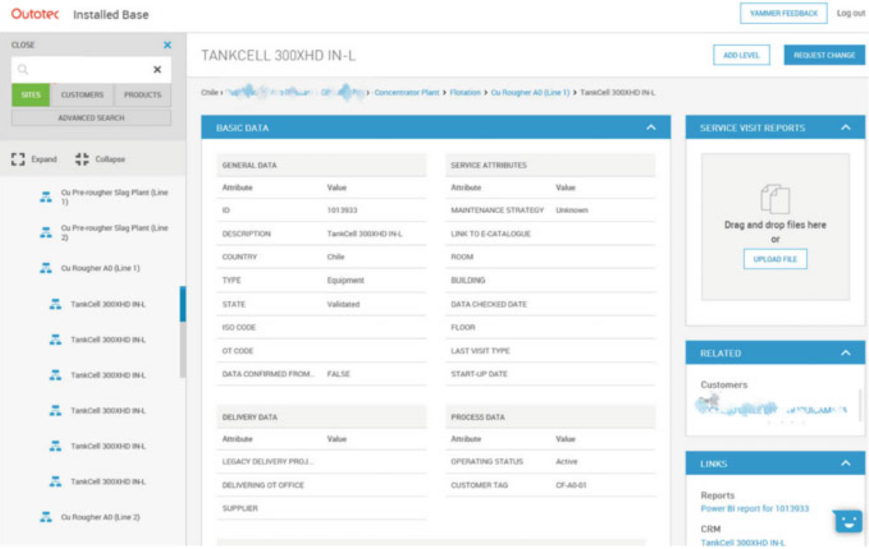


Fig. 4 System architecture



TANKCELL 300XHD IN-L

Chile › [redacted] › Concentrator Plant › Flotation › Cu Rougher A0 (Line 1) › TankCell 300XHD IN-L

GENERAL DATA

Attribute	Value
ID	1013933
DESCRIPTION	TankCell 300XHD IN-L
COUNTRY	Chile
TYPE	Equipment
STATE	Validated
ISO CODE	
OT CODE	
DATA CONFIRMED FROM…	FALSE

SERVICE ATTRIBUTES

Attribute	Value
MAINTENANCE STRATEGY	Unknown
LINK TO E-CATALOGUE	
ROOM	
BUILDING	
DATA CHECKED DATE	
FLOOR	
LAST VISIT TYPE	
START-UP DATE	

DELIVERY DATA

Attribute	Value
LEGACY DELIVERY PROJ…	
DELIVERING OT OFFICE	
SUPPLIER	

PROCESS DATA

Attribute	Value
OPERATING STATUS	Active
CUSTOMER TAG	CF-A0-01

Customers
[redacted]

Reports
Power BI report for 1013933

CRM
TankCell 300XHD IN-L

Fig. 5 Installed base portal

7 Streamlining Equipment PLM

Partially parallel to the developments on the Plant and Service side, we took a new look at PLM functionality for Equipment products. There, needs had emerged for making the customer-specific engineering, delivery and supplier collaboration more efficient. On the product management side, a better-defined modular library was needed.

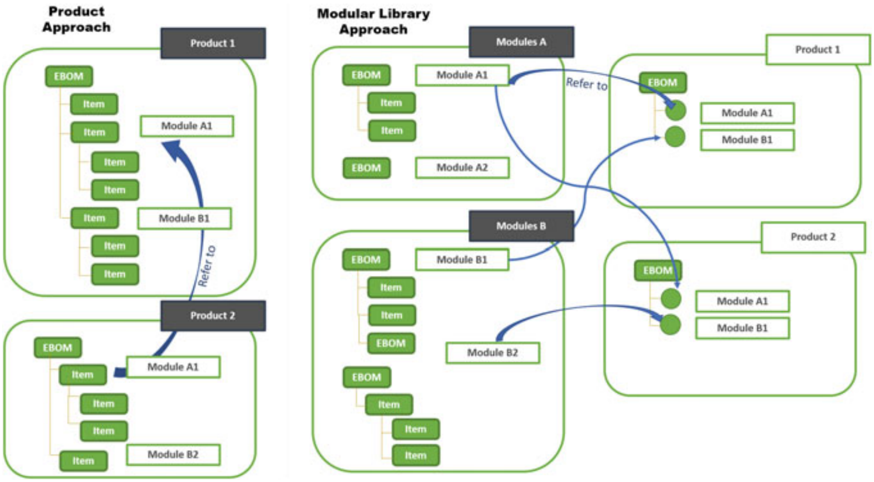


Fig. 6 The product and modular library approaches

(a) Enabling Modular Products

To run a successful business, we need to be able to handle both the Configure-to-Order, and Engineer-to-Order scopes. We also need to cater for different maturities of products and locations. We established a clearer guidance on how the modular product structures can be formed to support different businesses, and it is also implemented in the data model, item policies, behaviors and attributes.

We had originally a way to build complete Product eBOMs, and then cross-use product content, but this was a bit confusing and sometimes the product content was stored outside the PLM platform for easier library management.

To make the library more manageable, we established the module library where repeatable modules can be managed as a "family" and then connect to products and further deliveries. It is also improving the visibility of re-use of modules, and in cleaning up the features (Fig. 6).

(b) CAD-PLM Integration

The intertwined, concurrent nature of Mechanical CAD and PLM (PDM) is known. The vast majority of the structures in PLM are driven by product design, particularly the mechanical/physical aspects of the product. Therefore, it is important that the integration from the CAD systems to PLM works well. Streamlining the CAD-PLM integration helps product development and time-to-market, but becomes critical when products are engineered for customer requirements and with tight lead times.

In the initial concept, the integration from CAD to PLM was on a one 3D part → one manufacturing item basis. This is suitable for businesses with more repeatability and in-house or fully connected/automated manufacturing, but less convenient when the products are engineer-to-order and the manufacturing is outsourced as packages

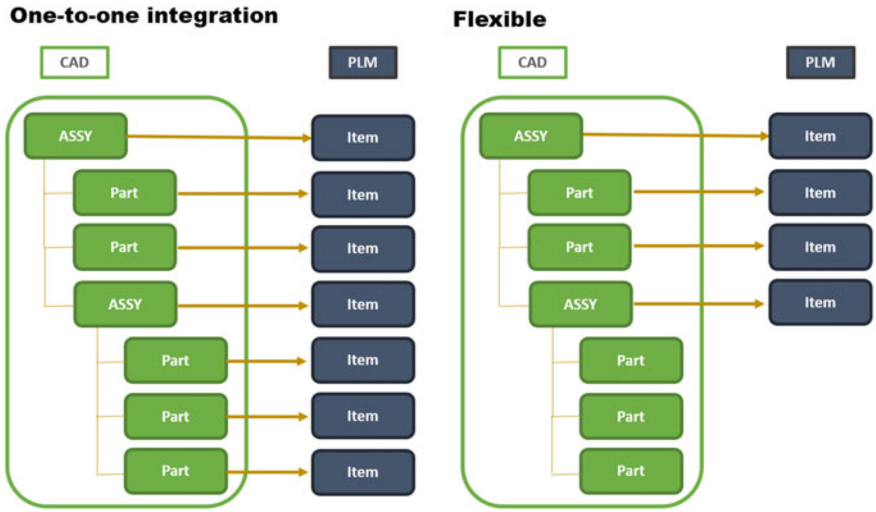


Fig. 7 A more flexible integration

(not individual parts). When, for example, complete welded structures are outsourced for manufacturing, it does not pay dividends to itemize every piece of the structure, especially if the manufacturing location and partner varies from delivery to delivery.

Hence, to make the PLM concept more scalable and suitable for more businesses, it was decided to make the CAD to PLM integration more flexible. While still allowing the one part → one item approach, it also supports the one assembly → one item workflow. This has led to a wider acceptance in the businesses and has also reduced the lead times (Fig. 7).

There are still more efficiencies to be gained on this area, and hence it will be looked at further in the next years' roadmaps.

(c) No More Documents in PLM?

Building on the previous point, the outsourced manufacturing and global flexibility in delivery still requires document enabled collaboration. Documents are referred to in contracts. When engineer-to-order products are used on a project basis, there are also other documents than just the design and manufacturing drawings. Memos, logs, instructions, certificates, etc. need to be connectable in the product context, and reliably handed over and traced, both to Customer and to Suppliers (Fig. 8). Received documents must also be traceable and connectable to context. On the other hand, one should take full benefit of the Configure-to-Order scope and ready-made documentation.

In the initial concept, product and engineering documents had to be pulled out from PLM, combined with the project documentation and managed outside the PLM platform.

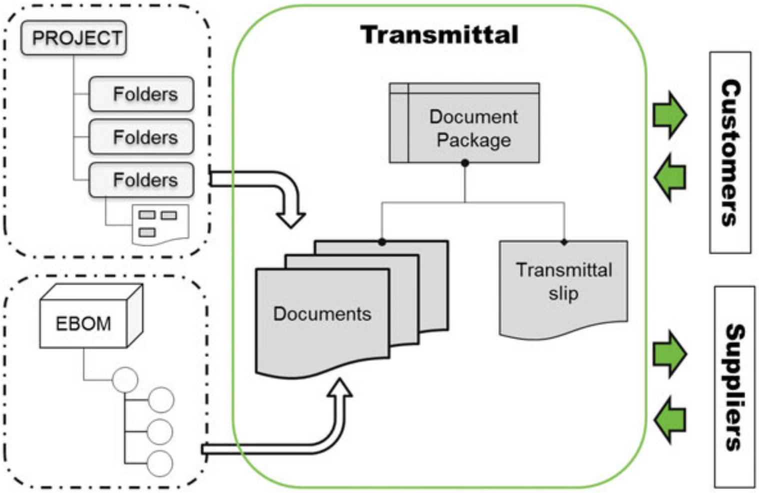


Fig. 8 Document management and flow

We defined and developed an add-on to the PLM platform that now integrates the document management, transmittals and receipts; both of the product as well as the project side, in the context. Furthermore, we are able to trace differences between transmittals; for instance, documents issued "for information" compared to "approved for fabrication" compared to all subsequent revisions—adding parts, removing parts, changing specifications, etc. It is then easy to collaborate when one can focus work and clarifications only on changed scope. This has brought efficiency and traceability into delivery operations.

8 Lessons Learned

(a) The Value of Product Data is in Sharing

Most efforts in this journey boost the further use and benefits of the data generated in the classical product engineering by opening it up better for streamlining delivery, collaboration with manufacturers, and most importantly, serving our customers. In other words, sharing the data and working on the common structure rather than each discipline on their own.

(b) Training Doesn't Stop After the System is Up and Running

One of our PLM initiative's pillars was the creation of a learning platform—a cohesive training environment where people could learn PLM. The project focused on jointly developing a clear process, how-to-instructions and an online learning curriculum tailored for each role.

We prepared a learning platform where we structured all the materials, and we crafted a marketing campaign to promote it through webinars, information sessions and online training.

We began to see results almost immediately. People in the organization welcomed the PLM learning and visited the site frequently to participate in the webinars, answer pools and open questions on social media, respond to comments and share their ideas in common meetings.

PLM is not something you can plug and play into an organization. It requires thought, change management, hands-on support and training. We made communication and learning a priority to create a culture that fostered constant knowledge-sharing. The team developed a common understanding of the overall PLM process.

(c) Ensuring Business Focus in PLM Developments

Some say that PLM is never ready, there is always something to fix or improve. This may be true and needed as well. However, the "why" and "what" should always precede the "how". When different locations began the journey and started to adopt the common systems, requests started to flow: "we are used to seeing x in relation to y, not z" and "the change order workflow of A-B-C should rather be A-B-A-C-D" and so on. Similarly, the IT solution can always be tweaked and adjusted; infrastructure, integration layers, and so on. Without clear governance, the output of the development may be serving only a subset of requirements, or create less than optimum value. First steps in aligning the business focus and technical development was to merge Concept Development and Technical Development. This helped improve the team spirit and transparency and predictability towards business.

Later in 2017, we wanted an even better alignment of development in the complete extended business value chain. This encompasses not only PLM, but also CRM, ERP, Engineering platforms, Collaboration and Document Management, Supply and Manufacturing, all the way to handing over to Service business. We also wanted to continue strengthening the handshake of Equipment and Plant, and not have these solutions developed in a silo. The Scaled Agile Framework (SAFe) was chosen as a guideline, to which an "Agile Release Train" was combined from the mentioned areas, representing the entire Equipment and Plant Business. Another Agile Release Train makes up the Service business value chain, where the PLM continues as one of the platforms alongside Spare parts, Field Services, EAM and MRO.

One aspect of the SAFe is its scalability and transparency—from corporate strategy through business processes into application roadmaps, all synced into enterprise architecture. Adoption of SAFe has received positive feedback both from business and development—more transparency, better prioritization, understanding also towards enablers (such as concepts, access models, infrastructure, UI/UX), not only new features and functionalities. At the same time, we have got (and required) more business participation into the ceremonies such as roadmapping, program increment planning and inspect and adapt (demos and retros).

9 Next Steps

As mentioned above, PLM is never ready. In the era of Digitalization, Industry 4.0, Internet of Things, and all other hyped new things, this certainly seems the case now more than ever. New business efficiencies and growth opportunities are emerging—and at the same time, business needs to run with existing systems on 24/7, without hiccups. Key is how to devise the roadmaps for processes, concepts and solutions in such a way that boosts efficiency of today's business steps, while paving the way for the future leaps. There are still discontinuities and one-way synchronizations in the current digital landscape—one example being the integration between CAD and PLM models. Paradigms such as "digital continuity" and "model-based enterprise" hold many possible implementation models and certainly price tags as well—can we (and should we) connect ALL company functions around the 3D/4D/5D product models …?

As the saying goes: there are two kinds of amazing places. Those that you must see with your own eyes before you can believe they exist. And those that you must believe in before you can see they exist. Going forward, we will need courage to also walk the latter path in some areas to be able to see what the reward could be!

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Helena Gutierrez was PLM Implementation Manager and Director, Product Lifecycle Management at Outotec from 2013 to 2017. She was responsible for PLM programme management, including creation of development plans, schedules and resource commitments to develop, test and deploy PLM improvements and changes. Her role included gathering, managing, and roadmapping enterprise requirements for PLM applications, product information management and business processes. Helena studied Aerospace Engineering at Universidad Politécnica de Madrid. In 2017, she founded Share PLM, a consulting company specialized in training and eLearning for PLM.

Trustworthy Product Lifecycle Management Using Blockchain Technology—Experience from the Automotive Ecosystem

Manuel Holler, Linard Barth and Rainer Fuchs

Abstract Rooted on the principle "from cradle to grave", the lifecycle-driven approach to managing products like automobiles and related services has been recognised as a pivotal approach in research and practice [5, 15]. Digital technologies have continuously fostered the further development of product lifecycle management (PLM) in recent decades [17]. Nowadays, novel disruptive technologies offer even more important advances for providers and users of such solutions alike [14]. For the case of the automotive industry, intelligent products have created seamless visibility over the vehicle operations [9], big data techniques allow for the creation of sound insights [10], and blockchain technology holds the potential for trustworthy vehicle data management [2, 7]. The economic potential of preventing fraud and providing correct data is vast. Solely for the case of mileage manipulation, financial damage of around 9 billion Euro is estimated for the European Union [3]. Accurate data establishing the basis for digital services potentially delivers a global revenue in the 100 billion Euro range [11]. While these benefits of decentralised and encrypted data management are clear in theory [6, 18], less knowledge is available about the practical implementation of such blockchain-based solutions [2, 7]. The purpose of this case study [19] is to reflect experiences from a project in the setting of a leading automotive player which targets development and roll out of a trustworthy product lifecycle management using blockchain technology. Specifically, the study at hand mirrors insights from the automotive ecosystem focusing on the business-to-business context, involving fleets, OEMs, and repair shops. Such a case study seems valuable as research and practice call for real-world insights on blockchain applications especially outside the financial industry [1]. After this abstract, the second part of the case study provides a sketch of product lifecycle management and blockchain technology itself. In the third part, further details on the case of vehicle operations in

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the automotive ecosystem are given. The fourth part illustrates findings in terms of experience from the realisation of trustworthy product lifecycle management. In the fifth part, a discussion on the diverse and relevant hurdles to overcome is followed by a description of limitations and a view towards the future.

Keywords Product lifecycle management (PLM) · Blockchain technology · Distributed ledger technology · Automotive ecosystem · Case study

1 A Sketch of PLM and Blockchain

To summarise, product lifecycle management is the "business activity of managing, in the most effective way, a company's products all the way across their lifecycles" [15, p. 1]. While the first lifecycle stage (beginning-of-life)—the product still within the company—could be assessed as well-covered, the subsequent lifecycle stages (middle-of-life, end-of-life)—the product already at the customers and users—were in a great measure invisible [9, 17]. The closure of this gap has led to closed-loop product lifecycle management leveraging the capabilities of intelligent products [9, 17]. Particularly for the automotive context, these developments are manifested in the concept of the connected car [4]. Besides this far reaching impact of information technology and the strong method- and process-orientation, the socio-technical nature and holistic approach involving organisational aspects has been highlighted [5, 17].

In short, blockchain can be considered as a decentralised event record [1]. More precisely, Beck et al. [1, p. 381] name the blockchain as "a distributed ledger technology in the form of a distributed transactional database, secured by cryptography, and governed by a consensus mechanism". While the concept has been around for some time, it became popular in 2008 with the first application, Bitcoin, by Satoshi Nakamoto [13]. Although considered as a fundamental technology, such as cloud computing [6], until now the connection to the finance industry has been strongest [18]. Nevertheless, researchers and practitioners increasingly debate on a multitude of distributed records beyond finance, such as trustworthy health records or education records [1]. Such an application which exploits blockchain as the foundation for product lifecycle management [2, 7] represents the focus of this case study.

2 The Case of Vehicle Operations in the Automotive Ecosystem

This case study [19] aims to share insights on the development and roll-out of a trustworthy vehicle data management within a leading automotive supplier. As one of the first works on blockchain-related product lifecycle management applications, an exploratory research strategy seems favorable [19]. Predominantly, the realisation of a complex blockchain network qualifies this single case as a revelatory case [19]. In addition, an application in the automotive industry is interesting as this is an economically significant industry sector [11].

Contextually, the solution emerged from the digital innovation group on its way to digitally transform an automotive supplier. It was then continually further developed. The application that securely manages technical—not financial—records is part of a larger transaction platform in the context of digital services. Technically deeply integrated into the car, a variety of data from inside and outside the vehicle are logged and processed to third parties such as insurance companies. Main use cases are the storage of mileage and operating hours, history of owners, history of repair shops, and vehicle parameters for diagnostic purposes. From a blockchain perspective, each participant (e.g., fleet, OEM, and repair shop) represents a node in the distributed ledger system. In contrast to other current endeavors, the solution is designed as an open system. To date, a proof-of-concept to show the feasibility and a pilot to test the large-scale functionality are available.

From a methodical perspective, this study follows the case study advice of Yin [19] to generate rich insights. In terms of data collection, predominantly qualitative data (interviews, business and technical workshops, and supporting documentations [19]) were collected while accompanying the innovation project during the year of 2018. Relating to data analysis, content analysis [12] advised by an adopted PESTEL framework [8] was performed. Such a framework was chosen as the need for a macroscopic framing emerged during the analysis process. In total, political, economic, social, technological, environmental, and legal obstacles [8] could be uncovered in the data.

3 Experience from the Realisation of a Trustworthy PLM

3.1 Unclear Regulation of Blockchain Applications in Key Markets

A first obstacle relates to politics. Upon the novelty of the blockchain technology in business and society, the political attitude and corresponding regulation is evolving step by step. While some regions are rather neutral or even positive towards these new developments, in the Asian and especially in the Chinese market there exists an unclear regulation of blockchain applications. This seems particularly challenging as the Chinese market has evolved to a globally leading one for luxury vehicles and corresponding mobility services alike. In this context, a market researcher based in China and commissioned for the project noted: "*The topic of blockchain is a highly sensitive one in China and the chances are high that there will be strong restrictions on domestic and foreign companies offering such services.*" (Market Researcher, China, May 2018).

3.2 Intricate Definition of Data-Driven Services and Resulting Business Models

The second challenge can be counted among economic considerations. Both providers and users agree on simple use cases like trustworthy mileage tracking and operating hours logging. However, questions arise in more complex scenarios (e.g., repair processes in workshops) requiring the intricate definition of data-driven services and resulting business models. For instance, questions like the following ones come up: Which vehicle data needs to be collected, and with which frequency? When is an adequate level of trust in the system achieved? How are the revenues shared among the ecosystem participants? The project lead responsible for business development reported on these experiences as follows: "*All of our partners clearly recognize the benefit of the seamless and trustworthy vehicle operations management of our solution in their business, but it is hard to quantify and monetize this trust.*" (Project Lead, DACH region, May 2018).

3.3 Frequent Misunderstanding of Blockchain as Finance-Related Instrument

A third obstacle refers to challenges with a social character. Blockchain technology in its novelty and potential disruptivity is still associated with several myths. Even for executives from the innovation or mobility field, the generic character of blockchain as a decentralised database is often not clear. There is frequent misunderstanding of blockchain as a finance-related instrument. This fact seems especially distinctive in the physical innovation-dominated automotive industry with its rather traditional players that are gradually transforming themselves into digital companies. A member of the business development team phrased this fact in an exaggerated way: "*In our conversations with customers we often face the challenge that the solution—mainly from the daily news—is associated with the financial services industry. The technological potential of blockchain in other areas is underrated.*" (Team Member Business Development, DACH region, February 2018).

3.4 Immature Software and Documentation

The fourth challenge falls under the cluster of technological issues. Over recent years, the software market has generated novel distributed ledger technologies such as Ethereum and Hyperledger at almost six monthly intervals. For the development process of robust software applications, the corresponding immature software and documentation lead to operational difficulties. While tool support and documentation is good enough for standard procedures, in many specific situations the trial-and-error method is still required. In this context, a software engineer managing code implementation reported: "*For instance, it is well-documented how to create nodes in the network, however the dynamic adaptation such as the addition or removal of further stakeholders is not documented very well. Here, we mostly use assistance from software engineering forums.*" (Software Engineer, DACH region, March 2018).

3.5 Challenging Integration of Required Ecosystem Partners

A fifth obstacle addresses environmental points. To create a comprehensive logbook of the car, the collection and processing of internal and external vehicle data is essential. Accordingly, for an automotive supplier as the operator of such a logbook, this implies the integration of the required ecosystem partners. On the one hand—for the internal vehicle data—the technical connection to the car needs to be made, either in the sense of a retrofit device or by developing its own electronic control unit. In this context, the heterogeneous vehicle models and OEM backend systems are burdens. On the other hand—for the external vehicle data—the onboarding of repair shops is equally important. Here, for example, the securing of the repair processes represents a major challenge. An interested fleet customer reflected: "*It is a strategic decision to join such an ecosystem, as you cannot change that every day.*" (Head of Innovation Fleet Customer, The Netherlands, June 2018).

3.6 Dichotomous Handling of Personal Data and Data Protection

The sixth challenge is concerned with legal aspects. With the General Data Protection Regulation (GDPR) becoming effective in 2018 and other laws being at the ready, the rights of individuals are reinforced. In particular, this comprises the extension of existing rights and the creation of new rights such as the "right to be forgotten". However, one central characteristic of blockchain is immutability, which in turn implies the dichotomous handling of personal data and data protection. The relevance of this challenge can be seen by the recruitment of a Chief Privacy Officer to address these tasks. In this sense, a team member of the business development team pointed out the solution: "*With personal data being written immutably in a blockchain, certain mechanisms need to be implemented to keep compliant with the General Data Protection Regulation.*" (Team Member Business Development, DACH region, April 2018).

4 Diverse and Relevant Hurdles to Overcome

This case study reflects insights from a project in the automotive ecosystem which targeted the development and roll out of a trustworthy product lifecycle management using blockchain technology. Based on the empirical data collected and analysed, findings indicate the existence of diverse and relevant hurdles which need to be solved before the opportunities of a trustworthy vehicle data management can be exploited.

The nature of the obstacles can be characterised by high diversity. While the challenge of “Intricate definition of data-driven services and resulting business models” is seen as economic and the “Challenging integration of required ecosystem partners” as an environmental aspect, the “Unclear regulation of blockchain applications in key markets” is associated with politics. Interestingly, several issues could be identified which go beyond the assumed technology-driven challenges, such as the “Frequent misunderstanding of blockchain as finance-related instrument” which empowers the demand for a socio-technical approach [5, 17]. For another, their relevance differs profoundly. Whereas in the context of the hurdle “Immature software and documentation” it may be just a matter of time to achieve more maturity, there are others that can be assigned to strategic points—e.g., “Dichotomous handling of personal data and data protection”. These might be business-critical if not addressed adequately.

Certainly, this case study merely represents a snapshot in the complex implementation process [12, 19]. In spite of this limitation, we hope that this study makes a contribution by serving as an initial empirical work on application of blockchain technology in the context of mobility beyond financial transactions [1, 13] and support for the continuous further development of product lifecycle management in the 21st century [15, 16].

The results nevertheless imply the need for further work. In the narrower sense, both research and practice together should develop, validate, and study additional blockchain-based applications in the lifecycle beyond the middle-of-life phase, for instance in the beginning-of-life stage. In a wider sense, beyond the case of product lifecycle management in manufacturing industries, the applicability of blockchain in further fields and industries may be investigated.

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Integrating PLM into Engineering Education

PLM Case Study

Robert Van Til

Abstract This case study considers an approach to educating students in Industrial and Systems Engineering, Engineering Management, and Systems Engineering programs on Product Lifecycle Management (PLM) concepts as well as on the use of industry relevant PLM tools. The case study follows how Oakland University's Industrial and Systems Engineering (ISE) Department has integrated PLM concepts and tools into its degree programs. The integration has occurred, and continues to occur, over 3 phases as outlined below.

(1) Integration of PLM techniques and tools into existing courses.
(2) Development of courses that teach PLM tools and their application.
(3) Development of a PLM dual education program with industry.

Note that the beginning of the second phase is not contingent on the completion of the first phase, and likewise for the third phase with respect to the first and second phases. Each phase is an on-going effort, with later phases beginning after the previous phase has been initiated and is underway.

Keywords PLM education · Industrial and systems engineering · Industry 4.0 · Dual education

1 Background

Oakland University is located in Rochester, Michigan, USA and founded its Industrial and Systems Engineering Department in 2005. The department launched its ISE B.S.E. and ISE M.S. degree programs in 2007. In addition, it took control of an existing Engineering Management M.S. program, which it revised and relaunched in 2011. The department also participates in an existing school-wide Systems Engineering Ph.D. program. In 2017, it began offering a Systems Engineering M.S. degree.

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The initial focus of the ISE Department was on obtaining ABET accreditation for its ISE B.S.E. program both in Industrial Engineering and in Systems Engineering, which was obtained in 2009. While benchmarking other ISE programs during those early days, the department's faculty were considering possible theme areas for the department. They observed departments at several other universities with a focus on areas such as lean, healthcare analytics, data analytics and others. But many of these themes seemed to involve only a limited number of department faculty. With a small founding group of 6 faculty members, such a focused theme was not a good choice.

With the assistance of the department's Industrial Advisory Board members, the ISE faculty centered on a theme of Product Lifecycle Management. While PLM has a variety of definitions, the one that best describes how it is implemented in the ISE Department is:

> Product Lifecycle Management follows a product through all stages of its lifecycle, that is, conception–design–engineering–manufacturing–service–disposal.

Note this definition is not unique, there are various definitions for the stages of a product's lifecycle.

2 Technical Versus Coordination

The concept of PLM used by the ISE Dept. in developing its education program involves separating it into 2 layers:

(1) Lower layer—technical layer: Considers the software tools used in the various stages of the lifecycle, e.g., CAD, FEA, simulation (discrete event, ergonomics, robotics, etc.), MES, ERP, etc. The ISE Dept. focus is primarily on the use of these technical PLM software tools in performing engineering analysis, rather than on the tools themselves (for example, using a discrete event simulation software tool to do a bottleneck analysis or an ergonomic software tool to do a repetitive stress analysis of a manual assembly process). Being an Industrial and Systems Engineering department, the faculty decided to initially concentrate on the "engineering and manufacturing" stages for this layer.

(2) Upper layer—coordination layer: Considers the storage and handling of all data and decisions from the various software tools, users and decision makers on the technical (lower) layer. The data are stored in a single database with all interactions between the software tools and their users with this database as well as between the users and various decision makers (both within a given stage of the PLM lifecycle as well as between stages) coordinated by a PLM coordination software tool. Courses developed for this layer cover all stages of the product's lifecycle.

While almost all ISE faculty members' teaching and research interests involve some aspect of PLM on the technical layer, some also work on the coordination layer. This is one of the reasons why PLM has become a focal area for the ISE Dept., all

ISE faculty are involved in some aspect of PLM. But the primary reason for this focus is the importance of educating engineers on industry-relevant PLM concepts and tools.

3 Phase 1—Integrating PLM Tools into Courses

After initially working with another PLM software company, the ISE Department joined the Siemens PLM Academic Partnership Program in 2011. Through its involvement in the program, the department obtained access to the Tecnomatix suite of PLM software and Teamcenter, as well as access to training and technical assistance.

The three main software tools the ISE Department began using from the Tecnomatix suite were:

- Jack—ergonomic simulation software
- Plant Simulation—discrete event simulation software
- Process Simulate Robot—robotics simulation software

Basically, Teamcenter is used to manage product requirements as well as store and maintain all digital data generated during the product's lifecycle.

Initially, the ISE Department began integrating these PLM software tools into a variety of existing courses starting with *EGR 2600 Introduction to Industrial and Systems Engineering*. EGR 2600 is a second-year course that is required for all Mechanical Engineering, Electrical Engineering, Computer Engineering and ISE students. Both Plant Simulation and Jack are used in EGR 2600. The primary focus of EGR 2600 is to serve as a first course in engineering probability and statistics while also providing an overview of Industrial and Systems Engineering.

In EGR 2600, students are given assignments using Plant Simulation or Jack that demonstrate the effects of random behavior on realistic, engineering related systems. In one assignment, the students use Plant Simulate to model and analyze the performance of a service system (for example, a bank, coffee shop, etc.). Customers arrive at random times and enter a queue to wait for service from one of three stations. If wait time in the queue is too long, customers will leave the queue. Service time for each station is also random, and students analyze the effect of various assignments of employees from a worker's pool to the stations on customer throughput.

In order to complete a given EGR 2600 assignment, students are given an associated Plant Simulation or Jack assignment user manual containing detailed instructions on how to use the particular PLM tool to complete that assignment. Hence, the focus is on using the PLM tool to perform the desired analysis, not on how to operate the tool.

Some other courses in which the PLM tools were initially introduced include:

- *ISE 3341 Ergonomics and Work Design* (Jack)
- *ISE 4469/5469 Computer Simulation of Discrete Event Systems* (Plant Simulation)

- *ISE 5560 Product Lifecycle Management* (Teamcenter)
- *ISE 4422/5422/ME 4740 Robotic Systems* (Process Simulate Robot)

Note in some of these courses, students complete assignments using a particular PLM tool while in other courses the use of a particular tool is demonstrated.

4 Phase 2—Creating Courses Teaching PLM Tools

A year or so after the introduction of the PLM software tools into its courses, the ISE Department conducted an informal assessment of their effectiveness. Feedback received from students, alumni and employers of alumni noted that while it was very positive that students were using these tools, it would be an improvement if students were given the opportunity to learn more on how to use the various PLM tools.

Prior to, as well as during, the introduction of these PLM software tools into courses, the author attended existing PLM software training courses for industrial personnel offered by a vendor. These short-term training courses, usually 3–5 days, had a very tight focus on how to operate the given tool. In talking with the industry participants attending the courses, there were primarily two types of opinions concerning them. The first type was from people who were current users of a competitor's software and were in the course to learn "where the buttons where located" because their company had purchased the particular software tool. For example, a throughput simulation engineer who had been using other discrete event simulation tools and would now also be using Plant Simulation. This first type of attendee felt very comfortable with the training course.

The second type of person attending the training courses was not an expert on the tool covered in the course, but was sent to the course to learn both the tool as well as to determine how it could be used in their current job assignment or by their colleagues. The feedback from the second type of attendee was of being overwhelmed. Many noted they were quickly learning a lot of details about the PLM software tool, but were unsure on how to apply it effectively.

The combination of these two items, program assessment and attending vendor training courses, led to the development of courses that focus on teaching PLM tools and their application. These courses have aspects of both training (i.e., learning how to operate the tool) as well as education (i.e., learning how to apply the tool), and are titled *PLM Applications* courses.

These PLM Applications courses meet for half the time of other ISE courses, 7 weeks (4 contact hours per week) rather than the 14 weeks (4 contact hours per week) for other courses. Since they are elective, not required, students select them based on their interests and career goals.

The following six PLM Applications courses have been developed and are currently being offered:

- *ISE 4461/5461 PLM Applications—Product Data Management* using Teamcenter
- *ISE 4462/5462 PLM Applications—Robotics* using Process Simulation Robot

- *ISE 4463/5463 PLM Applications—Ergonomics* using Jack
- *ISE 4466/5466 PLM Applications—Change Management* using Teamcenter
- *ISE 4900/5900 PLM Applications—Throughput Simulation* using Plant Simulation
- *ISE 4900/5900 PLM Applications—Manufacturing Process Planning* using Teamcenter

For example, the list of topics in the *PLM Applications—Throughput Simulation* course are as follows.

(1) Introduction of Discrete Event Simulation (DES)

  - The basics of DES, comparisons to other types of simulation
  - The role of DES in industry, review of the business value
  - Review of the DES industry

(2) Introduction to the Plant Simulation application and environment

  - Overview of the Plant Simulation application
  - Review of the User Interface, basic workflows and datatypes
  - Understanding the essential steps to building and delivering a successful simulation scenario

(3) Modeling of processes, material flow, and workstations

  - Overview of the Plant Simulation object/process model classes
  - Basic and advanced simulation model creation and verification
  - Model verification and validation

(4) Putting it all together—Building simulations

  - Overview of the Experiment Manager and other verification tools
  - Building and running the set of Test and Verification runs
  - Iterating models and simulations for proper scope and fidelity
  - Correlation to real world studies and data

(5) Presenting Simulation results to management

  - Presentation of simulation goals/objectives/business value to non-engineers
  - Overview of 3D visualization as a simulation output
  - Providing recommendations for decision/action

Feedback from ISE Department's core stakeholders (students, faculty, alumni and companies) has been very positive with respect to the PLM Applications courses. An illustration of their value to companies has been observed by the willingness of some local companies (both large and small) to enroll their engineers into individual courses on a non-degree basis. Another large company hired an Oakland University ISE graduate as their first "Digital Manufacturing Engineer."

5 Phase 3—PLM Dual Education with Industry

A traditional dual education system combines apprenticeships in a company with education at a vocational school. This system is practiced in several countries, primarily in Europe. The ISE Department is developing a variation on this concept to develop an *Industry 4.0 Internship Program*. This internship program combines university-based learning with industrial experience.

The basic structure of the Industry 4.0 Internship Program is as follows.

(1) A company identifies a project that requires the use of a particular PLM tool. The company works with the ISE Department to recruit students interested in working on the project as an intern, with the final selection of the intern by the company.
(2) The company pays the intern to enroll in the appropriate PLM Applications course to learn the tool needed for the project.
(3) After finishing the PLM Applications course, the company pays the intern to work on the project for at least 2 consecutive semesters (10–15 h per week during fall or winter semesters while taking classes and 40 h per week during summer semester). The intern works on the project under the supervision of both company personnel and an ISE faculty member.
(4) At the end of the internship project, the company is free to offer a full-time position to the intern. If so offered, the intern is not required to accept.

During 2018–19 academic year, the ISE Department is piloting the Industry 4.0 Internship Program on throughput simulation projects using Plant Simulation with two local companies (an automotive OEM and an aerospace company). If the pilot is successful, future plans are to expand into other areas such as ergonomics, human factors and robotics.

6 Issues and Future Plans

The primary issue of concern is the ability for the ISE Department to maintain the use of the PLM software tools in its classes. Constructing an appropriate digital model and the associated student materials for a given class assignment can be time consuming, especially for faculty who also have research and service requirements. This leads to concerns with updating existing digital models as well as developing new ones for use in assignments. Development of an infrastructure to update current digital models, and to develop new ones, for use in various class assignments is currently under study.

Another issue of concern is the ability to move from older PLM tools to newer, start-of-the-art tools. The ISE Department is currently facing this issue as it has begun work to move from the Jack ergonomics tool to the newer Process Simulate Human.

Future plans for the ISE Department include developing new courses that fit within its PLM focus. Two areas currently under consideration involve Manufacturing Execution Systems (MES) and Application Lifecycle Management (ALM).

PLM at GROUPE PSA

Jean-Jacques Urban-Galindo and Serge Ripailles

Abstract This case study shows how the PLM environment has evolved at GROUPE PSA since the 1960s. During the initial period, the focus was on systems that mainly addressed the specific needs of individual departments, and improved the performance of individual engineers. Work processes were organised around drawings. This approach changed in 1998, with the INGENUM project. Its objective was to set up a progressive reference frame for product and process definition based on a single physical digital model for all product developers. A third phase started in 2012, with the COMPANY PLM project. The objective of this ongoing project is to integrate all data related to the design, manufacture and maintenance of automotive products, including software components, in a common corporate repository for all participants. The scope, approach and lessons learned are described for each phase.

Keywords PLM · eBOM · mBOM · DMU · Digital Factory · System engineering · Configuration management · Variant management

1 GROUPE PSA

GROUPE PSA is a French mobility provider that designs, produces and sells cars and motorcycles sold under the Peugeot, Citroën, DS, Opel and Vauxhall brands. Its vision is to become a leading car manufacturer and a provider of mobility solutions to enhance its customers' freedom of movement on a day-to-day basis and around the world.

In 2017, GROUPE PSA had revenues of €65.2 billion, sold more than 3.6 million vehicles, and had 212,000 employees.

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GROUPE PSA is present in some 100 countries and develops activities in six strategic regions: China and South-East Asia; Eurasia; Latin America; Europe; India-Pacific; and Middle East and Africa.

To support the brands' global ambitions, GROUPE PSA is planning to launch one new vehicle per region, per brand and per year from 2018. To achieve this, it is deploying a targeted product strategy at global level, based on multi-brand and multi-region programmes.

2 From the 1960s to the Early 1990s

2.1 The 1960s

In the 1960s, automobile manufacturers developed, with their own teams, the first "in-house" CAD/CAM systems. Peugeot and Citroën, independent companies at that time, were both pioneers in the development of CAD applications for their particular industrial needs. Individuals, such as Paul de Casteljau at Citroën and Pierre Bézier at Renault, associated with Peugeot at that time, laid the mathematical foundations for the first representations of complex curves and surfaces such as those found in car body shapes.

Also in the 1960s, CNC machines started to be used in the manufacturing plants of automobile manufacturers. Tool movement instructions for these machines were calculated using programs that modelled elementary geometric shapes: planes, circles, cylinders, etc.

2.2 The 1970s

The approach of using "in-house" CAD/CAM systems continued into the 1970s. However, at the end of the 1970s, GROUPE PSA, created by Peugeot's successive takeovers of Citroën (1975) and Chrysler's European subsidiaries (1978), selected Computervision's CADDS software and developed a close partnership with this CAD system vendor. GROUPE PSA teams developed modules that were integrated into the systems developed, perfected and distributed by Computervision.

In parallel, GROUPE PSA developed internally a common information system, called SCE, to support, in a homogeneous and identical way, the development activities of its three design offices (Peugeot, Citroën, and ex-Chrysler). This development was intended to facilitate economies of scale by making it easier to implement the components common to the Group (engines and gearboxes) and to standardise relations with the Group's suppliers' network, the supply chain. The system included use of a common vehicle coding system (LCDV) throughout the Group based on a common dictionary of attributes ranging from marketing to after-sales, engineering, manufacturing and commercial distribution with 2 coherent formats:

- A 32 bit fixed format from the Renault Peugeot partnership,
- A variable length format combining a common root and a variable list of attributes (technical and commercial).

The SCE Common Information System managed the design BOM, product-related drawings, and the status of information for the Methods (also known as Manufacturing Engineering), Purchasing, Manufacturing and After-Sales teams. It also introduced the “Notice of Dissemination of Information” authorising creation and modification of a document.

The reference document at this time was the drawing. Sometimes it would be made manually on a drawing board, sometimes it would be output from a CAD system.

2.3 The 1980s

In the early 1980s, the Group started to use, as soon as it became available, the CATIA CAD system developed by Dassault Systèmes, distributed by IBM.

Use of the two CAD systems (CADDS and CATIA) was organised and specialised according to the type of part: CADDS for bodywork parts, CATIA for mechanical parts, powertrain and suspensions.

2.4 The Early 1990s

During the 1990s, both CADDS and CATIA were used. From the first years of the decade, syntheses of the areas where design was critical (in particular the engine compartment) were carried out using CATIA-based systems developed by GROUPE PSA’s internal teams.

To design a complex product, such as an automobile, one of the objectives is to make these critical technical areas, such as the engine compartment, very compact. The best use of the available volume traditionally required the production of physical models in order to verify the consistency of the definitions of the volumes of neighbouring parts, the absence of interference between them, to assess the ease of assembly operations on the assembly line, and to ensure after-sales accessibility to components that might require intervention.

The costly cycle of design, part production and verification was repeated until consistent part definitions were obtained.

In the 1990s, it became possible, building on CAD models of parts, to assemble a Digital Model of a specific volume of the car, the Digital Mock-Up (DMU). With the

DMU, designers of the mechanical and bodywork parts of a vehicle project could see representations of neighbouring parts and take into account their virtual presence, thus avoiding interference from the very beginning of the design process.

As their work progressed, designers saved their CAD models in a database reserved for the “vehicle” project. The team responsible for the “vehicle synthesis” managed, on the basis of these still partial definitions, regular reviews, area by area, in order to ensure the compatibility of the designs of the various parts. This eliminated a large number of physical models compared to the previous process, resulting in substantial cost savings and, increasingly, a reduction in the time required to develop new products.

These digital models were also the data source for performing, with finite element models, calculations to predict and evaluate the behaviour of future vehicles. This made it possible to considerably reduce the number of physical prototypes that would be required to verify compliance with the safety standards in force. At GROUPE PSA, the first applications of this approach began in the early 1990s. They were adopted on a massive scale, but with software that was still in its infancy, for the development of the Peugeot 206 in 1995/96.

2.5 Lessons Learned and Recommendations

Before Peugeot’s acquisitions of Citroën in 1976 and Chrysler Europe in 1978, the 3 independent companies each had their own organisations, processes, “cultures”, information systems, and coding systems.

The strategic ambition of achieving sales volumes that would ensure the Group’s profitability by sharing parts and components was fortunately quickly accompanied by the establishment of a common purchasing department and the development of a common information system, SCE, to bring together the research departments around common processes, while maintaining their management autonomy.

In this phase, CAD was still limited and provided mainly 2D model drawings.

The SCE system, developed in partnership with the IT departments of the 3 companies, made it possible on one hand to share a common process model with configuration management based on unified rules. On the other hand, it made it possible to establish common coding rules both for parts, and which was more complicated, for car configurations taking into account technical and commercial diversity. This LCDV coding ensured the one-to-one correspondence between the 2 representation modes: a fixed format coding and a variable format coding in order to ensure compatibility with the “downstream” applications of each company.

The sharing between the 3 cultures made it possible to take advantage of each other’s progress and to question inefficient ways of working, in order to improve them.

The robust base thus built allowed the development of the following steps.

Following the first common application, SCE, all the applications of the 3 production companies (product structures, BOMs, routings, supplies, production management) and commercial distribution companies were able to take into account this reference framework in order to ensure consistency from marketing to after-sales.

They were then gradually unified up to 1995.

3 The INGENUM Project (1998–2004)

As the year 2000 approached, a redesign of product design processes was required in response to the need for increasingly shorter development times (time to market) requiring simultaneous (or concurrent) product and process design. It was also necessary to take advantage of the new organisation set up by the grouping of the Research and Methods Departments in the early 1990s.

The progress made with the Digital Model led to company management initiating a program to generalise this technology to all development programs.

At this time, software vendors were beginning to offer mature solutions for managing all design data (PDM systems) and, at the same time, the continuous progress in computing power and high-speed data transmission network technologies was being confirmed day by day, opening up new medium-term prospects for the organisation of engineering teams. In order to promote the desired evolution of operating methods, the strategic priority was to **share data**.

Also at this time, questions were raised about the Group's CAD system choices. Conversions of part models designed with geometric modellers from different software vendors raised operational difficulties. It was finally decided to replace the CADDS geometric modeller, then used for bodywork parts design, by CATIA and to build the Digital Model management application using ENOVIA/VPM, also from Dassault Systèmes.

The SCE application, mainly focused on the drawing object and unsuitable for managing the multiple intermediate states of definitions (the "in-process" data), required a redesign to take into account the progressive convergence of solutions.

Moreover, commercial choices were being limited by a too-close link with the technical choices: technical authorisations were administratively necessary to modify commercial offers (pack options for example). This slowed things down and required unnecessary work.

The time had come for a major revision after more than 15 years of good and loyal service. A review of the data model, based on components, elementary products was necessary.

As it was seen that the DMU required both CAD models and parts lists, elements of the eBOM, it was decided to build the DMU based on the eBOM, itself built progressively. The progress of the project is then represented by Fig. 1.

The combination of these ambitions gave birth to a project, called INGENUM, officially launched in January 1998.

After a few months of consultation, the development plan was drawn up. It provided for a gradual implementation in 3 defined stages, taking into account both the maturity of the software solutions on the market and the expected gains in improv-

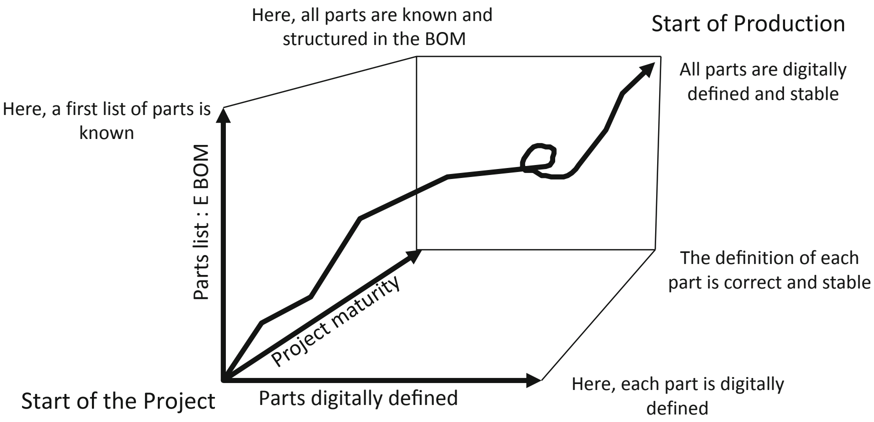


Fig. 1 The DMU development needs CAD models and part-lists

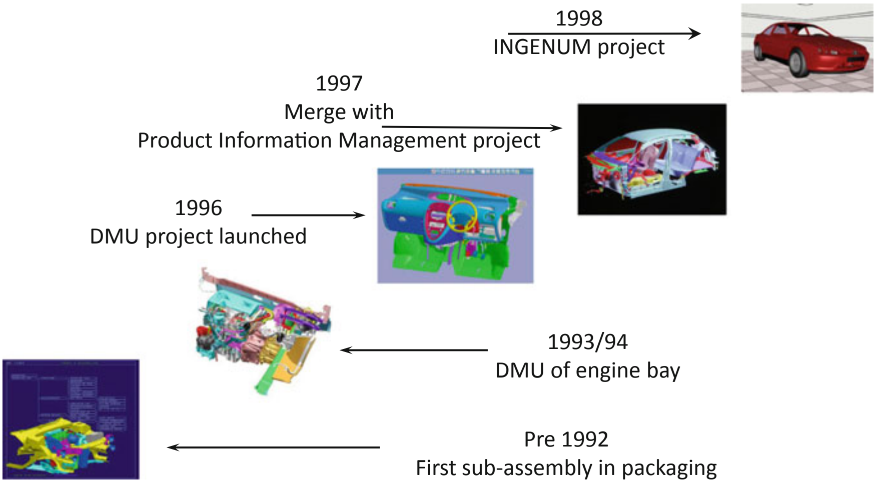


Fig. 2 Some milestones in the progress of digital technologies in the 1990s

ing the operational efficiency of the engineering teams. IT architecture choices were oriented towards the implementation of solutions based on increasingly powerful software packages, available or under development (Fig. 2).

Defined in the first months of 1998, the plan would be implemented throughout the period 1998–2004. Conceived as a coherent whole, its implementation phases were progressive steps.

3.1 Deployment of the Digital Model

The first step in the INGENUM project was the deployment of the Digital Model in the Extended Enterprise. It aimed to generalise to all projects, and to the entire car, practices that had been gradually implemented on individual projects.

The objectives of this step were to, on one hand, implement CATIA for bodywork development to replace CADDS, and on the other hand, deploy the Digital Model under the control of ENOVIA/VPM **to facilitate data sharing**.

To improve collaboration in the Extended Enterprise two features were provided to designers. Firstly, "CAD conference" sessions that allowed remote sharing, through high-speed networks, of analysis of the design of a part by geographically distant participants. Secondly, remote consultation of the GROUPE PSA digital model by authorised suppliers via a secure ENX (European Network eXchange) network.

By positioning the Digital Model at the centre of the project, at the heart of the detailed vehicle design, significant changes in operating modes were made.

3.2 Digital Factories

The second major theme was the implementation of the Digital Factories.

The ever-increasing performance of digital systems, hardware and software, which made it possible to visualise increasingly large sets of parts, paved the way for new fields of application for these technologies, those of manufacturing process design.

The aim was to set up digital representation systems to simulate processes, optimise them even before they were put into service in the workshops and, finally, record the data describing the processes in the global reference framework defining the product and its manufacturing processes.

This activity, traditionally carried out by the "Methods" departments, was essential to ensure the efficiency of production and the regular quality of high technology goods produced in large series. It had to be conducted simultaneously with the design of the product itself if the required level of performance was to be achieved on the Function-Quality-Costs triptych.

The investments involved in designing and building the tools for a "new vehicle" project or a new engine family are considerable; they represent a very significant part of the budget of these projects.

The prospects for savings in this area of expenditure, the gain in the time required to set up—running-in and ramp-up—the shop floor justify the development and implementation of specific systems in industries such as the automotive industry, where investments are sizable.

The main activities concerned were foundry, forging, machining and assembly of components, stamping, bodywork welding, painting and final assembly of the vehicle.

IT systems referred to as “Digital Factory” offer functionalities that make it possible to do each job better; they make it possible to better:

- Define all the elementary tasks making up the routings, sequences and groups on the workstations that will allow the product to be manufactured as defined by the design office
- Calculate the successive stages of part machining, the trajectories of welding, painting and heavy part handling robots
- Represent the shop floor in three dimensions, distribute the workstations, check accessibility and judge the ergonomics of the actions required of the operators.

At the beginning of the millennium, few such solutions were proposed by software vendors because the market prospects were limited to very large industrial companies; they did not justify sufficient investment in research and development especially as the various companies had different needs and limited further this emerging market.

Finally, systems to facilitate the accomplishment of a particular task, often coupled with office automation systems such as Excel, existed and were easy to use. Their integration into a more structured system, more demanding in data management, was difficult.

GROUPE PSA decided to make progress, business by business, constantly keeping in mind the objective of integrating elementary data into the same global information system model in order to ensure a permanent overview of the state of product definitions and manufacturing processes.

3.3 Progressive Reference for Product and Process Description

The third major theme was the implementation of a Progressive Reference for Product and Process Description.

In line with the development of the Group’s strategy, which, since the early 1980s, had set up a common information system to support its engineering activities (even though the Group’s structure was still made up of three companies—Peugeot, Citroën and the former Chrysler subsidiaries renamed Talbot—each with its own R&D Department and Methods Department), the aim was to put in place a new generation of applications.

This new engineering support information system was to:

- take into account organisational changes such as the regrouping of the R&D and Methods Departments and the increasingly important role of suppliers in design
- encourage new working methods that had developed: strengthening the “project” organisation, simultaneous product-process design
- integrate the digital systems that had invaded the design and method offices
- limit internal developments by taking advantage of software packages that, by now, covered very wide areas, including for companies the size of GROUPE PSA

In addition, it was necessary to ensure continuity of the articulation with production management, commercial vehicle distribution, purchasing management and costing applications.

The overall architecture of this structure, its backbone, was based in particular on the shared description of the products (cars and the parts that they are made from), each function being able to build its applications according to its particular needs.

The central role of the data repository was key to the architecture of the project. Its implementation provided an opportunity to revise some points that required data improvements, such as a more precise identification of successive versions of part definitions during the prototype development phases, as well as the decoupling between the rules governing the association of technical variants and those guiding the choice of options in the commercial offer.

3.4 Resulting Changes

In the mid-1980s, the number of CAD stations in the Group was in the order of a few hundred; ten years later, in the mid-1990s, thousands of stations were installed in GROUPE PSA's design offices.

The shift to 3D design transformed the role of the drawing. It is still the official document proving intellectual property; it defines all the elements necessary for the manufacture and inspection of parts that comply with specifications, including tolerances on production dimensions. It brings the design activity to an end, but this activity was essentially based on 3D geometric models, gradually refined from a first sketch of the envisaged external shapes.

Successive iterations of the design at the various stages of the project, i.e. prototype, pre-production and production vehicles, generate multiple versions of digital models that must be carefully identified and stored in order to be found without error.

The implementation of a robust information system for describing the composition of vehicles in terms of component parts, Bills of Materials, and documents describing them, drawings, calculation notes, allowing easy searches for technicians, is essential if this system is to become a strict reflection of the reality of the design office's activity and replace the too many manually managed tables in office automation systems that became widespread, sometimes to compensate for the shortcomings of the structured applications in place.

The digital design systems that, until this time, had mainly improved the individual performance of the participants, were now leading the Group into a phase where progress was focused on the efficiency of the joint work of a guided team, motivated by a shared objective.

This approach could only succeed with intensive data and information sharing; advances in digital technologies now made this possible. The approach presupposes that everyone will accept, for the collective good, the view and criticism of others in the early stages of their work, when the options that determine quality and costs are decided.

The systematic implementation of these new operating modes highlighted the limits of the numerical representativeness of flexible parts such as electrical harnesses or part envelopes in their movements such as those that make up the exhaust line.

It also became clear that there was a need for greater rigour in the management of the interfaces between the vehicle's equipment and its structure, which, on a small car number about 200, and in the need for better coordination between CAD and Bill of Materials management.

3.5 Results Achieved

The expected improvements in the physical assembly time of prototypes thanks to the early detection, by numerical analysis, of interference between adjacent parts with incompatible definitions were confirmed: a saving of three weeks on a phase that previously lasted seventeen weeks was thus achieved.

Over the thirty years from the 1970s, the distribution of roles between OEMs and their suppliers changed considerably. Suppliers were initially confined to the manufacture of parts entirely defined by the OEM's design office, the slow circulation of information making it difficult to take supplier opinions into account regarding production difficulties. The scope for optimising solutions through more efficient product-process design remained very broad. Gradually, a few suppliers started to participate in the design of certain functions; they became real specialists. At the beginning of the 1990s, with the advent of the "project platform", key suppliers sent representatives to join the OEM's engineering teams. They could thus participate in the evaluation of solutions and guide choices in order to improve the quality/price ratio.

3.5.1 Modular Product Structure

Since 1998, the Group's strategy has focused most of its commercial offer on a limited number of three platforms for small, medium and large vehicles. They bring together the elements of the structure and the parts not seen by customers in order to reduce design costs and increase the quantities produced, thus reducing unit costs.

The multiple silhouettes of the Peugeot and Citroën brands are developed on these platforms.

This strategy has strengthened the requirement for a modular description of vehicle ranges and reinforced the need for stricter coordination of the development and production of vehicles.

Like other car manufacturers, GROUPE PSA has built its product structures in a modular way combining a technical configurator and sub-assemblies, the combination of which ultimately constitutes the single vehicle desired.

The vehicle coding consists of a series of codes, the technical configurator defines the combinations of options accepted in the line, the commercial options presented to customers but also the underlying technical characteristics imposed.

The manufacturing and commercial distribution information systems are built on the same vehicle definition code. The commercial configurator, which presents the product offer to customers, is a subset of the technical configurator.

3.5.2 ISO 10303 "STEP" Application Protocol AP214

The STEP AP214 standard defines a global data model to take into account the specificities of the automotive industry such as the diversity of a product group, the description of manufacturing and assembly processes, and the process plans.

This data model answers the recurring question that all manufacturers ask themselves: "Can we define a single product structure for all the company's needs"? It concludes that uniqueness is not a satisfactory answer and that at least two views are needed.

A "design" view, most often structured by following a functional division into systems and subsystems according to the product axis, and a "manufacturing" view, which gradually assembles physical sub-assemblies, in an order dictated by the feasibility of shop floor operations. This "manufacturing" view is multiple when the product is manufactured on several sites, an adaptation of the systems to the specificities of the site and production rates may be necessary.

Multiple views of the same product must of course describe the same composition, without error. Only a global, integrated model can achieve this result without excessive efforts of comparison and resynchronisation.

This model, which is close to the logical data structures in place in GROUPE PSA systems, was on the right track to stabilise in the mid-1990s.

In July 1997, GROUPE PSA took the strategic decision to choose it as a reference for the description of its products in all its new information systems developments.

The search for a software package that would meet GROUPE PSA's needs was organised around specifications submitted to the main vendors in 1998. It was based on the STEP AP214 data model, which it was hoped would guide software developers in their own development plans.

SAP met GROUPE PSA's specifications with a software package developed at the request of the Volkswagen Group, iPPE (integrated Product & Process Engineering). A detailed analysis showed that the "business objects" on which GROUPE PSA's design processes were organised were satisfactorily represented in this software.

Able to manage distinct—but consistent—structures between design and manufacturing needs, iPPE could handle the diversity of the Group's products. It was chosen as the backbone for future systems, the foundation of "configuration management".

Interoperability with digital representation systems was built using the AP214 model as a guide.

Evolution of ENOVIA VPM was specified by GROUPE PSA teams to improve its diversity management functionalities in accordance with the AP214 model. The coupling between digital model and product structures was thus made relatively easy.

3.5.3 Changes to the Development Process

The choice of SAP to implement the new information system was not neutral in the rules to be respected for its proper use. Reflecting the "Germanic" culture of its designers, data control is strict, updating responsibilities are clearly defined, and planned procedures must be strictly followed. Circumvention is risky and the consequences of deviations from the rules can be serious.

After having assessed the coherence of the edifice that this software package represents, it was quickly decided to avoid any modification of the product's technical data model by aligning with the only possibilities available through its "parametrics". The only specific developments allowed were to improve the presentation of some screens in order to facilitate access to reference data by authorised users, in as intuitive and easy a way as possible.

GROUPE PSA also reviewed in depth management rules, and clarified the responsibilities of the participants, and removed the ambiguities that had gradually crept into practices due to some particular exceptional events.

The fundamental reflection on the importance of sharing quality information, representative of the reality of activities, in an area of the company where initiative and imagination are encouraged, sometimes in opposition to a certain discipline, has had beneficial consequences.

The elimination of many special cases with poor justification has simplified procedures.

The formal recording in the system of everyone's decisions has led to a better understanding of the scope and actions of each of the participants, and to solidarity in obtaining the final result.

The essential role of the "Technical Management" professions, responsible for updating product structures, has been rediscovered. They were previously perceived as "administrative", but were re-positioned and have become major players in the management of the collective act of design.

The requirement for data quality as soon as it is entered into new applications is no longer discussed.

Finally, control of the product's components throughout its life cycle, "Configuration Management", has been reinforced by confirming the responsibility of the designers of the parts supported from the earliest stages by the Configuration specialists. A new design maturity and validation process incorporating these changes was implemented.

3.5.4 Consequences for Related Applications

During this period, several other applications were being developed under the SAP software package. They were highly dependent on the structural choices made in the INGENUM project. They included a new application for managing the production of prototype and pre-series vehicles and the complete overhaul of the purchasing management application, which was initially developed in the early 1980s to support the merger of the purchasing departments of the three companies making up the Group.

These major applications were built using the product definitions set up by the INGENUM project, in particular the "articles" reference frame and the components and structures of the vehicles to be assembled.

The initialisation of the data in the application supporting the purchasing activity was the occasion for a strict overhaul of their quality, a "cleaning" which, although it seemed a little onerous at the time, was finally extremely beneficial; it allowed the application to start under the right conditions.

3.6 Lessons Learned and Recommendations

With the development of 3D CAD and digital mock-up, the development of simultaneous product/process engineering and offline robot programming, the SCE application reached its limits.

The full integration of CAD into the process provided the opportunity to consistently address the configuration management of all digital models.

This led to improved tracking of part versions in the validation phases by integrating prototype manufacturing with fast evolving definitions in the development phases.

Configuration Management was refined by involving BOM Managers upstream, as soon as the need for a new part was decided. Reviews of digital models were based on the eBOMs, ensuring simultaneously the geometric development and quality of BOM expressions with all the complexity of variant combinations.

The "backbone" reference framework also ensured the correct creation of mBOMs and routing descriptions.

The evolution of commercial offerings in each specific market required much more flexibility—while staying within the limits of the authorised technical combinations. Vehicle descriptions were improved by better articulating technical options and commercial choices while ensuring their consistency.

The processes and tools put in place were ready for a new wave of progress that was already being felt: electronics and embedded computing, as well as further evolution towards approaches based on system engineering, the first steps of which had been implemented in 2000.

4 The COMPANY PLM Project (2012–2020)

The objective of the INGENUM project was to set up a progressive reference frame for product and process definition based on a single physical digital model for all developers. This project ended in 2004.

In 2012, GROUPE PSA launched the COMPANY PLM project (Fig. 3). Its objective is to integrate all data related to the design, manufacture and maintenance of automotive products in a common corporate repository for all participants.

4.1 Improvement Drivers

This project integrates several principles already set out in the framework of LEAN PRODUCT DEVELOPMENT:

- The efficiency sought is above all collective (efficiency is by no means the sum of all local performances) and is reflected in processes and a set of deliverables common to all participants.
- Efficiency is about using as little energy as possible to provide a deliverable. The ideal is to no longer create what already exists (we are talking about CARRY OVER).
- Efficiency then consists in "equipping" these processes in a single working environment that allows each participant to have the information they need (without risk of error and waste of time) to make their deliverables available. This principle can be illustrated by the concept of SINGLE SOURCE OF TRUTH.

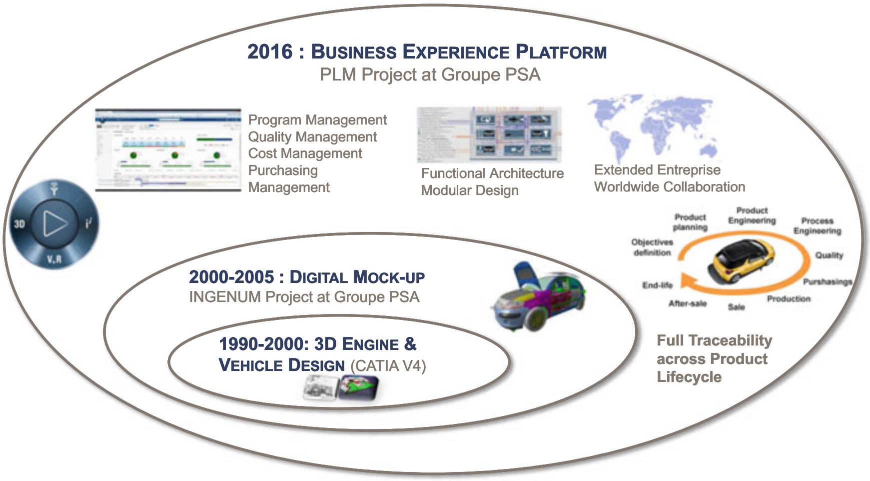


Fig. 3 PLM project at GROUPE PSA

Finally, these principles must respect and integrate the fundamental needs that are:

- Protection of the company's information and intellectual capital
- Integration of the Extended Enterprise (the company, its suppliers and partners)
- The ability to justify the validity of one's choices at any time.

In short, to equip on the same platform all the processes of creation, and then configuration management, of product-related data over the entire life cycle, a strategic challenge for any company.

4.2 GROUPE PSA's Ambitions and the Roadmap

The INGENUM and COMPANY PLM transformation projects responded to this logic of progress with the implementation of, first PDM, and then PLM.

This evolution has accompanied that of the automotive product and its ecosystem in the 21st Century:

- A certain complexification of the product (low emissive powertrain, autonomy and assistance, mobility profiles and interaction with the environment) which requires a functional and systemic design of the product in its environment.
- A competitive environment that requires rapid availability of innovations and, therefore, acceleration of product design and launch processes.
- A consumer and legal framework that imposes traceability and justification of design (from systemic requirements to physical components).
- A globalisation of the company and its network that makes it necessary to set up a secure platform accessible to the Extended Enterprise.

The four main ambitions of the COMPANY PLM project are as follows.

The first ambition is to work together and efficiently (between the different disciplines, with JVs and suppliers).

- Organise and structure all design documentation as a full and linked flow of data (functional, geometric, electrical, electronic, component, component, validation data, etc.)
- Ensure their uniqueness and (secure) availability to all internal and external participants.

The second ambition is to apply rigorous configuration management to drastically limit the number and cost of changes:

- Link, trace and version data sets throughout their life cycle and in their context of use.
- Carry out a reliable analysis of the overall coherence and impacts in the event of evolution or modification.

- Automate and secure the process of managing changes in development projects and in mass production.

The third ambition is to deploy System Engineering widely, integrating modular policy and promoting reuse:

- Define and equip the creation and management of structures (requirements, functional, technical and industrial architecture) and the links that unite them, through to the integration and validation plan.
- Deploy working methods based on the use of generic and already existing solutions offered to users.

The fourth ambition is to put in place a fair and efficient monitoring system to manage projects and help take decisions:

- Generalise the management of data maturity and the management by deliverables.
- Automate the creation of dashboards based on unique, reliable, referenced and accessible information.
- Implement analysis and intelligence applications around the data.
- In view of the importance of the systems and their consistency (completeness of the data model), the COMPANY PLM project (following the INGENUM project) was conducted as part of a strategic partnership with Dassault Systèmes.

4.3 The Scope

The scope covered by COMPANY PLM includes all the processes and deliverables of R&D (Fig. 4).

The PLM platform covers (based on a single data model):

- Project management processes and purchasing relationship management
- The transversal process of management of release, change and impact analysis
- The processes of system design and then functional, electrical, electronic and physical architecture
- Construction processes and BOM management (configuration and diversity)
- The processes of design of the manufacturing process, after-sales and manufacturing
- Management processes and integration of suppliers and partners.

Its global architecture (Fig. 5) is based on a backbone logic ensuring the integration of business applications and the link with operating systems (including the company's ERP system).

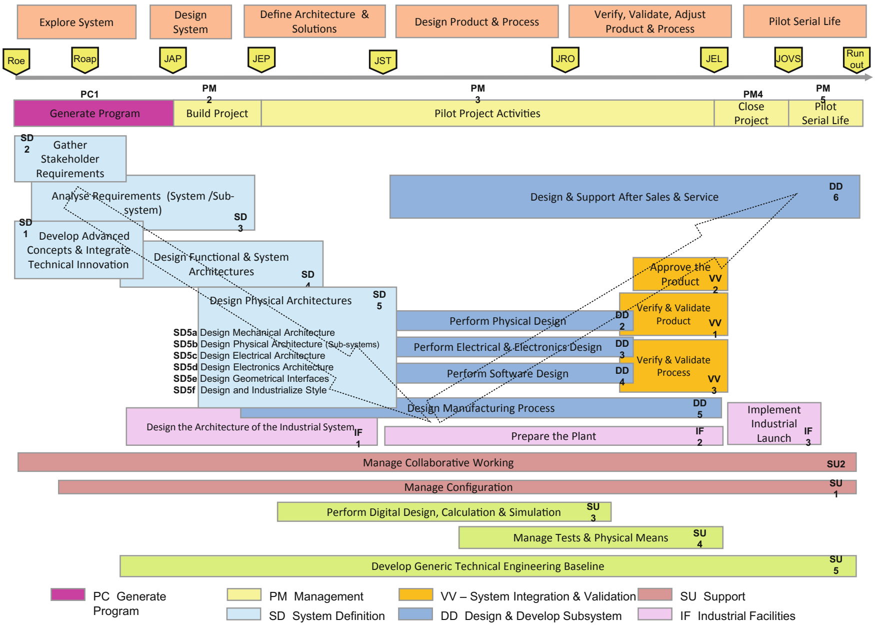


Fig. 4 Scope of COMPANY PLM

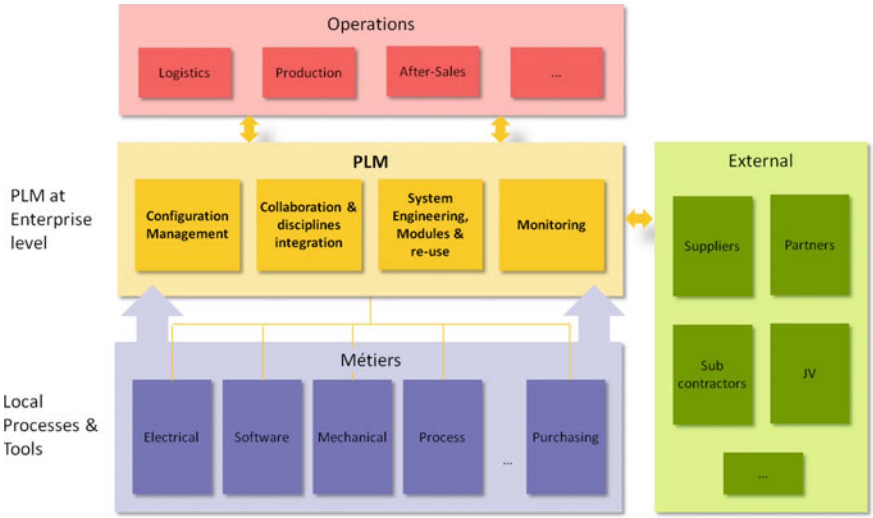


Fig. 5 Global architecture

4.4 The Working Method

The working method for defining and implementing the company's PLM solution respects the principles of LEAN and above all the fact that a project of this type is above all a change project.

This mode of work can be summarised as follows:

- Make an assessment of the existing situation (processes, applications) in order to identify pain points, gaps and breakdowns.
- Based on this assessment, build a "want to be" around processes and deliverables and position the expected gains.
- Formalise the processes and deliverables from "want to be", and build a business model of the data that will be manipulated (what data, what behaviour, and what interactions).
- Based on this redesign of processes and the business data model, start an "application development" activity in Agile mode and by process groups (including the system vendor partner).
- Don't wait until everything is finished to start applying the solution.

In the end, and given the scope of the project, the implementation of COMPANY PLM is progressive (each new development project integrates an ever-increasing number of processes).

4.5 The Results

The results are measured using several Key Performance Indicators:

- Deployment (all new projects started since June 2016 are in PLM) and number of users
- Scope (number of processes included in PLM)
- Stakeholder satisfaction (by survey and comparison with the initial situation)
- Validation of the resolution of the pain points identified during the initial diagnostic phase
- Robustness of the associated deliverables, syntheses and analyses

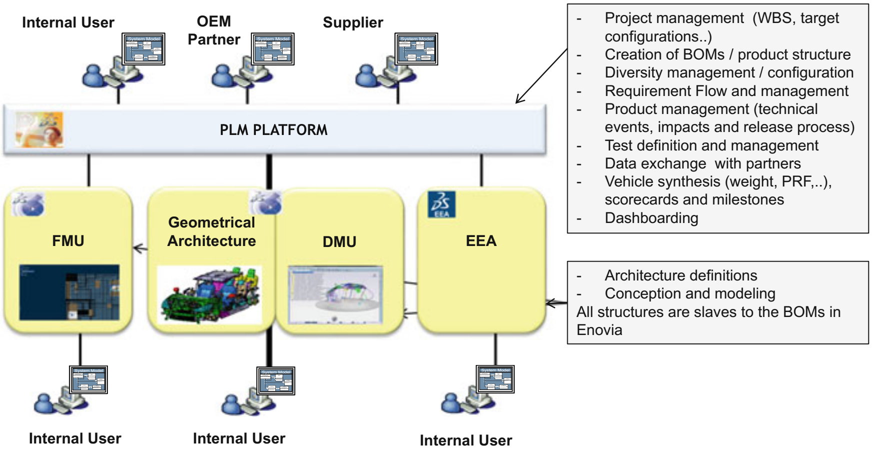
At this stage the available architecture is as follows (Fig. 6).

The architecture is based on OOTB standard solutions. Some further solutions will become available after the R2019x release of the 3D Experience platform.

The architecture covers all product-related processes. An extension is expected in 2019 for process design and simulation.

The global PLM platform integrates, around a unique data model:

– The requirement flow and system engineering following a standard Engineering Structure. The processes and deliverables are organized (in the PLM) respecting



- Project management (WBS, target configurations..)
- Creation of BOMs / product structure
- Diversity management / configuration
- Requirement Flow and management
- Product management (technical events, impacts and release process)
- Test definition and management
- Data exchange with partners
- Vehicle synthesis (weight, PRF,..), scorecards and milestones
- Dashboarding

- Architecture definitions
- Conception and modeling

All structures are slaves to the BOMs in Enovia

Fig. 6 Current architecture

the 9 views method defined by CESAMES and implemented in the OOTB 3DS platform. We are now talking about integrated functional mock-up (FMU).
- A complete change in the way of managing the product based on the BOM definition and no longer on the DMU.
- A deliverable management that includes object life cycles and automates parts release.
- A dedicated service that creates the KPI and carries out the analysis in order to help users in their day by day jobs.

The solution is used by 7000 people (as of October 2018), and has been used on all the projects started by GROUPE PSA since mid-2016.

4.6 Lessons Learned and Recommendations

The first lesson focuses on engagement and complexity. The implementation of PLM is above all a strategic change project. It represents a major expense but above all it leads to a change in behaviour that requires management involvement and training. The implementation of PLM can only succeed if its definition (processes) is clear and shared (understood and requested) by business managers and others working in the product lifecycle.

The second lesson follows from the first.

- Never automate a process before it is defined and shared.
- The implementation of the functional architecture and the integration of requirements management was pre-empted by a change project which had the mission to define the organisation, operating modes and the rules of the game.

The third lesson is the consequence of the first two. Such a project can only succeed if:

- The entire company is convinced of its necessity
- User support and training is managed as a prerequisite
- The “automation” is only carried out when the processes are defined and validated
- The value added to the collective is demonstrated in particular by syntheses, dashboards, traceability and impact analyses available in real time

And, last but not least, this kind of project must be deployed step by step (in coherent packages of processes) without waiting for everything to be defined. Every new project uses more PLM processes than the previous one.

4.7 Next Steps

The COMPANY PLM project plan is being maintained with the objective of integrating as many business processes and deliverables as possible, and using applications based, for example, on artificial intelligence to automate or assist stakeholders in their quest for efficiency.

5 Lessons Learned

Like all major automotive manufacturers, GROUPE PSA has been using digital technologies to improve its performance since their introduction, but has always kept in mind that the purpose is not to have IT tools but to have clear business processes that are supported by good IT tools.

From the early days of CAD to the implementation of the latest software developed by the most advanced software vendors, working methods have been regularly reviewed to improve the effectiveness of development teams.

The Group’s information systems have always been considered an essential part of the organisation and performance of its vital processes in an industry where fierce global competition requires the constant pursuit of collective efficiency or risk disappearing. This is why IT is omnipresent and must itself be at the level of the best, while being economical with all the resources committed.

The implementation of the latest generation of information systems offers a global architecture that is perfectly integrated into the company’s information system. It provides thousands of engineering professionals with information support to coordinate their individual actions by synthesising design systems and devices to manage the composition of the major “dossier” that constitutes the documentation of an automotive project.

This investment effort—because it is one—in the information system and business process efficiency has largely contributed to the very significant reduction in the development time of a new vehicle, which is now almost 104 weeks (2 years), compared to 3 years at the end of the 1990s and 5 years a few decades ago. It also allows the company to integrate such new industrial challenges as complexity management, working in the extended enterprise, and functional modularity.

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Structuring a Lean Engineering Ontology for Managing the Product Lifecycle

Mariangela Lazoi and Manuela Marra

Abstract Many companies refer to PLM considering only the IT side and ignoring the organizational impact. The organizational aspects of PLM can be represented using an ontology providing a support to address issues and actions. Based on these premises an action research was carried out to increase awareness on dimensions and elements characterizing the product lifecycle in the engineering groups. The aim is to easily represent in an ontology the complexity related to the lifecycle of aerospace products, capturing relevant dimensions, relations and impacts for improving manufacturing activities through a reduction of errors, reworks and missed information.

Keywords PLM · Ontology · Processes · IT · Organization

1 Industrial Context: Background and Starting Situation

The context of the research is a large aerospace group made up of several divisions working in different sectors of the aerospace industry. The divisions produce products (such as helicopters, aircraft, aero structures, airborne and space systems) with specific characteristics in terms of IT tools used during design activities and management approaches applied during product development. All divisions are characterized by a very high degree of complexity of both the technology and organizational structure involved. The adoption of PLM is a common practice among all divisions. Some of them manage the lifecycle from only a conceptual point of view while most of the divisions identify PLM with the IT systems supporting the engineering group (PLMS). Complexity in the elements managed and the impact on the processes involved are sometimes underestimated. Problems of the impacts of PLMS arise later when the IT investment has already been made. Furthermore, given the peculiarity of the aerospace supply chain, it often happens that a divi-

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sion has different PLMS for the programmes in which it is involved. Each programme leads, therefore, to a specific way of working in which reviews, IT systems, flows of activities are established by the OEM and by the product type. In this context, however, the company's standard and legacy tools are also used and integrated.

The main aerospace production approach is engineering-to-order (i.e. high technological complexity, high product variety, significant customer participation in product specification, low volume per product, and high involvement of stakeholders) and the product lifecycle is strictly related to the product development programme and customers' orders. Errors, ambiguities or misunderstandings at the design phase can result in substantial costs, which occur during the manufacturing and later stages of the product lifecycle [5].

Consequently, PLM means an integrated management of technological, methodological and strategic issues along the whole product lifecycle. It is important to understand that product data is not created and used only in a specific activity but it is linked to the whole set of data that is created and used during the product lifecycle. Having this awareness, inefficiencies related to waste of time, energy and resources can be avoided. Additionally, the cost of having the right information inside the company is less than the cost of inefficiencies in manufacturing. The understanding of these issues is not immediate. It needs consciousness and knowledge of the impacts and relations among all the elements of the whole product lifecycle.

The need for a harmonized and integrated management of all the PLM managerial issues, that guides this research, emerged in an aerospace group characterized by the simultaneous presence of multiple NPD programmes, the adoption in the different divisions of various PLMS and different PLM practices. This scenario leads to the coexistence of several meanings for the same terms, several different software licences to be managed, as well as difficulties in sharing information between divisions of the same group.

2 The Research Activities

Based on the literature and on the analyzed industrial context, this research activity aims to create a managerial structure that identifies and connects all the functional areas of the engineering groups of the analyzed context to the product lifecycle data, information and processes needed to provide an organization-wide view about product lifecycle management. Consequently, the aim is to represent in an ontology the complexity related to the lifecycle of aerospace products, capturing relevant aspects related to milestones, reviews, organization structure, operative processes and IT resources used. These aspects characterize the managerial landscape of activities, flows of information and tools involved in the product lifecycle. The research activities are addressed through the proposal of an ontology that aims to support managerial activities in order to make "lean" the operations and optimize manufacturing.

The manufacturing phase of a product lifecycle takes in results and practices realized and decided in the early design phases that have important impacts in the manufacturing activities. In the manufacturing phase, the cost of changes is higher than in the preceding phases, this is due to longer time of implementation, shop-floor configuration, involvement of machines, goods and so on. Companies need and ask for product and process design that can produce low (better no) errors and reworks during manufacturing. To reach this result an efficient and effective management of all the complexity of information, steps, systems, structures related to a product lifecycle can have important and positive feedbacks.

Therefore, for attaining the desired results, an action research was carried out through a strict collaboration in an integrated team made up of three University researchers and five company technicians and engineers. The researchers had a management engineering and computer science background that was integrated with the competences of the involved technicians and engineers. The latter were representative of the engineering groups of the company's divisions, they had experience in process management and engineering improvement initiatives.

The team worked to collect, analyze and systematize all the relevant information useful to synthetize and express the managerial aspects of a product lifecycle and to link these with manufacturing impacts that can emerge. The research activities had a duration of 18 months with monthly coordination meetings to share preliminary results and address further actions. Qualitative data were collected using official documents and interviews with product engineers and IT systems leaders. Furthermore, every three months, focus groups with managers and directors were organized. In the focus group, preliminary results were shared and feedbacks were collected about completeness of elements, highlighted linkages and references to be used for expressing the instances for each domain's taxonomy.

Stage by stage an ontology structure was defined with domains, classes and suggestions for taxonomies. The ontology was focalized on lean engineering insights led by process improvements, waste reduction and optimization in all the aspects of product lifecycle management. For these reasons, it was named Lean Engineering Ontology—LEontology. A database containing the complete structures was also built to provide a tool in which all the values of the taxonomy's elements were available, and to better support search of information and relations among concepts.

3 The LEontology Implementation

According to Mostefai and Bouras [10] an ontology acts as a reference and shared vocabulary for a certain application area. According to the authors, it is complex to model, manage and utilize effectively and efficiently all the product knowledge emerging along the lifecycle in an ontology. In this study, this challenge is faced and ontologies are considered as the way to explain a phenomenon and the related context. Considering El Kadiri and Kiritsis [3], ontology is a relative truth of a specific concept and through different entities, attributes and relations, an ontology can be developed to express all the aspects related to the lifecycle management of complex products.

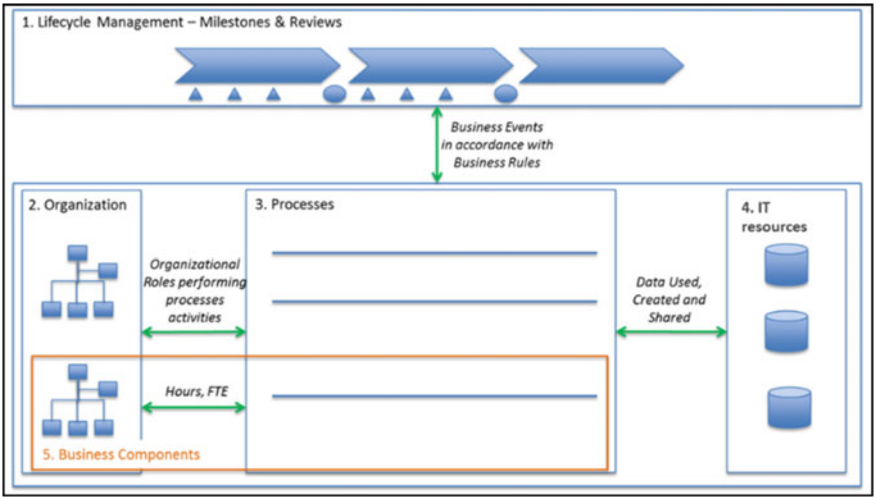

Fig. 1 LEontology's domains and relations

Following the approach suggested by Chungoora and Young [2] to represent product and manufacturing knowledge models, the LEontology is structured in five domains (Fig. 1). These are: (1) "Lifecycle Management" contains information about phases, design reviews and milestones of product programmes; (2) "Organization" is the domain about the organizational roles and related competencies involved during reviews and processes; (3) "Engineering Processes" refers to processes involved for design and manufacturing and to the flow among processes and core activities; (4) "IT resource" has a focus on software solutions used to store, create and share data and information; (5) "Business component" is the last domain with an integrated perspective on organizational and processes aspects enriched by information about costs [i.e. hours, Full Time Equivalent (FTE)].

The proposed domains are linked. The "Lifecycle Management" domain is linked through business events with the "Processes" domain. To allow this relationship, business events need to be in line with defined business rules. Furthermore, the "Organization" domain and the "Processes" domain are related via organizational roles involved in processes and activities. The "IT resources" domain links to the "Processes" domain with the data that can be used, created and shared. Finally, the "Business Components" domain is linked with the "Organization" domain and the "Processes" domain through the use of common information for hours and FTE (Full Time Equivalent) evaluation.

The LEontology is therefore composed by the cited five domains. Each domain has classes and relationships. In each class, there are specific attributes that characterize the domain.

3.1 The Lifecycle Management Domain

The "Lifecycle Management" domain contains information about phases, design reviews and milestones of products in relation to a specific programme. A phase review (PR) is a periodic verification test performed at the end of each phase to attest that the planned objectives/results are satisfied. Actions are established to overcome specific issues and to guarantee the satisfaction of requirements. Milestones (M) are defined moments inside a phase that can report about one or more design reviews carried out in the same time period. Milestones are usually grouped for specific topics (e.g., contract, system, development milestones) and are distributed along the time flow of the lifecycle phases. The Design Reviews (DR) are carried out to verify and validate partial or final results of defined activities on a product. This domain has five classes. "Lifecycle" where information about the programme and related order is available, this class is the link with the product. "Phase" has attributes to identify each phase of a lifecycle. "Phase Review" provides information for the review of a defined phase. "Design Review" is used to collect information on this kind of review and it is directly linked with the last class of this domain. Finally, "Milestone" that highlights the milestone's features.

3.2 The Organization Domain

Each company has its organizational structure and often, in the case of large companies and corporations, each unit has its own specific organization. The organizational structure is usually the result of company/unit history and of experience and managerial preference. In literature, a unique reference standard doesn't exist for organizational structure. In the same way, in the industrial context, several organizational structures are available for different engineering units. Consequently, the first step of the analysis of this domain was the observation of the organizational company's charts and the linked coordination mechanisms for highlighting similarities and differences among the structures. The Organization Domain has, as classes, "Organizational Role" to describe the main roles involved during the lifecycle and "Competency" and "Competency Type" to characterize the competencies required in the roles and activities. Based on Fortunato et al. [4], "Competency Type" can be of three typologies: *Method* represents procedures, company policies, methodological standards, implementing rules and calculation methods applied in an activity; *Technology* is the tool or technological knowledge used for the activity; *Product* refers to the physical characteristics (size, shape, etc.) and the complexity (detail or assembly) of the realized object.

3.3 The Processes Domain

Processes is a large context in which differences in lexicon and in the lower level decomposition are very common. For the Processes Domain, activities are considered as the basis elements that can be combined and re-used in several processes. Furthermore, processes are not disconnected: a set of processes generates input and therefore, one precedes another; a set of processes is launched as a consequence to consume output that has been generated. The network of processes is the neural connections of the company/units working. Understanding them makes it possible to develop knowledge for taking actions in the right place. Activities are also the element of connection between the Processes domain and the Business Component domain.

In the Process Domain there are: “Business Event”, “Activity”, “Process” and “Relationship Process”. The “Business Event” class is the core of the LEontology to enable the shift between the different views, it is the bridge between the Lifecycle Management Domain and the Process Domain. “Activity” is another relevant class, it contains several information about activities and has many linkages with the other classes. “Process” identifies the processes executed and allows to group activities. “Relationship Process” is the class which specifies linkages with the previous and next processes.

3.4 The IT Resources Domain

The IT Resource Domain ontology is a classification of IT systems to support engineering processes through a consolidated management across different organizational units. The ontology is focused on the business activities that a specific IT resource can solve and support. For its development, the IT resources are classified in three areas: knowledge, information and data processed [8]. The data area consists of CAx systems used to create and modify most of the data generated and generated during the lifecycle of the product. The information area consists of the technologies that allow managing both product and processes information (e.g., BOM and Configuration Management, Digital Mockup, Simulation Process Management, Requirement Management, Material Management, Manufacturing Process Management, Content and Document Management, etc.). Finally, the knowledge area (Dashboard and Analytics Systems) consists of technologies that deal with processing the information (knowledge) to have a complete and updated vision of all the systems involved; dashboarding systems and engineering analytics tools make it possible to aggregate data and synthesize information to support strategic decision making.

The IT resource Domain has two main classes: “IT resource” which identifies the software used and “Category IT resource” which classifies the software based on data, information and knowledge management.

3.5 The Business Components Domain

The Business Component Domain is based on CBM (Component Business Model), a framework developed by IBM [6] to model and analyse an enterprise through a logical representation or map of business components or 'building blocks'. CBM supports a set of strategic operations which can be accomplished through a pure process-based approach. Each component usually has five dimensions: business purpose, activities, resources, governance and business services. For the aim of this ontology domain, only activities and resources are considered.

This Domain is composed of a single class: "Business Component" where the components are named and linked to activities and roles.

3.6 LEontology Structure

In Table 1 and Fig. 2, the whole structure is represented to provide an integrated view of the LEontology. Domains are linked and integrated through direct relationships between classes.

4 The Results: Implication, Benefits and Extension

4.1 Managerial Implications

The proposed LEontology provides a clear and integrated way to map all elements related to a company's PLM including the product lifecycle reviews and stages, the organizational roles involved, the processes executed during the lifecycle of a product and the IT systems used. This represents a useful knowledge asset for a company that can be used for several activities: documentation, diffusion of a PLM culture and a shared meaning of PLM related terms, company cross-analysis and re-organizational initiatives, licence costs rationalization, etc.

Documentation is the most immediate use of the LEontology. Allowing sharing structured information in the whole company and with company's stakeholders, it can be used to inform employees about a PLM culture. An employee's task is a small part of a wider set of activities that affect the product lifecycle performance and its impact is usually unknown. Best practices and lacks could be observed in the tasks executed for similar process and in the use of IT systems. The sharing of unambiguous meanings to terms assigned to PLM elements (e.g., design review names) creates a group's PLM awareness, necessary for cross-analysis (inter-/intra-division), for improving IT management and collaboration. Using the ontology, it is possible to have a PLM reference guide shared among different divisions that, at the moment, doesn't exist. Furthermore, creating instances of the LEontology, the

Table 1 LEontology domains, classes and attributes

Domains	Classes	Attributes
Lifecycle	Lifecycle	– Lifecycle name – Lifecycle description – Program reference – Reference order
	Phase	– Phase name – Phase description – Elapsed time – Scope phase
	Phase review	– Phase review name – Phase review description – Deadline phase review
	Design review	– Design review name – Design review description
	Milestone	– Milestone name – Milestone description
Organization	Organizational role	– Organizational role name – Organizational role description – Organizational role type
	Competency	– Competency name – Competency description
	Competency type	– Competency type – Competency type description
Process	Business event	– Business event name – Business event description
	Activity	– Activity name – Activity description – Activity type – Used data – Created data – Resources number
	Process	– Process name – Process description
	Relationship process	This only contains the relationships among the identification numbers of the "process" class (i.e. id_process, id_previous process, id_next process)
IT resource	IT resource	– Software name – Software description – Software version
	Category IT resource	– Category software name – Category software description
Business component	Business component	– Business component name – Business component description

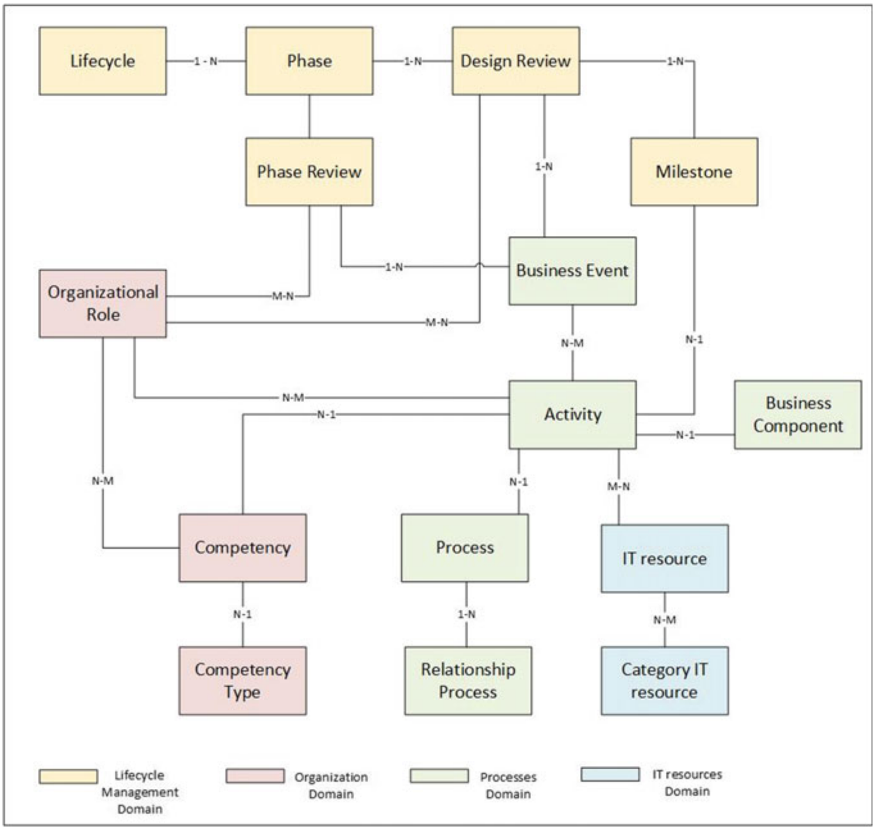

Fig. 2 LEontology structure

aerospace companies could monitor, scout and decide looking to the same reference model in the PLM field. This can be useful in particular during re-organization initiatives or in the proposal of corporate policies.

The LEontology, structuring relevant PLM dimensions and their relations and impacts in the organizations and in the product and processes engineering groups, enables improvement of manufacturing activities through a reduction of errors, reworks and missed information. Aiming to optimize processes and reduce errors offering an integrated view on the engineering processes, the LEontology can enable operative mechanisms to improve the design of products with relevant impacts on manufacturing. A better knowledge of engineering processes, a wide understanding of the different roles involved in an organization, an analysis of the IT systems used to reduce overlap and duplication of information have positive impacts on the product design.

4.2 State of Arts Relations

The ontology presented in this paper is original because it is more focused on managerial issues when compared to the others available in the literature on PLM. It overcomes a lack of completeness [3] since the whole lifecycle related information is covered. A missing contribution and direct linkage with product structure is evident, but it is overlap through the focus on lifecycle phases and activities that makes it possible to also address product issues through a direct reference to programme and order. Phase, Business Event and Activity classes are in common with the work proposed by Matsokis and Kiritsis [9], even if they are used for a different scope (i.e. to integrate data from different systems) and also the linkage in the overall ontology is different. Considering also the ontology proposed by Lee and Shu [7], where a layer of product manufacturing model is available for describing the knowledge of the physical items that are manufactured, this research activity enriches this state of art including organizational aspects. Furthermore, even if the study of Sanya and Shebab [11]) has a different focus of the ontology treated in this paper, in both cases a reference ontology for aerospace engineering activities enables the creation of a knowledge base with a multidisciplinary value.

In addition, based on the role of ontologies suggested by El Kadiri and Kiritsis [3], the LEontology plays three relevant roles for PLM: *trusted source of knowledge* since concepts, properties and relationships are provided; *database* because creation, storage and sharing of the ontology data are enabled by the web tool that supports also instantiation; *knowledge base* from the rules and relationships among classes it is possible to make inferences and have a complete picture about the context.

Finally, as observed also in Borsato et al. [1] and Sanya and Shebab [11], the need of standardization in the meaning of terms used inside a company is an important issue to be addressed. In the LEontology, it is achieved with a top down approach carrying out a first stage of analysis in literature or in the industrial context, based on the domain, of the terminology that is latter discussed and agreed in a focus group.

5 Lessons Learned and Future Research

Based on the needs of an aerospace company in terms of improving engineering activities and harmonizing the information and elements involved, the paper describes the development of a Lean Engineering Ontology for improving the management of product lifecycle issues. Five domains are defined: Lifecycle Management, Organization, Processes, IT resource and Business Component. The domains are composed of classes and links among classes for enabling a complete integration of the whole knowledge managed in the ontology. The LEontology is created by the collaboration among representatives of different divisions of a large aerospace group and academia, guarantying solid fundamentals linked to industrial practice.

The proposed ontology is general and of immediate application. Time and complexity of application depends on the availability of information inside the division and on their collection and analysis. Furthermore, processes involved in the lifecycle are core for the ontology and their representation and systematization could be used also for other activities of documentation or analysis inside the companies.

A main limit of the LEontology is the lack of a direct link with the product structure. This lack is a conscious decision of the authors. It is motivated by the need to strength the role of the product lifecycle related to the programme more than by the physical structure. The LEontology aims to be an ontology supporting managerial activities.

Future research will collect all the instances for each entity using different case studies. In this way the information for each domain will be used for the development of specific instances for a given company context.

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Alfa Laval's OnePLM

Björn Wilhelmsson

Abstract This case study looks at the benefits and lessons learned resulting from Alfa Laval's OnePLM program. Alfa Laval AB is a €3.6B provider of products and solutions based on its three key technologies of heat transfer, separation and fluid handling. The drivers for OnePLM go back to 2012, when a "pain point hunt" identified some 300–400 pain points related to product data management. Company management understood the problems were impacting the business, and the OnePLM program was launched. By 2018, OnePLM had been rolled out in 3 of Alfa Laval's Business Units. Benefits have been achieved in many areas, including a rationalisation of the product portfolio, better insight of customer needs, and introduction of standardised business processes. A key benefit of the approach taken in OnePLM is that it has enabled a practically self-financing PLM program. Among the lessons learned have been the importance of: top management commitment; key stakeholder involvement; change management; focusing first on information; and having the right implementation team and partners.

Keywords PLM program · Product architecture · Product portfolio management · Lessons Learned · Configure to order

1 Company Background

Alfa Laval AB is a leading global provider of specialised products and engineering solutions based on its three key technologies of heat transfer, separation and fluid handling. Alfa Laval's heat exchangers transfer heat from, for example, one liquid to another. Separation technology is used to separate liquids from other liquids, and to separate solid particles from liquids or gases. The Separation offering includes separators, decanter centrifuges, filters, strainers and membranes. The fluid handling offering includes pumps, valves, and tank cleaning equipment.

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Alfa Laval serves customers in many industries, including: food and beverage; chemical and petrochemical; pharmaceutical; marine and diesel; machinery; mining; and wastewater treatment. Alfa Laval's business is divided into three Business Divisions: "Energy"; "Food and Water"; and "Marine" that sell to external customers, and one division, "Operations" covering procurement, production and logistics.

The Business Divisions (BDs) are split into a total of twelve Business Units (BUs). Each Business Unit is very much oriented towards one, or a few, core products.

Three different internal operating models meet the different needs of customers. The "Standard" model applies to the sale of standardised components through channels and online. This model is for products and spare parts which are 100% predefined and can be purchased with a single item number in, for example, a web shop. "Configure-To-Order" (CTO) applies to standardised components with standard configuration formats for adaptation to specific applications, capacities, etc. This model has been applied successfully for several decades. The "Engineer-To-Order" (ETO) model is for customised systems and solutions for customers with specific, order-unique requirements. This approach has grown substantially in recent years due to many relatively recent acquisitions.

Alfa Laval invests about 2.5% of its sales in research and development launching between 35 and 40 new products every year.

Alfa Laval has over 300 products in its three major product lines. Many of these have thousands of variants, resulting in several million unique part numbers.

The aftermarket is a significant part of the company's business. Alfa Laval's products have a long service life, which leads to a large installed base that—to varying degrees and with varying frequency—requires both spare parts and service. Alfa Laval has thousands of products installed throughout the world. As a part of service contracts, it maintains an inventory of spares to support these products, some of which have hundreds of spare parts, for up to 40 years.

In 2017, Alfa Laval had annual sales of about 3.6 billion Euros. The company had 29 production sites worldwide, and about 16,400 employees, most of whom were in Sweden, Denmark, India, China, the US and France.

2 OnePLM: The Starting Situation

The drivers for OnePLM go back to 2012, although the OnePLM program itself wasn't launched until 2014. In 2012, business processes weren't standardised, each Business Unit having its own set of loosely defined processes. R&D and Operations often worked together cross-functionally, but Service/Aftermarket didn't. There weren't enterprise standards for some important concepts and terms such as lifecycle states. There wasn't a central repository for parts and products. Much of the product information management was handled in a combination of Excel and ERP. Only two BUs used a Product Data Management (PDM) system. There wasn't a common ERP system. There wasn't a common CAD system.

The launch of an eBusiness solution in 2011 highlighted that there was a lot of incomplete and incorrect product data in the company. In response, a "pain point hunt" was launched. It identified some 300–400 pain points around the company, all related to product data management in one way or another. These included: low product data quality; a lack of engineering change control; unclear ownership of product data; product configurators that weren't easy to use; finding reliable data was often time-consuming; insufficient Master Data Management; no proper product portfolio management, for instance, no phase-out culture; the roles and responsibilities of BUs and Operations weren't clear and defined; and customer complaints about late deliveries and incorrect information.

The root causes were identified. Among them were: unclear governance of data; local approaches to global problems; multiple and manual entry of data into a multitude of systems; poorly-defined product models that were often inflexible and designed to meet R&D and Production needs, but not those of Sales and Service. Many activities were very dependent on the knowledge of particular individuals.

Company management understood that the problems were impacting the business. In 2014, they launched the OnePLM program with clear instructions to strive for one solution for the entire company, hence OnePLM.

PLM was defined as the process of managing the entire lifecycle of a product from its conception, through design and manufacture, to service and disposal. Product information was seen as vital: throughout the value chain; throughout the product lifecycle.

The objectives of OnePLM are to: provide high quality product information for products and spare parts; accelerate response to customers and changing markets using modularised products; reduce waste in core business processes; and provide a platform for digital descriptions of products, production processes and equipment.

Soon after the program was launched, the enormous assortment (product offering) in Alfa Laval was highlighted. This results from on-going innovation, acquisitions and meeting customer requirements. However, a large part of it appeared to be dormant—and incurring significant costs. In response, management added a fifth objective for OnePLM, "Drive professional assortment control". They also set "assortment wash-out" as a pre-requisite for a BU to join the OnePLM program.

The scope of OnePLM was defined as the processes, standards and tools for the creation, maintenance and distribution of product information during the entire product lifecycle. The scope included a common modular product architecture and a standard product information model. The product architecture addresses products, modules, module variants, module sets, parts, etc. The product information model includes BOMs, CAD models, technical documents, material standard documents, engineering configuration rules, etc. The processes in the scope of OnePLM include New Product Development (NPD), Engineering Change, Design to Order (DTO); Document review and approval; and Assortment Control. The tools include Configurators, CAD, PDM, Business Intelligence, and manufacturing ERP systems.

3 The Approach

The OnePLM program has a full-time Core Team and part-time representatives from Business Units. In addition to the Program Director, the Core Team includes PLM Business Analysts and Architects, an Information Manager, a PLM Solution Owner, a PLM Solution Architect, and an Organisational Change Management (OCM) Lead.

The OnePLM program reports to Alfa Laval Group Management, and is sponsored by the Chief Financial Officer (CFO).

OnePLM works in three streams: Development; Roll-Out; and Production as illustrated in Fig. 1. All are based on a common “OnePLM template”. A new version of this package is released every four months. It contains: standards and definitions for product and product information architecture and objects; support for business processes; the latest versions of the tools; and support for these tools. The template contains many PLM capabilities, not only the basic ones such as parts and BOM management, but also document and content management. The template will continue to grow with more PLM capabilities in the future.

OnePLM is rolled out on a Business Unit by Business Unit basis, starting with BU Gasketed Plate Heat Exchangers, BU Hygienic Fluid Handling, and BU Decanter.

During roll-out to a particular BU, implementation of the basic PLM capabilities is mandatory, but add-ons such as document management are voluntary.

The Core Team’s role in roll-out includes: ensuring that the solution is fit for the BU’s business; guiding the BU through the rollout of OnePLM; leading the change management effort in the BU; providing training; and cleansing and enhancing product data (Fig. 2).

One of the main responsibilities of the BU representatives in the program is to adapt products to the new standard Product Architecture. The BU representatives also perform massive data cleansing and enhancement to ensure high quality data from

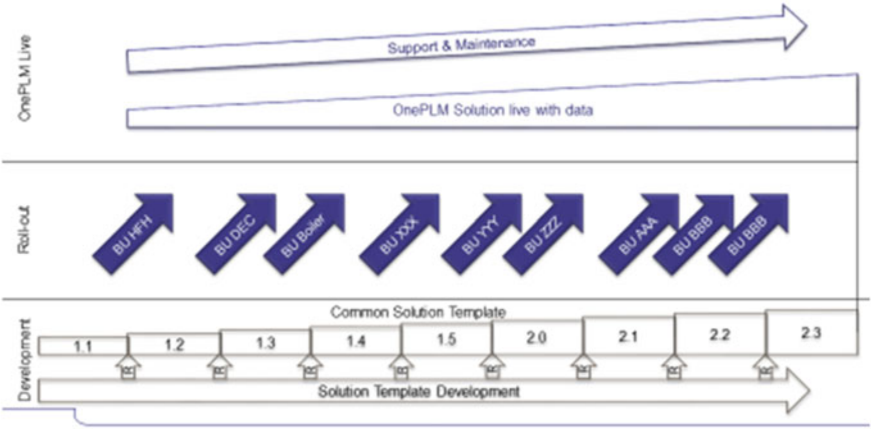


Fig. 1 The three streams of OnePLM: development, roll-out and production (OnePLM live)

Alfa Laval common Processes, Standards and Tools for creation, maintenance and distribution of product information during the entire product lifecycle

Guides the Business Unit through the rollout of OnePLM to ensure a smooth transition and rapid return of investment

Fig. 2 The core team has one mission and set of deliverables for development, left, and another mission and set of deliverables for roll-out, right

Day 1. They also, supported by the Core Team, drive the BU change management activities.

4 The Implementation

The first development of the OnePLM template addressed the CTO area. From the beginning it had been clear that a modular Product Architecture (PA) would have to be defined. And that it should be common across the different CTO product groups in the company. It took close to 18 months and two failed attempts to develop the PA concept. However, the third attempt succeeded, showing that the PA actually worked on 4 completely different products.

The PA is the common language in Alfa Laval's Digital Trinity, so it must be kept very clear and clean, otherwise automation of CTO business would be very difficult if not impossible. The common Product Architecture is at the heart of the Digital Trinity which is made up of: a Configurator (single source for producible product configurations); OnePLM (common product information standards, processes and tools); and standardised supply chain tools and processes, as illustrated in Fig. 3. The Trinity includes or interfaces to other capabilities: Configurator interfaces to Customer Relationship Management (CRM) and Sales ERP systems; OnePLM includes an Engineering configurator, CAD and PDM; supply chain tools interface to supplier and Manufacturing ERP systems.

Another activity has been the implementation and management of the PA from a Master Data Management (MDM) perspective.

In parallel to defining the PA, the necessary standards for the objects making up the PA, such as modules, module variants and parts were defined. Lifecycle states were standardised. From the beginning, an information-centric approach was taken. It has been maintained, tools must come later.

A third parallel activity was definition of standardised business processes, such as the Engineering Change process. It had been thought that alignment of many BUs, each with its own way of working, would be tough. However, a combination

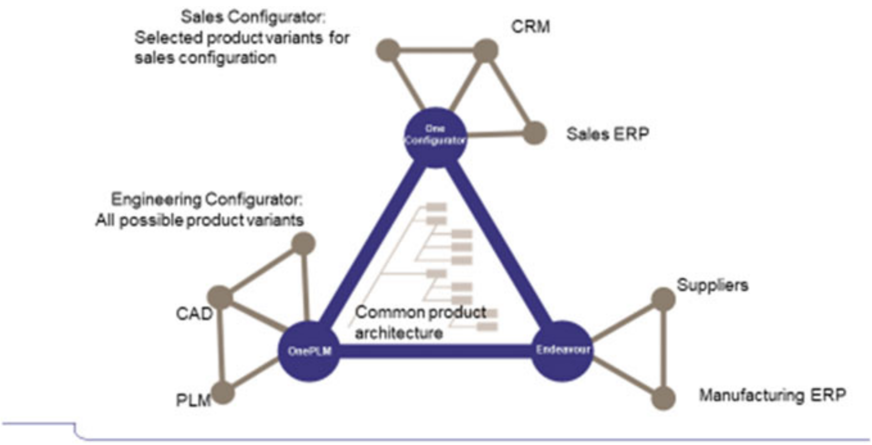


Fig. 3 The "digital trinity" with the modular and standardised product architecture in its very centre

of many common pain points, a common and accepted PA, and a clear vision of how CTO should work in the future made this work quite smooth in the end. In addition, processes were developed for Wash-Out and Annual Assortment Review.

Another activity was to take fundamental decisions about "what will be done where" from a system point of view. One such example was where to manage variation. The candidates were the configurator, the PDM system and the various ERP systems. In the end, the decision fell on the configurator. The PDM system is "just" a repository of objects, having no logic as to what goes into which BOM or product. Another fundamental decision that was made was to manage eBOMs in the PDM system, and mBOMs in the ERP systems. (However, in 2018 a pilot was started with the mBOM also managed in the PDM system.)

5 The Result, Benefits

The pre-requisite of performing an assortment wash-out has resulted in a number of benefits and customer insights, both expected and unexpected.

Analysis of data for one product group showed 15% of product variants and 48% of spares hadn't been sold for more than 15 years but were still being maintained. Furthermore, that data revealed that 96% of all orders used only 50% of the available variants. Similar patterns were found for other product groups. This is graphically illustrated in Fig. 4.

Using the reports that the analysis tool provided, Product Managers decided to reduce the number of variants for new sales by some 20% and the number of parts, many of them, but far from all, almost dormant, by over 60%. These reductions led to significant cost savings by not having to maintain them with prices, costs, operations,

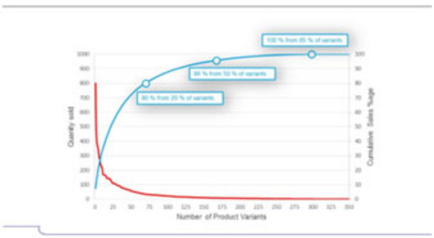
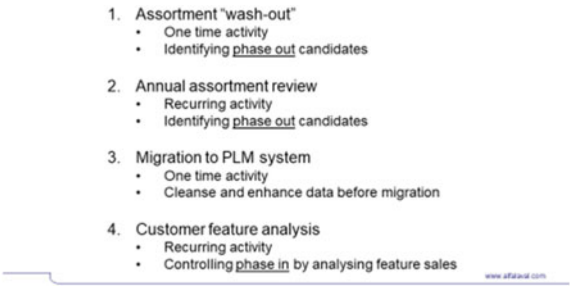


Fig. 4 Graphs for product group "A" showing number of sold product variants, left, and number of sold spare parts, right. Note the very long tails

Fig. 5 Four different use cases for the assortment analysis tool



1. Assortment "wash-out"
   - One time activity
   - Identifying phase out candidates
2. Annual assortment review
   - Recurring activity
   - Identifying phase out candidates
3. Migration to PLM system
   - One time activity
   - Cleanse and enhance data before migration
4. Customer feature analysis
   - Recurring activity
   - Controlling phase in by analysing feature sales

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suppliers, compliance and so on. This is the first use case of the analysis tool, called assortment "wash-out", in Fig. 5.

To ensure that focus is not lost on product portfolio management/assortment, Group Management also decided that the efforts need to be sustainable. Consequently, there's now a standardised, mandatory process for annual assortment review and phase-out, which is use case number 2 in Fig. 5.

A positive side effect of the wash-out is that the number of parts to be "dressed up" (cleansed and enhanced) to the new OnePLM standard was significantly reduced. This is use case 3 in Fig. 5. This provided an opportunity to increase the ambition for quality of the migrated data. In the design phase of the analysis tool, a lot of time was spent to get a better understanding of data structures in the legacy systems, and this makes the subsequent data migration to OnePLM easier.

Another very useful aspect of the analysed data is the customer insights that help to better specify new products. This is use case 4 in Fig. 5. By analysing which customer features have sold and which have not sold, it is now possible to better scope the desired buyable features in the CTO business in order to reduce time to market and streamline the supply chains. Some features that were previously offered as CTO for older products will now be available only as Design to Order (DTO).

Understanding the true nature of the product assortment and performing the massive wash-outs have enabled a self-financing PLM program.

Many of the “classical” PLM benefits are also visible, but as the starting point or baseline was not quantified (as a result of not having to provide a traditional business case), these benefits are more difficult to measure.

Key benefits include: a common language to define products; single data entry; consistent data quality; better and faster search for information; improved business processes which now have clear roles and responsibilities. The involved IT systems “talk to each other” and are becoming the digital backbone for connectivity. The analysis tool helps to optimise the product assortment. The modularisation inherent in the PA means more product variants with fewer components; better product differentiation; and faster time to market for new variants. Furthermore, OnePLM allows full control of releases to sales and the supply chain so that product launches can be optimised. This all leads to: more re-use of designs; better decision-taking; more efficient compliance; and more time for value added work.

6 Next Steps

At the end of 2018, OnePLM had been rolled out in 3 BUs, and many more BUs were interested in taking the entire OnePLM offering.

In parallel to the rollouts to the BUs, new capabilities were built and added to the common solution template. In 2019, capabilities for more efficient spare part management will be added in order to support that very important business. Other plans are to create capabilities for external compliance requirements in general, with a particular focus on export control. Many compliance requirements need more stringent substance management in order to be able to roll up the chemical composition of a complete product from its constituent parts.

Approaching roll-out for the next BU, there’s a need to move towards “Engineer-To-Order” (ETO). The first steps are taken by a hybrid between CTO and ETO called DTO (Design-To-Order). This process can be applied to CTO products using the new Product Architecture. Just like the CTO process, the DTO process starts in the configurator. It applies when the customer cannot find there exactly what is needed. A “best-fit” configuration is made with a free-text remark about the true need. This “best-fit” is the starting point for the DTO design engineer, who then designs whatever needs to be designed, and either replaces something or adds to the “best fit” BOM which then becomes the true BOM for that particular order.

Another concept about to be launched is the creation of parts, part BOMs and 3D assemblies “on the fly”, i.e. in the order process. Instead of the historical CTO approach which dictates creation of all variants (parts and part BOMs) before a product is released for sale, the new approach will only require creation up-front of the variants that are sure to be sold. Thanks to design automation and an automated order flow, OnePLM will create the needed parts, part BOMs and 3D models “on the fly”. This activity will be governed by the engineering rules that have been pre-defined for that particular product class. With this approach, there will be no creation of “waste” variants that are never sold, and each variant will have at least one customer. By tracking which variants are created "on the fly", it is hoped to be able to identify very early some market trends that otherwise would be difficult to detect before everyone else also sees them.

A sister program to OnePLM has started to look at how Industry 4.0 can be applied at Alfa Laval in order to help the business as well as the customers of the equipment. It's still early days, but it's clear that OnePLM will be the backbone for digital twins not only of the products, but also of the manufacturing processes and equipment.

7 Lessons Learned

The OnePLM program team has identified a few "key success factors" for PLM.

Top Management commitment is essential. The pain points and their consequences were explained to the CEO and Group Management. They gave their approval to proceed. The CFO has been the Program Sponsor since its launch and that has been a major success factor as that role is "neutral" to the different stakeholders in the PLM context.

Another key success factor is Change Management. For most people who are "hit" by PLM, it means a new way of working. Often, a bit of the flexibility which many enjoyed in the past is lost, something that is perceived as negative by some people. Some roles, for instance in R&D, are expected to provide more information than in the past, not for their own benefit, but for the benefit of downstream data consumers. That is often a hard sell for which the support of first and second line management is absolutely key. The OnePLM program has worked consistently with a large change management toolbox, including a psychometric tool for assessing change readiness.

The approach to justification of the OnePLM program has been to focus on the pain points in the business, not on the monetary benefits. It has been found that, by focusing on the pain points, which nobody can deny, it is far easier to get the attention of the key stakeholders as opposed to building a traditional business case which can easily be shot down. It was found that calculating the precise expected monetary benefits was an impossible task. The "reduce waste" aspect can perhaps be answered, although with great uncertainty, but the "impact for customers" aspect is impossible to trace back to PLM efforts. It is a matter of faith and belief in the cause!

The OnePLM approach has been to focus first on the information, and above all, the information that needs to be exchanged in the business processes. It was known from the start that, to automate the processes, the information that was sent needed to be 100% consistent across the system landscape. The common PA is the very foundation upon which first the processes were built and, eventually, the IT systems participating in the business processes. One eye has been kept on the Master Data Management aspects of information management, in order to avoid duplicating or creating redundant data.

It’s been important to take a holistic view for OnePLM. The program has included work on improving business processes, product information, and information systems, even on improving the way some products are modularised. A very positive side effect of the latter is that the BUs in question are now able to offer a larger variation than before to the market without having to develop new parts.

It’s been important to have a strong Core Team and to keep it stable over the long term. The core team is relatively small and consists of people with both business and IT backgrounds and, in many cases, also many years of experience within Alfa Laval. The core team is firmly anchored in the business organisation and operates as a proxy for the entire business when it comes to functional requirements for the IT solutions. Effectively, the core team has its own IT department, which is run using agile methods, so the time from decision until having something in the systems is usually very short.

Another key success factor is having the right IT implementation partners. This wasn’t easy, it took three attempts to get it right. Naturally, the partner has to be very knowledgeable about the chosen IT systems, but that’s not enough. They must also have a structured approach for knowledge transfer between their clients (as well as between their own employees, on-site as well as off-shore), a continuous training program for their employees, an ability to scale up and scale down when needed, and general business acumen.

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Applying Product Usage Information to Optimise the Product Lifecycle in the Clothing and Textiles Industry

Karl Hribernik, Dena Arabsolgar, Alessandro Canepa and Klaus-Dieter Thoben

Abstract The clothing and textiles industry is facing intense challenges regarding shorter product lifecycles and increasing customer demands. The market expects new collection proposals up to every 15 days now instead of twice a year previously. The frequency of new collection design is especially demanding for small companies in the sector, who are under pressure to accelerate their design process whilst at the same time more precisely target customer groups to avoid unsold garments and returns. They also need to more efficiently manage their product lifecycles and supply chains to keep up with the higher speed of collection development. By gathering and analysing Product Usage Information (PUI) from customers, influencers and other stakeholders in the clothing and textiles product lifecycle, these companies can get quicker and better insights into fashion trends, customer expectations and market parameters. Precise knowledge about, for example, what colours, materials, styles and fittings are in demand can help companies develop new collections to more precisely meet market demands. In addition, sharing that information throughout their supply chain in a collaborative way can help accelerate processes throughout the lifecycle and contribute to overcoming the new market challenges. This article presents a use case from the Italian clothing and textiles company Dena Milano in which different sources of PUI were investigated to support the design of new collections and to update existing ones which better fit the expectations of the market, increase sales, and reduce the need for prototypes and the amount of unsold garments. It describes the development, trial and evaluation of a collaborative IT platform which collects, aggregates, analyses and visualises PUI to improve the target processes. Among the

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sources of PUI investigated in the use case are social media, company documents and databases, and different types of customer feedback. A novel approach to extracting fitting information from images was also developed as a part of the platform, as was a collaborative tool for idea management which involves stakeholders throughout the collection lifecycle in a collaborative open innovation process. The article begins with an introduction to the use of product usage information in the product lifecycle, and the background to its potential benefits in the clothing and textiles industry. The research approach and the activities carried out are subsequently described. This includes a detailed look at the PUI selected in the use case. The next section describes the architecture of the developed IT platform, with a focus on the tools designed to extract fitting information and collaboratively managing ideas. A section outlining the application of the IT platform in the use case follows. The next section presents the evaluation of the application of the IT platform from the point of view of Dena Milano. Sections describing the achieved benefits and an outlook to future work conclude the article.

1 Introduction

Manufacturing companies are today confronted with increasingly global and dynamic markets and are consequently driven to reshape their strategies to meet the challenges of the 21st Century towards competitiveness, productivity and sustainability. Shorter product lifecycles, ever more demanding customer requirements especially towards product quality, sustainability, environmental impact and consumer health as well as the necessity to establish new streams of revenue via the servitization of physical products are just some examples of the challenges industry faces in today's market.

Product Usage Information (PUI) is a valuable asset which can help companies tackle these challenges. It can give companies insights into how their products are used and can be mined to understand how to better design and manufacture products, as well as to offer services designed to meet their customers' real current needs.

PUI is information which is generated when a product is in use. Usage is the primary process of the middle-of-life (MOL) of the product lifecycle according to [1]. The same authors also locate service and repair processes in MOL. This is shown in Fig. 1, with the MOL and its major processes highlighted. A definition of PUI can thus be narrowed down to information about a product generated in the MOL phase of the its lifecycle.

In a wider vision the product marketing lifecycle can also be considered which is related, for example, to a clothing new product style definition and design development (BOL), production and sale season (MOL), decision to represent it or not for the next corresponding season (EOL). This second level of analysis is particularly significant for all design-based domains and becomes critical when the rate of renovation of style is very frequent.

Fig. 1 The product lifecycle with MOL highlighted

PUI is available from three distinct channels: (1) conventional sources, (2) digitalised products, which make use of the Internet of Things, and (3) Internet sources, including social media, e-commerce and other platforms. Conventional PUI such as CRM systems, helpdesk or maintenance protocols give insight into customers' interactions with the manufacturer or service provider, and document processes such as repairs or service. Digitalised products can provide quantitative information via embedded sensors about usage behaviour patterns, contexts and parameters. Social media can provide information about customers' experiences, problems and wishes with regards to the products and services they use. By analysing PUI from combinations of these channels, companies can get a more complete picture of their products' and services' MOL, which can help improve processes in other lifecycle phases such as product design.

Challenges regarding shorter product lifecycles and increasing customer demands are especially intense in the clothing and textiles industry. Here, the entire collection of a specific season is considered the product and the object of marketing lifecycle analysis. Collections are subject to frequent design renovations: in the past, a new collection was required every six months (Fall/Winter and Spring/Summer seasons), but following the success of Zara a change of proposals might be reduced even to 15 days [2], with an extremely fast substitution of design and colours. Another example is the Moncler's Genius [3] project, where new design collections are presented almost every month, each one with a focus and target usage domain in popup shops sold for a very limited period, to create "event" expectations in customers and to reduce leftovers and discounted sales. Moreover, the market expects new collection proposals to closely follow new fashion requirements and even external conditions (weather, ultimate catwalks, fashion bloggers' proposals, etc.). The traditional business model of sale, with a full price season followed by discounts for leftover clearances, is substituted by a continuous proposal of small quantities of new items which are offered simultaneously in shops and e-commerce (sharing the same inventory in an omnichannel synergy) which sell out very quickly. If properly managed this strategy both satisfies the market's need for novelty and sustains the margins. However, the traditional production chain process of 20 months from collection design to delivery is no longer appropriate for these new market conditions.

This means that information to design new collections needs to be collected very quickly, directly from both existing and potential customers, and efficiently shared back into the supply chain to optimise timing and adapt to the fluctuating demands of the market. PUI in this sector comprises details about expected and effective sales, together with feedback from customers. Since this is subject to frequent changes, the supply chain needs to be set up to react accordingly, so that questions about how best to gather PUI, analyse it appropriately and share it with stakeholders throughout the product lifecycle are critical research issues.

To better address these challenges, the Italian clothing and textiles company Dena Milano designed a use case to investigate how PUI can contribute to optimise and accelerate their ideation, design, production and distribution processes. The aim was to use PUI to support the design of new collections and to update existing ones which better fit the expectations of the market, to increase sales, and to reduce the need for prototypes and the amount of unsold garments. To achieve this, Dena Milano needed to improve the frequency, amount and quality of information it received from both existing and potential customers. Research in the use case was directed towards improving (1) the collection of customer feedback about bought garment usage, (2) the collection of customer feedback about new collection proposals, (3) the collection of information from social networks, electronic marketplaces and e-commerce websites, and (4) the improvement and increase of the quality of information collected about fittings of garments from both current and potential customers.

2 Research Approach and Activities

The first step was to define a business story, from which requirements towards an IT platform for handling PUI could be elicited. It covers the creation of a new collection of men's polos with cotton shirt inserts for the upcoming spring/summer season, for which colours, sizes and patterns must be defined (Fig. 2). Dena Milano described a simplified view of their collection creation process covering six steps which could be improved with PUI:

(1) Identify trends for the upcoming collection from social media.
(2) Collect ideas about details for an upcoming collection from feedback, competitors, and potential customers' ideas.
(3) Identify fittings of current products related to the market.
(4) Merge all collected PUI to create a provisional collection structure.
(5) Share the collected information with stakeholders in the product lifecycle, such as stylists, suppliers and manufacturers.
(6) Predict trends of fitting changes for the garment.

The next step was to analyse the requirements of the six steps outlined above. This produced a large initial list of requirements, which was discussed between

Fig. 2 Examples of men's polos by Dena Milano

Dena Milano and the RTD and technical partners involved. This iterative process produced a distillation of five groups of major requirements (Table 1).

The next step was to select sources of PUI which fulfil the requirements. The first three groups of major requirements relate to which PUI needed to be collected. Table 2 shows the selected PUI mapped to the major requirements they fulfil. The next sections provide more detail about the PUI sources, including the rationale for their selection and examples of the PUI itself.

2.1 Social Media

Social media is an important source of information about up-to-the-minute fashion trends, customers' satisfaction with existing clothes, and their wishes for future collections. It is an indispensable source of knowledge for the fast-moving fashion section. However, the volume of information generated on social media makes it difficult for small companies to accurately and timely interpret and apply it to their processes. Figure 3 shows an example of PUI on Lookbook, showing the results of a search for the hashtag "#polo", for "guys + girls" and the date.

2.2 E-commerce

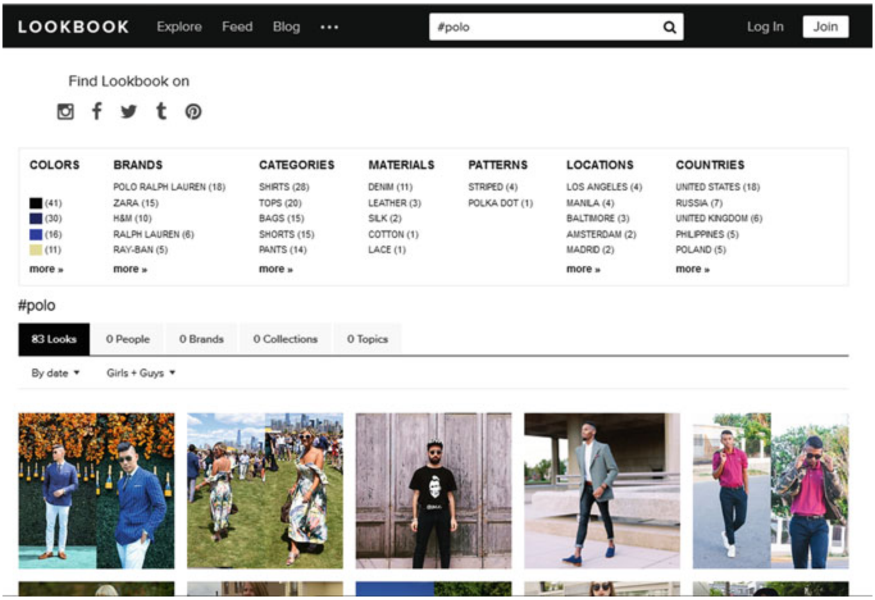
Besides brick-and-mortar stores, Dena Milano sell their products on their own e-commerce site, which allows customers to enter feedback, product reviews, etc. Figure 4 shows a five-star review about a cashmere coat by the user "Silvia". The back-end of the site contains additional information like the number of products in

Table 1 Major use case requirements

Major requirement group	ID	Examples of major requirements
Support new collection definition	A1	Involve external designers
	A2	Improve the early engagement of customers
	A3	Identify fashion trends
	A4	Identify marketplace information
Support collaboration among supply chain actors	B1	Exchange information between customers.
	B2	Designers
	B3	Modelists
	B4	Manufacturers and
	B5	Retailers
Support the evaluation of customer feedback	C1	Acquire information about fitting,
	C2	Quality,
	C3	Duration,
	C4	Colours,
	C5	Issues in returned garments, etc.
Aggregate different sources of PUI	D1	To create a provisional structure of the collection
	D2	Provide coherent access to all PUI
	D3	Provide a single point of access to all PUI
Simulation & prognosis	El	Provide simulations about most popular fitting trend changes
	E2	Compare PUI of homogeneous seasons extracted from sales, ecommerce, web and statistical aggregated data

Table 2 Selected PUI sources

PUI source	Major requirement ID													
	A1	A2	A3	A4	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5
Social media		✓	✓	✓	✓					✓	✓	✓	✓	✓
E-commerce		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Excel files and company databases			✓	✓	✓									
Fitting information			✓	✓						✓				
Product idea information	✓	✓	✓		✓	✓	✓	✓	✓					



COLORS	BRANDS	CATEGORIES	MATERIALS	PATTERNS	LOCATIONS	COUNTRIES
	POLO RALPH LAUREN (18)	SHIRTS (28)	DENIM (11)	STRIPED (4)	LOS ANGELES (4)	UNITED STATES (18)
■ (41)	ZARA (15)	TOPS (20)	LEATHER (3)	POLKA DOT (1)	MANILA (4)	RUSSIA (7)
■ (30)	H&M (10)	BAGS (15)	SILK (2)		BALTIMORE (3)	UNITED KINGDOM (6)
🟦 (16)	RALPH LAUREN (6)	SHORTS (15)	COTTON (1)		AMSTERDAM (2)	PHILIPPINES (5)
🟨 (11)	RAY-BAN (5)	PANTS (14)	LACE (1)		MADRID (2)	POLAND (5)
more »	more »	more »			more »	more »

Fig. 3 An example of PUI on Lookbook

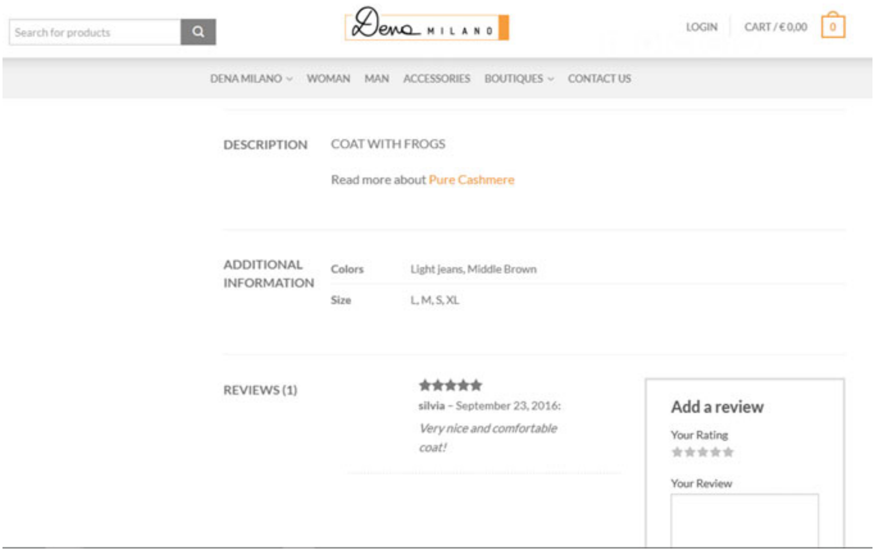
stock. A systematic aggregation and analysis of this information in combination with other PUI sources can help Dena Milano design better collections.

2.3 *Spreadsheets and Company Databases*

Dena Milano tracks product information such as the number of products on store or details about orders in spreadsheets. Other information, such as orders and sales, are tracked in separate files in Google Documents. Figure 5 shows an example containing the number of products for each size, which is required to understand which sizes need to be procured and which are in stock. To systematically use this PUI to visualise aggregated order, sales and warehouse information, a system is required to identify, extract and integrate data from various structured file formats.

2.4 *Fitting Information*

More than 90% of European consumers consider clothing design and size [4] much more important than care or allergy indications. The human body is characterised by different shapes, ranging from athletic to thin and long-limbed or to fat and obese,



DESCRIPTION COAT WITH FROGS

Read more about Pure Cashmere

ADDITIONAL INFORMATION

Colors: Light jeans, Middle Brown

Size: L, M, S, XL

REVIEWS (1)

★★★★★

silvia – September 23, 2016:

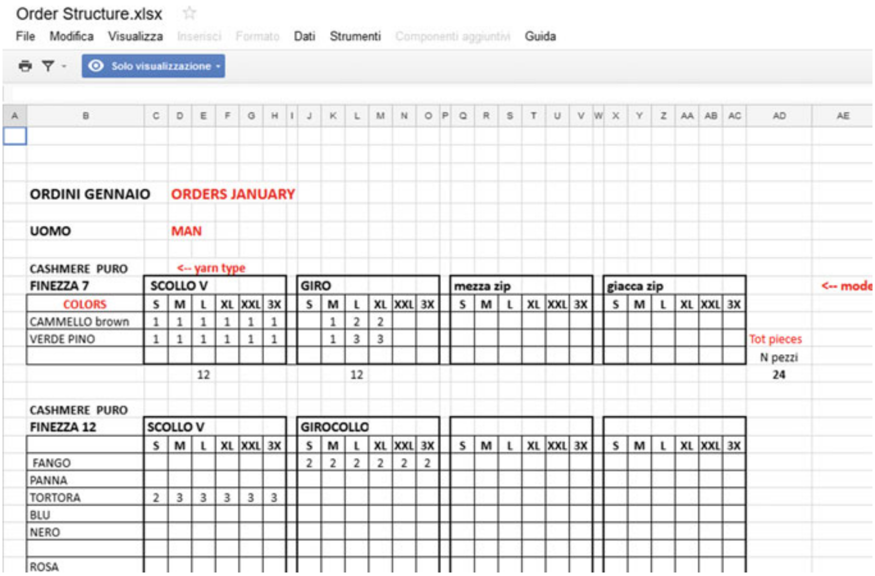
Very nice and comfortable coat!

Add a review

Your Rating ★★★★★

Your Review

Fig. 4 Example of a customer review



ORDINI GENNAIO ORDERS JANUARY

UOMO MAN

CASHMERE PURO <-- yarn type

FINEZZA 7	SCOLLO V						GIRO						mezza zip						giacca zip						<-- mode
COLORS	S	M	L	XL	XXL	3X	S	M	L	XL	XXL	3X	S	M	L	XL	XXL	3X	S	M	L	XL	XXL	3X	
CAMMELLO brown	1	1	1	1	1	1		1	2	2															
VERDE PINO	1	1	1	1	1	1		1	3	3															Tot pieces
																									N pezzi
			12						12																24

CASHMERE PURO

FINEZZA 12	SCOLLO V						GIROCOLLO																	
	S	M	L	XL	XXL	3X	S	M	L	XL	XXL	3X	S	M	L	XL	XXL	3X	S	M	L	XL	XXL	3X
FANGO							2	2	2	2	2	2												
PANNA																								
TORTORA	2	3	3	3	3	3																		
BLU																								
NERO																								
ROSA																								

Fig. 5 An example of a spreadsheet

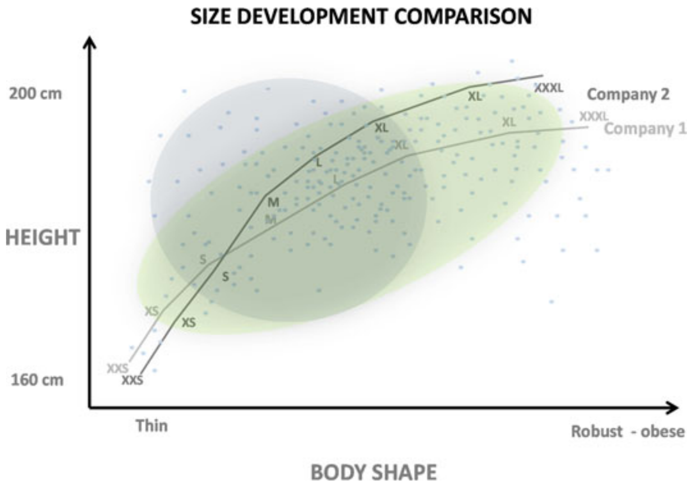


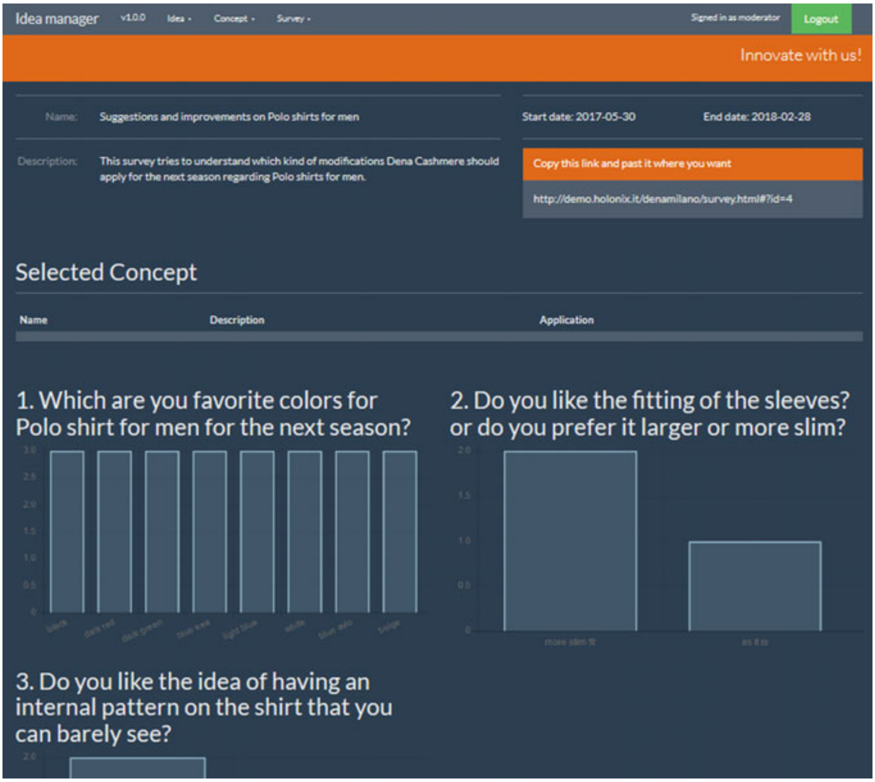
Fig. 6 Size development comparison

called morphotypes. The proportion of the measures (e.g. shoulders in relation to waist, hips, arms, collar) are different for each morphotype but statistically constant within each in relation to height. Based on the designer's and modelist's knowledge of the brand's consumer distribution, measures are not defined under a linear function but vary in relation with the most likely body shape per customer or group of consumer height. Clothing is generally produced with granular offers based on sizes to satisfy a wide range of consumers. In Fig. 6, the X axis represents the body shape from thin to obese, and the Y axis the height. The population is shown as a cloud of points. The size development of a clothing company can be represented as a line in this morphotype space (grey lines in Fig. 6).

Clothing design not only deals with visual aspects but also with satisfying market fitting needs by size development, covering as many consumers' morphologies in the target group of the brand as possible. This is generally done based on the experience of the modelist, relying on information from previous sales. Statistical models are only used by a few large, advanced brands. There is currently no concrete knowledge about consumers' real measures. Thus, collecting this PUI is an extremely relevant research problem. In this use case, the company I-Deal aimed to extract fitting information for different consumer target groups from images on the Internet and from the e-commerce sales.

2.5 *Product Idea Information*

To more precisely design collections to fit their customers' wishes, Dena Milano required a new source of PUI able to capture their customers' feedback and ideas.



Name: Suggestions and improvements on Polo shirts for men

Start date: 2017-05-30 End date: 2018-02-28

Description: This survey tries to understand which kind of modifications Dena Cashmere should apply for the next season regarding Polo shirts for men.

Copy this link and past it where you want

http://demo.holonix.it/denamilano/survey.html#?id=4

Selected Concept

Name	Description	Application

1. Which are you favorite colors for Polo shirt for men for the next season?

2. Do you like the fitting of the sleeves? or do you prefer it larger or more slim?

3. Do you like the idea of having an internal pattern on the shirt that you can barely see?

Fig. 7 Example of a customer survey

This new tool should gather ideas from a fan forum, create surveys and share the results with different stakeholders. Figure 7 shows an example of a customer survey. In this case, the survey is aimed understanding which modifications Dena Milano should make in the next season of men's polos.

3 Implementation

The next step was to develop an IT platform which fulfilled the use case requirements. Further use cases outlined in [5] were considered to ensure the platform is applicable to other sectors. Figure 8 shows a simplified architecture of the resulting FALCON Virtual Open Platform (FALCON VOP), which is described in more detail in the following. A more detailed view was published in [6]. Which of the requirements shown in Table 1 the components address is indicated by giving their IDs in parentheses.

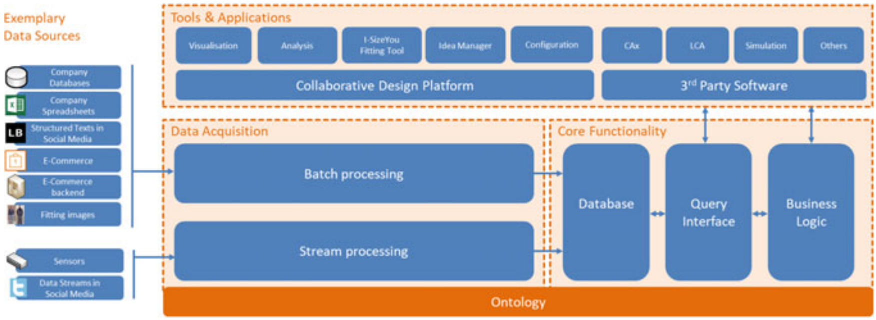


Fig. 8 Simplified architecture of the FALCON VOP

PUI is structured and made interoperable within the VOP by means of an ontology, which constitutes the information model fundamental to the entire platform. It consists of a general ontology for product-service systems, which can be extended by domain-specific ontologies for specific use cases. Here, a domain-specific ontology was built for the clothing and textiles sector, representing product and service characteristics such as styles, colours, fitting information, and other concepts. All platform operations, such as searching for PUI in social media, storing the PUI, querying, filtering and analysing it, are done using the ontology.

A data acquisition block connects the platform to different PUI sources. Batch processing allows connecting to sources including the company database, structured documents, e-commerce backends and structured texts in social media (requirement IDs A1–C5). A stream processor accesses sources such as streaming social media (requirement ID A3). Unstructured text is processed using natural language processing. This way, free text found in Dena Milano’s customers’ product reviews in social media can be analysed and compared with the ontology’s domain-specific concepts to identify, filter and structure relevant contents for further use (requirement IDs A1–C5).

The core functionality provides semantic uplift and storage of PUI, that is, mapping it to the ontology and storing it in a database (Triplestore). This way, PUI can be comprehensively queried in their semantic context and analysed, visualised or further processed directly on the platform or by other applications (requirement IDs D2–D3). In many cases, the PUI’s format isn’t appropriate for use in product development processes or software, but first needs to be pre-processed and brought into a suitable format and level of aggregation. For example, details of information about the colour of clothes shown in individual blog postings might not be helpful to a fashion designer, whereas an aggregation of colour similarities across many recent postings could indicate a trend which may inform the designer about what colours to use in an upcoming collection. The platform’s business logic component facilitates this kind of pre-processing (requirement IDs A3, A4, D2–D3, E2). The results can be output to all the platform’s applications as well as to 3rd party software via an open API (requirement IDs D2–D3).

Tools and applications are provided within a browser-based collaborative environment, which facilitates a synchronised, common view for multiple users working at different locations (requirement IDs B1–B5). Users can filter, visualise and analyse PUI here via an intuitive GUI (requirement ID E2). It can also be exported into 3rd party applications (requirement ID E1). A dedicated knowledge-based PSS development tool supports experts in modelling, communicating and documenting information flows and transformations related to their collaborative PUI-based development activities (requirement IDs E1–E2), allowing tracking and documenting PUI transformation and analysis operations (requirement ID E2).

Idea Manager is a web-based tool, developed by Holonix, which supports the idea generation part of open innovation (requirement IDs A1–A3, B1–B5). It offers an open, collaborative environment for sharing ideas, collecting reactions and comments on submitted ones, gaining qualitative and quantitative feedback from a target community, and using them to guide the idea selection process. Idea Manager allows idea collection without any restrictions on topics and supports stimulating the generation of ideas that offer solutions for given issues within a target domain.

I-SizeYou is a module specifically designed to solve the problem of extracting fitting trends from images. The company I-Deal developed an algorithm to measure the distance between user body shape and clothing size, which provides information about its fitting (see Fig. 9). This process puts the 3D shape of consumer body

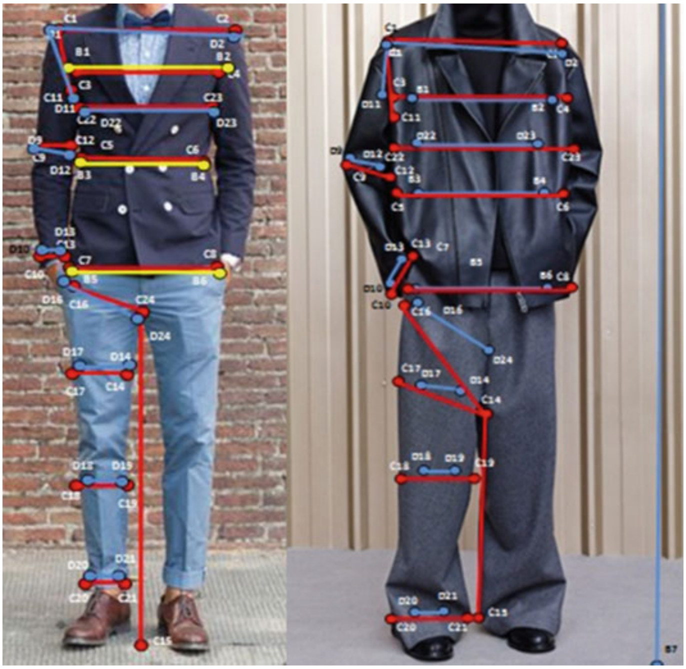


Fig. 9 Illustration of fitting information extracted from images

(blue lines) and the physical measures of the clothing on-sale (red lines) in direct connection, measuring the fitting of the clothing piece in the different parts of the body. Here, this process is carried out at aggregated level which compares the morphologies of a group of consumers representing a population and/or a target group with the size development of a given product. When this process is carried out as regards effective choice it is possible to identify the fitting preferences (tight, regular, over) of the group of consumers analysed. Per each specific measure it is possible to indicate in percentage the average level of detachment, that is how tight or loose a garment is, between user body measure and product ones, i.e. the most popular fitting.

4 Application

This section describes the application of the FALCON VOP in the six steps of the use case outlined in Sect. 2.

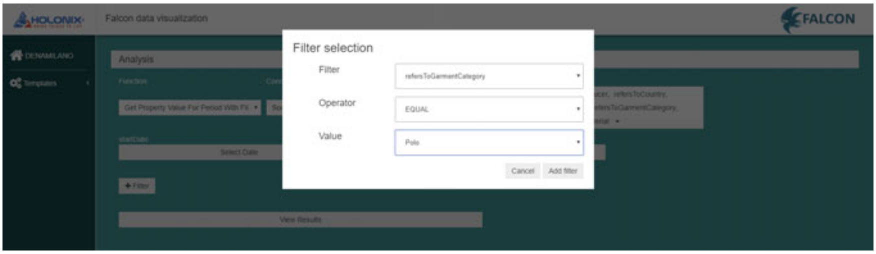
Step 1

Dena Milano wants to understand which the trendiest materials garments, colours, styles, etc. are for a new collection. The Collection Manager needs to interpret the results of the social media trend analysis. Trends for polo shirts were analysed using PUI from social media and customer feedback from both brick-and-mortar shops and e-commerce. Figure 10 shows how the expert selected collected PUI using filters such as garment categories, geographical area, period, gender, fashion style, brand, material, etc.

The results are presented as a list of posts filtered according to the selection (Fig. 11). Clicking on the links opens the original content, so that the expert can investigate the trends in more detail.

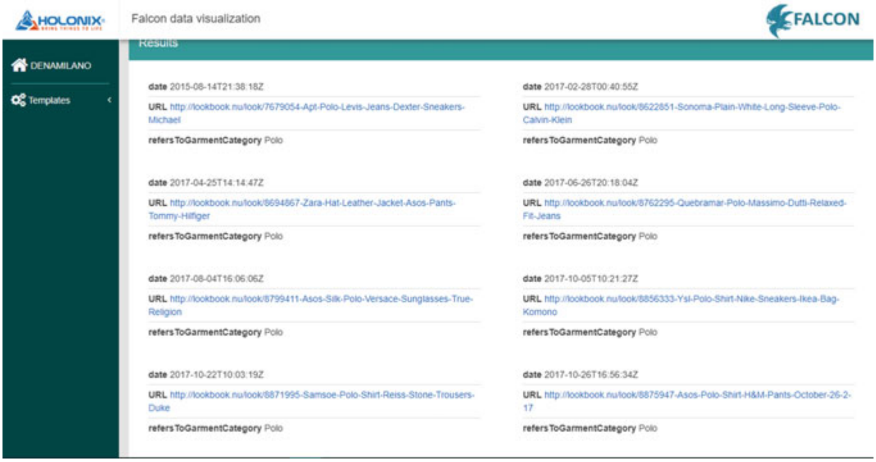
Step 2

A customer is looking for a polo shirt with long sleeves and inserts. He gives the idea to Dena Milano using the Idea Manager (Fig. 12), hoping that the company can



Filter: refersToGarmentCategory
Operator: EQUAL
Value: Polo

Fig. 10 Selection of PUI using filters



date 2015-08-14T21:38:18Z
URL http://lookbook.nu/look/7679054-Apt-Polo-Levis-Jeans-Dexter-Sneakers-Michael
refersToGarmentCategory Polo

date 2017-02-28T00:40:55Z
URL http://lookbook.nu/look/8622851-Sonoma-Plain-White-Long-Sleeve-Polo-Calvin-Klein
refersToGarmentCategory Polo

date 2017-04-25T14:14:47Z
URL http://lookbook.nu/look/8694867-Zara-Hat-Leather-Jacket-Asos-Pants-Tommy-Hilfiger
refersToGarmentCategory Polo

date 2017-06-26T20:18:04Z
URL http://lookbook.nu/look/8762295-Quebramar-Polo-Massimo-Dutti-Relaxed-Fit-Jeans
refersToGarmentCategory Polo

date 2017-08-04T16:06:06Z
URL http://lookbook.nu/look/8799411-Asos-Silk-Polo-Versace-Sunglasses-True-Religion
refersToGarmentCategory Polo

date 2017-10-05T10:21:27Z
URL http://lookbook.nu/look/8856333-Ysl-Polo-Shirt-Nike-Sneakers-Ikea-Bag-Komono
refersToGarmentCategory Polo

date 2017-10-22T10:03:19Z
URL http://lookbook.nu/look/8871995-Samsoe-Polo-Shirt-Reiss-Stone-Trousers-Duke
refersToGarmentCategory Polo

date 2017-10-26T16:56:34Z
URL http://lookbook.nu/look/8875947-Asos-Polo-Shirt-H&M-Pants-October-26-2-17
refersToGarmentCategory Polo

Fig. 11 Results of filtering PUI

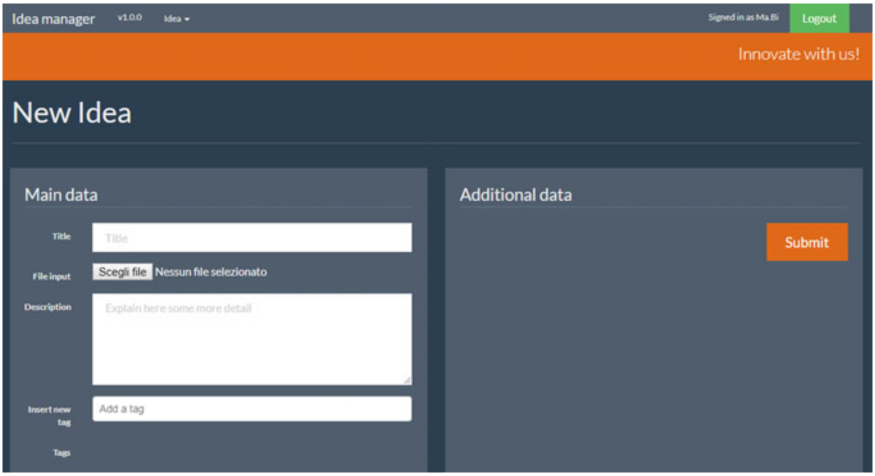


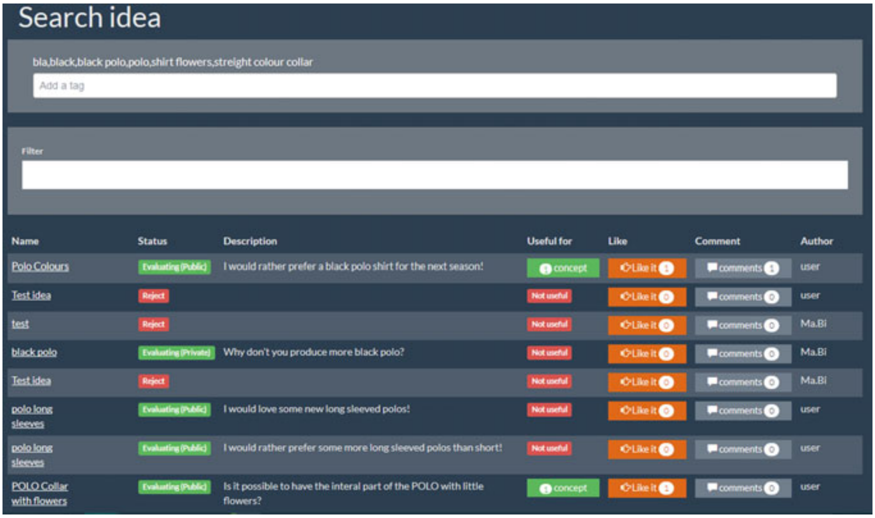
Fig. 12 New idea form

either find it for him or produce it. The Collection Manager is looking for proposals to improve the current season's collection.

Using the idea search function (Fig. 13) of the Idea Manager, she visualises all submitted ideas and chooses those relevant for the active season. She selects the polo with long sleeves and proceeds with the decision process, asking for suggestions through surveys.

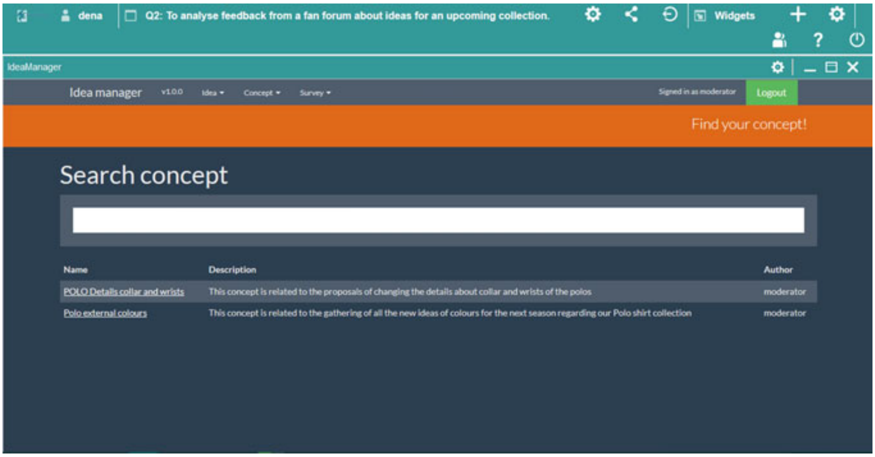
The Collection Manager selects the polo with long sleeves and creates a new concept to elaborate on (Fig. 14).

She creates a survey about colours. Figure 15 shows the survey's results.



Name	Status	Description	Useful for	Like	Comment	Author
Polo Colours	Evaluating (Public)	I would rather prefer a black polo shirt for the next season!	1 concept	Like it 1	comments 1	user
Test idea	Reject		Not useful	Like it 0	comments 0	user
test	Reject		Not useful	Like it 0	comments 0	Ma.Bi
black polo	Evaluating (Private)	Why don't you produce more black polo?	Not useful	Like it 0	comments 0	Ma.Bi
Test idea	Reject		Not useful	Like it 0	comments 0	Ma.Bi
polo long sleeves	Evaluating (Public)	I would love some new long sleeved polos!	Not useful	Like it 0	comments 0	user
polo long sleeves	Evaluating (Public)	I would rather prefer some more long sleeved polos than short!	Not useful	Like it 0	comments 0	user
POLO Collar with flowers	Evaluating (Public)	Is it possible to have the interal part of the POLO with little flowers?	1 concept	Like it 1	comments 0	user

Fig. 13 Idea search function



Q2: To analyse feedback from a fan forum about ideas for an upcoming collection.

Name	Description	Author
POLO Details collar and wrists	This concept is related to the proposals of changing the details about collar and wrists of the polos	moderator
Polo external colours	This concept is related to the gathering of all the new ideas of colours for the next season regarding our Polo shirt collection	moderator

Fig. 14 List of concepts

Step 3

The Collection Manager needs to purchase a new set of Polo shirts but doesn't know which size. She uses the VOP to get suggestions from the I-SizeYou module based on analysis of the morphotypes of her target customer group. First, she selects the PUI that describes the target customer group in the data visualisation module, which presents the results as a list (Fig. 16).

She can view additional information about each result (Fig. 17) and now has a good idea about which size of shirts she needs to purchase to satisfy her target customer group.

1. Can you order the colours from the one you like most to the one you don't like

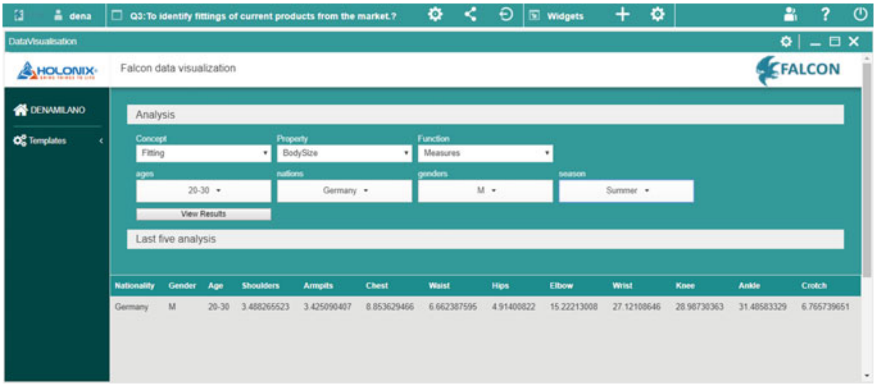
2. Do you have suggestions or comments?

Response	Occurrences
Black is missing!	1
I pretty much liked all of them, but i ranked them in the order i would actually prioritize buying them.	1
and while ??	1
I suggest you to add to your collection the black polo.	1
I suggest you to add to your collection a polo with a pattern.	1
Include a black polo in the collection.	1
Nothing it's new, these kinds of tshirts already exist	1

10. Can you order the colours from the one you like most to the one you don't like

Response	Occurrences
10 - Olive	6.555555555555555

Fig. 15 Results of a survey



Q3: To identify fittings of current products from the market.?

Falcon data visualization

Analysis

Concept: Fitting
Property: BodySize
Function: Measures
ages: 20-30
nations: Germany
genders: M
season: Summer

Last five analysis

Nationality	Gender	Age	Shoulders	Armpits	Chest	Waist	Hips	Elbow	Wrist	Knee	Ankle	Crotch
Germany	M	20-30	3.488265523	3.425090407	8.853629466	6.662387595	4.91400822	15.22213008	27.12108646	28.98730363	31.48583329	6.765739651

Fig. 16 Results of selecting PUI describing a target customer group

Step 4

The Collection Manager's task is to create the proposal structure for the men's polo. Using the VOP, she can visualise PUI both gathered by the system and available normally in a comprehensive view. This way, all PUI can be merged and put into relation within a unique workspace (Fig. 18).

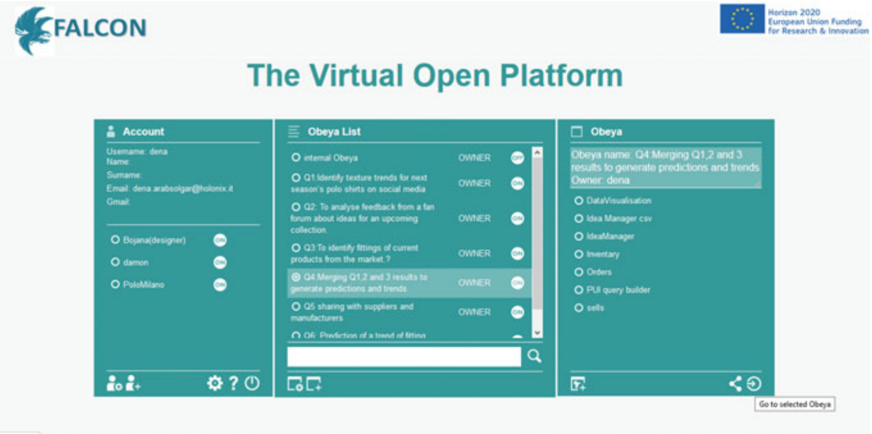
She acquires the PUI from all available sources and uses the Collaborative PSS Design Solution to visualise it (Fig. 19).

Body size explanation

Q3: Falcon is able to provide the average detachment level between body and clothing, on the basis of which the fitting trend estimated. Zero percentage detachment means very slim fitting clothing, usually applied for elastic apparel. The increase of the percentage highlight a tendency towards more detached pieced, usually called "over" fitting. The percentages per each cardinal point of the body (A-B-C-D-E-F-G-H-I-L) are summarised by 2 ones, the first for the uppoer part of the body and the second one for the lower part.

Q6: Prediction and simulation module of Falcon is able to estimate the level of detachment between the measures of a specific model and a target population of customers, which might be actual ones or from a new market, taking into consideration the preferences of the population defined in Q3. This means, for example, that when a population tends to buy more "over" fitting clothing than the season before, if a model is slim fitting and its measures remain unchanged, the level of matching decreases.

Fig. 17 Additional information about the results



Username: dena
Name:
Surname:
Email: dena.arabsolgar@holonix.it
Gmail:

○ Bojana(designer)
○ damon
○ PoloMilano

○ internal Obeya OWNER
○ Q1 Identify texture trends for next season's polo shirts on social media OWNER
○ Q2: To analyse feedback from a fan forum about ideas for an upcoming collection. OWNER
○ Q3 To identify fittings of current products from the market.? OWNER
◉ Q4 Merging Q1,2 and 3 results to generate predictions and trends OWNER
○ Q5 sharing with suppliers and manufacturers OWNER
○ Q6: Prediction of a trend of fitting

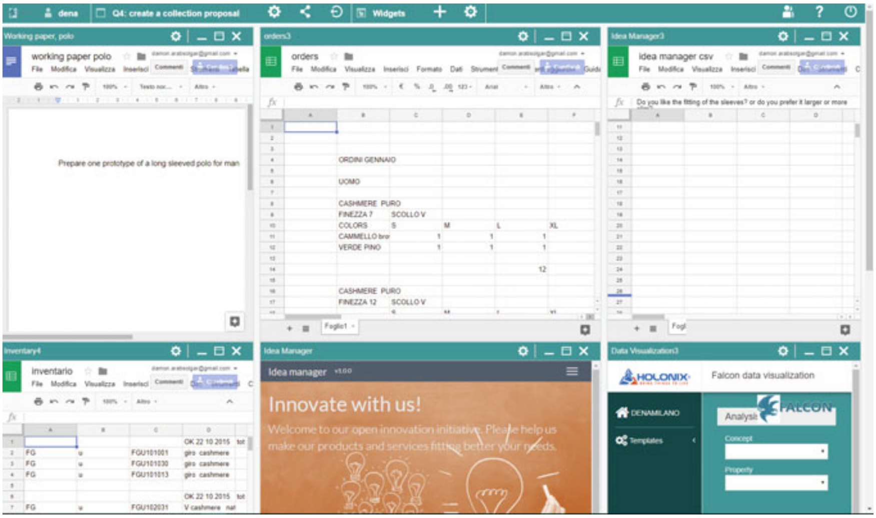
Obeya name: Q4 Merging Q1,2 and 3 results to generate predictions and trends
Owner: dena

○ DataVisualisation
○ Idea Manager csv
○ IdeaManager
○ Inventary
○ Orders
○ PUI query builder
○ sells

Fig. 18 A virtual workspace

Step 5

The Collection Manager needs to verify the capabilities of her supplier to produce a women's polo for the current season. She acquires information from company databases and web sources. She visualises the PUI in a collaboration workspace and shares it with the external actors (manufacturer, designer, etc.). She can give access to the information with different rights for different users, so that they can work on planning the supply chain of the polo together in a Virtual Obeya (a shared, web-based collaboration environment) of the Collaborative Design Platform (Fig. 20).



Prepare one prototype of a long sleeved polo for man

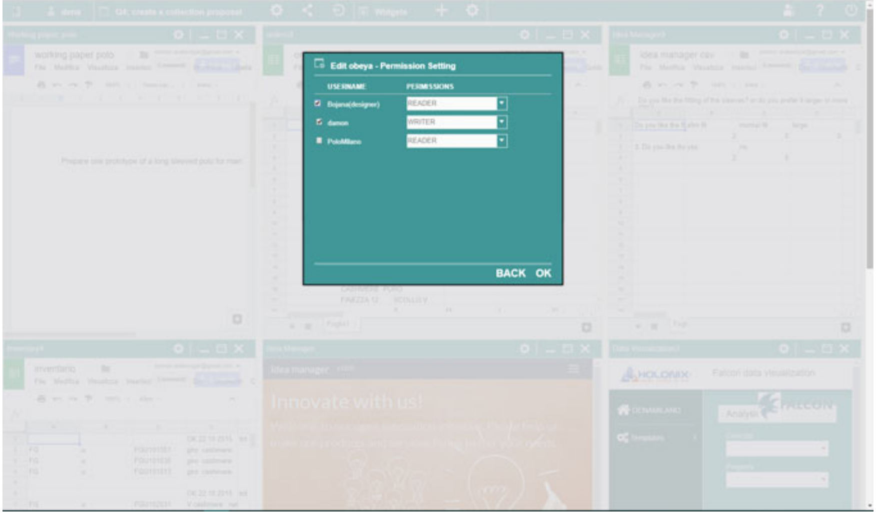
Do you like the fitting of the sleeves? or do you prefer it larger or more

Welcome to our open innovation initiative. Please help us make our products and services fitting better your needs.

	A	B	C	D	E	F
1						
2						
3						
4		ORDINI GENNAIO				
5						
6		UOMO				
7						
8		CASHMERE PURO				
9		FINEZZA 7	SCOLLO V			
10		COLORS	S	M	L	XL
11		CAMMELLO bro	1	1	1	
12		VERDE PINO	1	1	1	
13						
14					12	
15						
16		CASHMERE PURO				
17		FINEZZA 12	SCOLLO V			

	A	B	C	D	
1				OK 22 10 2015	tot
2	FG	u	FGU101001	giro cashmere	
3	FG	u	FGU101030	giro cashmere	
4	FG	u	FGU101013	giro cashmere	
5					
6				OK 22 10 2015	tot
7	FG	u	FGU102031	V cashmere	nat

Fig. 19 PUI visualised in the Falcon VOP collaboration space

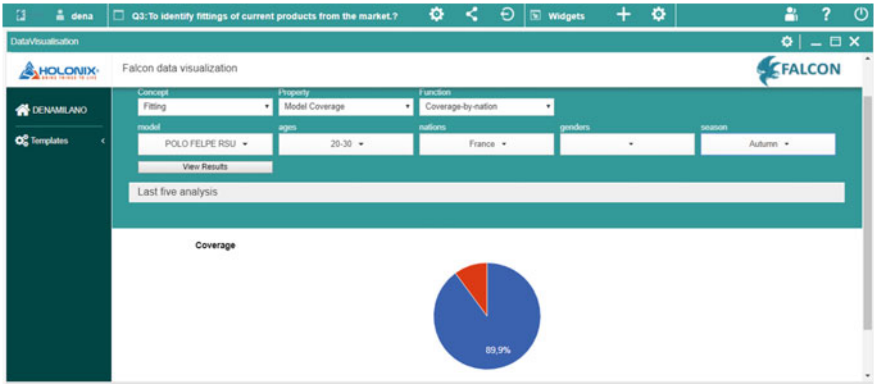


USERNAME	PERMISSIONS
☑ Bojana(designer)	READER
☑ damon	WRITER
☐ PoloMilano	READER

Fig. 20 A Virtual Obeya used by different actors in the supply chain simultaneously

Step 6

The process described in step 3 is applied to current market and products, whilst step 6 deals with forecasts and simulations for new garments and markets. Dena Milano wants to understand if the fitting of the defined garment is appropriate for the predicted upcoming spring summer season trends. After selecting the relevant information, she gets the result shown in Fig. 21 that the proposed polo is appropriate



Concept: Fitting
Property: Model Coverage
Function: Coverage-by-nation
model: POLO FELPE RSU
ages: 20-30
nations: France
genders:
season: Autumn

Fig. 21 Results of analysing the fitting of a concept

for 89.9% of the selected population. She thus knows that the design is very probably a good fit for the target market.

5 Evaluation Results

This section gives a brief overview of the results of Dena Milano's evaluation of the VOP for six steps of the use case, summarising the identified benefits and limitations of the platform.

Step 1

The VOP gives Dena Milano efficient access to PUI extracted from social media and the company's e-commerce system which can be flexibly filtered. This benefits the company by providing unique insights into all relevant information. The Collection Manager has quick access to what's going on in the fashion world, since the VOP automatically gathers PUI from influencers and potential consumers and keeps an eye on the existing e-commerce customers, saving a significant amount of time. The VOP additionally allows aggregating PUI to see numbers and percentages which helps take rational decisions.

The VOP is currently limited by the ontology definition. There is no easy way to extend the ontology with new terms and concepts, limiting for example the colours and garment types the platform can gather PUI about. It is also limited by the current selection of social media networks. Also, the platform does not yet consider other marketplaces or competitors' e-commerce sites.

Step 2

Talking to customers in person is one of the most important aspects of the company's business. Gathering additional remote feedback however proves very helpful, allowing interaction with customers not only during purchases or returns, but also when they are wearing the products. The VOP helps the Collection Manager by saving time collecting feedback, since it makes it available in a structured, digital form. The company can reach more people, including potential customers, and process more feedback and ideas. Cross-feedback also helps accelerate the design process.

Targeting of feedback gathering is currently a major limitation, since the VOP does not support the management of target pools. Direct feedback from customers in brick-and-mortar shops remains relevant. However, prototyping can be reduced by enabling the Collection Manager to propose digital renders and gather online feedback about what customers think about them, before entering a physical prototype phase.

Step 3

I-SizeYou provides useful information about fitting trends, at a proper level of granularity, to support the design of the next collection. The tool benefits the fitting development process, specifically increasing the success ratio of new design proposals. However, continuously updating the data collected by I-SizeYou is complex and the tool is currently hard to understand; better documentation and support for un-experienced users is required in the future.

Step 4

The VOP provides helpful tools which enrich collaboration and share vital information throughout the company. Actors such as the Collection Manager receive a comprehensive view of relevant data groups. Information no longer needs to be manually gathered together from different places—it's all available in one place digitally, from anywhere, at any time. This helps reduce the resources required to communicate and take decisions throughout the value chain, resulting in a reduction of unsold garments and prototypes. The collaborative nature of the tool allows digital brainstorming involving all relevant internal and external actors, saving time and increasing efficiency. The VOP'S native support for Google Documents makes platform adoption easy. A limitation is currently the management of permissions, rights and roles, which needs to be well defined before use.

Step 5

Visualising all relevant information within a single collaboration workspace is very helpful for the Collection Manager and saves a lot of time looking up and comparing different PUI sources manually. However, since the actors in the supply chain are not always technologically skilled, training is required to efficiently carry out this step. Also, significant effort will need to be invested into establishing a daily routine of using the VOP. These limitations need to be considered in the overall assessment of its applicability.

Step 6

As in Step 3, I-SizeYou is highly effective, fast to use and offers a good level of information granularity. However, its complexity requires un-experienced users to be provided with sufficient documentation and support to properly understand its results.

6 Achieved Benefits

The collection and analysis of PUI using the FALCON VOP benefits collection stylists and managers and sales department significantly by facilitating the acceleration and improvement of the ideation, design, production and distribution of new collections. By directly integrating PUI directly from both their existing and potential customers, Dena Milano was able to improve customer experience in several ways, making sure that they are always able to find exactly the garment they are looking for, whether in a brick-and-mortar store or via e-commerce. Using the platform, the company can stay up-to-date about what is happening on e-commerce and other marketplaces. It can more easily stay aware of current and incoming fashion trends and involve customers in the new collection design process. Also, Dena Milano can more easily understand customers' motivations for returning garments by correlating them with all the available information captured in the VOP.

Using the VOP, stakeholders throughout the product lifecycle can share PUI in structured user groups. The Idea Manager facilitates the exchange of ideas between Collection Manager, designer, manufacturers and customers, allowing the exchange of direct feedback and comments. The collaborative environment helps all actors share a common view of all relevant information. I-SizeYou facilitates for the first time an automatic collection of fitting information, helping the company more easily define the correct size developments for each target market, which can then be shared in the collaboration environment to be refined via customer feedback.

In addition, PUI can support Dena Milano in the definition of services for its customers and stakeholders. For example, I-SizeYou allows giving customers suggestions about which size to buy on the e-commerce site. Social media analysis allows the company to activate the supply chain in time to deliver new collections according to incoming trends. Finally, the company can use feedback about the quality of sold garments to intervene by giving suggestions on how to best maintain and wash the garments.

Dena Milano estimate the effect of the application of the VOP on selected KPIs as follows:

- Increase in turnover: 10–16%
- Product development lead time reduction (time-to-market): 5%
- Reduction of stocks and unsold lots by improved production steering: up to 15%
- Increase of product perceived quality: 5–10%
- Reduction of product development costs: on average 5–10%
- Reduction of the environmental footprint and resource consumption in the product development and production phases: ~5%

7 Outlook to Future Work

Future work mainly relates to extending the Falcon VOP to handle additional PUI sources. The clothing and textiles industry could benefit from information about the effective use of garments, for example the duration and frequency of use, or the garments' resistance to home washing. Accessing this kind of information is difficult, due to customers' concerns and rights about privacy, and because it is difficult to embed devices into the garments capable of collecting this kind of data. Networking IoT devices such as washing machines or smart phones with tags embedded into clothes could however facilitate collecting data about interactions between clothes and these devices. This could yield PUI giving insight into washing schedules, times and contexts in which garments are worn. This would shed light on how a garment holds up in daily use: how long can a material can be worn, which kind of washing is suggested, if it is really used worn for one season, etc.

Information about the end-of-life of garments could be very valuable for companies and society. Analysing PUI about garment reuse, their age at disposal, or how worn out they are can help create a more sustainable value chain, generating awareness in producers and consumers.

The identification of relevant terms in unstructured texts was a challenge in this use case. The domain-specific model currently only supports English, which needs to be extended to support languages in all target markets. Furthermore, the fashion industry is very much driven by novelty and new trends and garments are often identified with new terms. This limits the usefulness of identifying relevant content with predefined vocabularies. Thus, the domain-specific ontology should optimally automatically be updated with new terms and concepts. Methods of machine-learning could be investigated to solve this problem.

The current platform only supports trend analysis. The capabilities of the platform could be extended with forecasting capabilities, allowing the company to predict probable trends on the market before they arrive. This would give the company a strong competitive advantage in the very fast-moving fashion world.

I-SizeYou could be integrated into the e-commerce site to automatically collect fitting information from the customer and thus provide a better service.

Finally, extending the involvement of stakeholders to all actors in the product lifecycle will be a challenge, especially with regards to supply chain partners. To achieve acceptance from all actors, the research prototype of the VOP will need to be further matured, especially with regards to ergonomics and user friendliness.

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A New Framework for Modelling Schedules in Complex and Uncertain NPD Projects

Ann Ledwith and Evan Murphy

Abstract Producing reliable schedules for new product development (NPD) projects can be difficult. The uncertainty involved in NPD and the complex relationships between project tasks often leads to task repetition. This results in project schedules that are not linear and cannot be predicted using traditional methods. This case introduces a new modelling approach that aims to provide a more accurate and process specific representation of NPD project schedules. It was developed in a large multi-national component company and addresses the challenges they face producing accurate schedules for their NPD projects. The new approach uses a set of process specific variables rather than the subjective iteration probabilities used by earlier approaches. This results in more reliable project schedules accounting for specific project variations.

Keywords Project management · New product development · Project scheduling · Complex projects

1 Background

This case study examines a large multi-national electronic component company that designs and manufactures products for a variety of different industries. Producing new products and being market leader is integral to the firm's success and thus NPD projects are continuously undertaken. New products are developed across 15 separate product lines with varying levels of product complexity. A formal procedure is in place within the company that is followed for every NPD project. This procedure is used for development projects of all innovation levels: incremental, platform and radical projects.

The company procedure for scheduling any NPD project is to produce a baseline schedule on a project by project basis. The expected time to each milestone is estimated based on the requirements and specifications of an individual product. When

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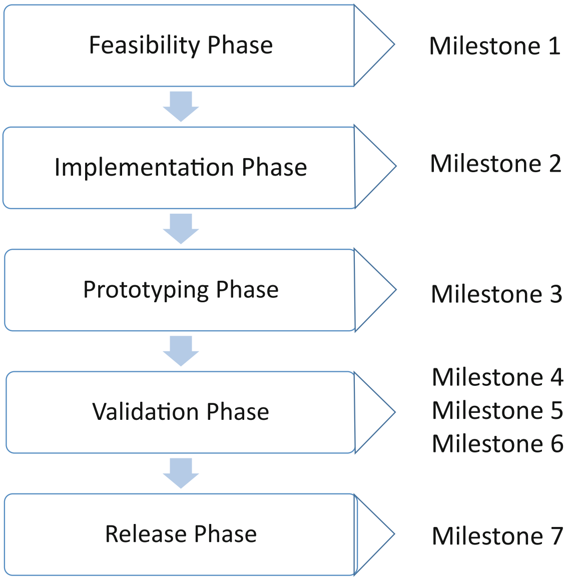

Fig. 1 NPD process phases

unforeseen problems are encountered, such as the need for an unplanned iteration, projects are re-scheduled to reflect the extended due date. While risk assessments are carried out in relation to product functionality, there is little risk analysis and contingency planning done concerning the project schedule. The procedure to be undertaken for any NPD project is formalised in the firm's official documentation, which identifies five process phases: (1) feasibility, (2) implementation, (3) prototyping, (4) validation and (5) release (see Fig. 1). Within these five phases there are seven milestones that are used as metrics to monitor project progress and the prospective Time to Market (TTM).

This formal NPD process is well established and has been developed over time and optimised by the firm as much as possible. Precedence and procedural constraints have resulted in a process that cannot be altered in terms of task sequencing.

2 Predicting Iteration in NPD Projects

The occurrence of iteration in a project can be either planned or un-planned [19]. Planned iteration is typically used to refine the output of inter-related tasks and can incorporated into a project schedule [2]. Unplanned iteration on the other hand occurs when tasks are repeated due to an unsatisfactory or expected task output or due to a change in project specification. Regardless of the cause, unplanned iteration is a fundamental feature of complex NPD projects and ignoring or even under-estimating potential iteration can have a serious negative effect on a project due to missed deadlines and cost over-runs [3, 5, 10].

The three main methods that have been used to model iteration in projects are: (1) Design Structure Matrix (DSM); (2) mathematical and optimisation models; and (3) computer simulation. These are described briefly below along with a critique of their applicability and practicality of use.

2.1 Design Structure Matrix

The DSM is a matrix based model that is used to represent dependency relationships and information flow between tasks in a project [21]. The goal of using the DSM approach is to group interdependent tasks together in order to minimise the number of project tasks involved in iteration cycles, resulting in a faster development process [24]. The process for building a DSM model is to get people knowledgeable about each task to determine the inputs and outputs for every task and to determine the relationships that exist between all tasks [2]. However, building DSM models for complex projects (such as product development projects) can be difficult, as the necessary data is often not readily available [17].

2.2 Mathematical and Optimisation Models

The problem of iteration in projects has also been addressed using established mathematical techniques and schedule optimisation algorithms. Luh et al. [16] generate an optimisation methodology for scheduling design projects with uncertain number of iterations. The simplified objective function of the model is to ensure on-time completion of a project with minimal failures occurring. Hardie [12] uses a Markov chain based model to represent the recursive nature of complex projects. By calculating the transition matrices for time periods in a project, the probability of completing a project within a specified time can be analysed. Ahmadi et al. [1] present a methodology for structuring development processes that uses a Markov chain to model iteration in the process. Smith and Eppinger [20] also use a Markov chain approach in conjunction with a DSM in their sequential iteration model for calculating the total expected time of a project containing task iteration.

2.3 Computer Simulation

From a project management perspective, computer simulation can be a useful tool, in particular for scheduling purposes [23]. The use of deterministic durations for project scheduling can be inadequate for many projects because of the inherent uncertainty involved [13]. Using computer simulation for scheduling enables the use of probabilistic task durations. The simulation of a schedule can provide a better understanding of how iteration will affect the overall duration of a project and thus can help in making project planning decisions.

Browning and Eppinger [3] present a simulation model that integrates task iteration and concurrency into schedule and cost risk analyses of a product development project. Flanagan et al. [9] use a simulation model to explore project sensitivity to task rework. Cho and Eppinger [6] present a simulation-based model that computes the distribution of lead-time in a project and also accounts for various forms of iteration. In their model, a DSM provides an overview of the information exchanges and probabilities in the project, while simulation is used to provide a quantitative analysis of an overall project duration that includes potential iteration. Wang and Lin [22] developed a simulation algorithm that incorporates task iteration and predicts schedule duration.

Several system dynamics simulation models have also been developed that address the problem of iteration. These models provide a means to better understand the dynamic behaviour of development projects and in particular the impact that task iteration can have on project performance [7, 8, 15, 18]. The primary uses of the proposed system dynamics models are as tools to aid in managerial decision making for NPD projects.

2.4 Selecting the Most Suitable Modelling Approach

Determining the most suitable approach for modelling iteration in NPD projects is dependent on a number of factors. Important considerations to account for include the complexity of the products being the developed as well as the maturity of the formal NPD process in place. The specific requirements of a company and the level of detail needed are also relevant when deciding on how to build an iteration model.

The DSM technique is a relatively simple concept and provides a quick and easy representation of potential iteration in a project. For a project that is quite un-structured, the construction of a DSM is beneficial for determining the information dependencies between project tasks. The addition of iteration probabilities and impacts to a DSM model can then give a broad indication of the risk and consequences of any potential iteration in the project. However, from a practitioner perspective the DSM approach does have potential limitations. Partitioning, or reordering, the matrix in order to eliminate or reduce iteration is a major function of the DSM technique. However, this re-ordering of tasks is unlikely to be feasible for companies that have well established procedures for developing new products. For the development of complex technology based products, the precedence relationships between tasks are often rigid with little scope for alteration. If this is the case, partitioning a DSM is a redundant process as the ordering of tasks cannot be altered.

The effectiveness of mathematical and optimisation techniques for modelling iteration is dependent on the requirements of a firm. Many of the proposed models cleverly use established mathematical techniques to accommodate iteration in a schedule. Such methods can be beneficial for exploratory investigation into the behaviour of a project under specified conditions and for determining a means to optimise a process. However, there are limitations when it comes to practicality and implementation. From a practitioner point of view, the modelling of potential iteration in a project is a means to an end where the effect on the entire project schedule is the main information of relevance. A pure mathematical or optimisation model requires the end user to have a degree of knowledge in the mathematical techniques being used. In reality, a scheduling model needs to be as user friendly as possible to ensure widespread adoption throughout a firm. While mathematical approaches can be fully customised when they are being constructed, the need for future modifications may be problematic. Applying updates to a pure optimisation model to reflect the evolution of an NPD process will likely be a time-consuming undertaking as model validity will have to be protected. In general, the inflexibility and the lack of scope for widespread use of this type of model make it infeasible in a practical setting.

The benefit of using computer simulation for modelling iteration is its practicality as well as the flexibility it offers. Many of the proposed models for incorporating iteration into a schedule operate on a project by project basis, where the constructs must be developed based on the particular project being assessed. The advantage offered by using a computer simulation program is that it can be set up to include different parameters and constructs based on the type of project being undertaken. Using simulation has two distinct advantages, (1) a front end user interface can be developed to increase the accessibility of a simulation tool and (2) the tool can be linked to databases already in place in the company to access historical project data. A model can be constantly updated to accurately reflect a company's actual project performance over a sustained time.

A limitation common across all approaches described above is the reliance on subjective estimates of task duration, iteration probabilities and consequences from management [11]. Browning et al. [4] also highlight the practical problems that can exist when using subjective measures in product development and the inherent uncertainty that exists at the beginning of an NPD project. The aim of this research is to minimise the uncertainty caused by subjective estimates and to provide a means of more accurately incorporating iteration into project schedules. The main focus is on 'digging deeper' with respect to the reasons for iteration in a NPD process and subsequently using this information to develop iterative schedules. The modelling framework proposed in this paper attempts to provide a more accurate and reliable method for determining schedules for NPD projects. Two primary research questions are addressed:

1. What is the most appropriate technique for modelling iteration in complex NPD processes?
2. How can iteration input parameters be more accurately calculated?

3 Approach Taken

Following on from a general investigation of iteration in the company's NPD process it was established that the occurrence of iteration was a complex issue that can arise for any number of reasons. In order to explore these underlying reasons for iteration, focus group sessions with 30 members of the R&D staff were conducted to get their input on the causes of iteration.

Three focus groups were conducted with each session having a mix of staff from different areas of the company. A KJ approach, named after its originator, Kawakita [14], was used for the focus groups, which provides the participants with an opportunity to provide their own views on a topic and then engage in consultation with their colleagues regarding the issue. The use of a KJ analysis approach was chosen as it suited the exploratory nature of the investigation. A pre-questionnaire was distributed to each participant prior to attending the focus groups. The aim of distributing this questionnaire was to collect opinions from designers on how they view the process of scheduling and the approaches that they currently use for developing schedules. Several question areas were presented to the groups but of relevance to this paper is the question:

> What are the main contributory factors to unplanned iteration occurring during the development of a new product?

Participants were first asked to provide their own specific answers to the question, following this they worked together to group similar answers under general classifications. An example of one of the groups output for this question can be seen in Fig. 2.

The information gathered in all three focus groups was discussed and analysed (with management input), resulting in the final identification of five general contributory factors to the occurrence of unplanned iteration:

1. The level of virtual testing (simulation) performed on a product during design
2. The level of upfront requirements definition of a product
3. The extent of new process and/or new technology risk in a product
4. The level and nature of the resources available for an NPD project
5. The level and nature of project planning involved

These five general variables were identified as being critical for fully explaining the occurrence of unplanned iteration in the firm. For a new project being analysed, the schedule over run (or slippage) associated with each of the variables is dictated by the type of project being undertaken; incremental, platform or radical. The defined variables will then in turn dictate the iteration inputs to be used for the scheduling model (Fig. 3). This approach enables a project manager to perform a risk analysis that provides a holistic perspective for project schedule uncertainty.

This proposed framework is a high-level representation of how a different approach can be used to model the occurrence of potential iteration in a NPD project schedule. Unlike previous approaches that have addressed this problem, a more

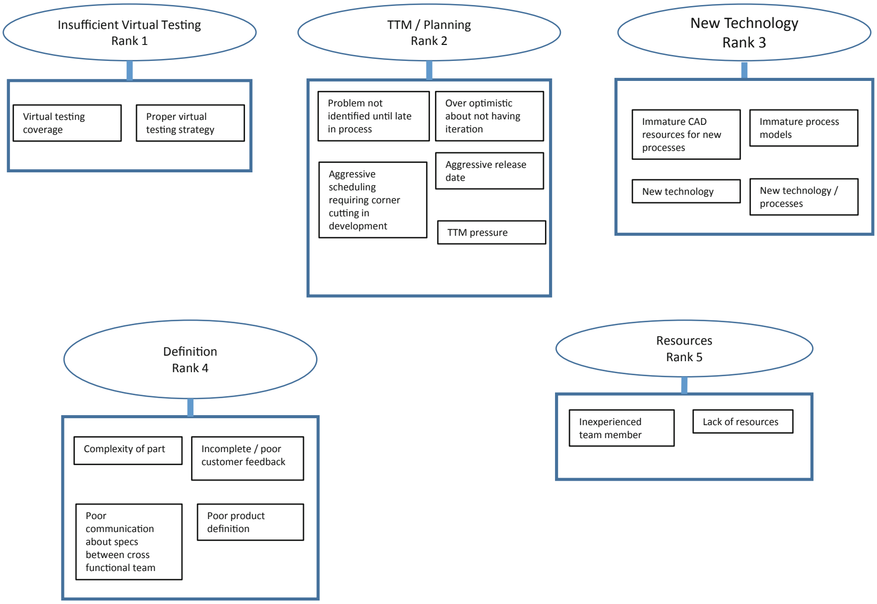

Fig. 2 Focus group responses

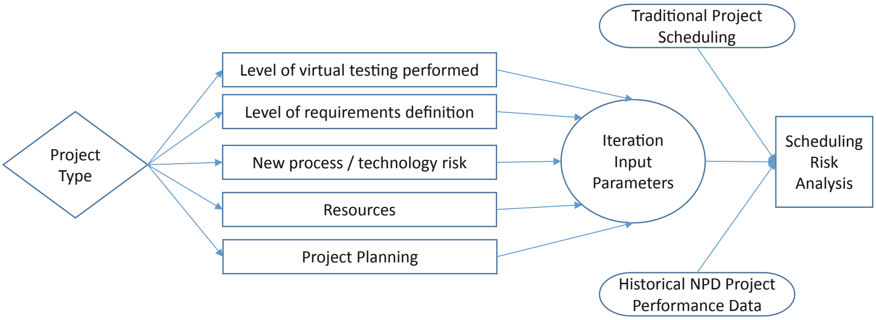

Fig. 3 Overview of proposed approach for determining producing a schedule risk analysis

descriptive layer is added to the modelling process that aims to minimise the uncertainty and inaccuracy that exists due to the use of purely subjective estimates. Using these factors to drive the modelling of potential iteration along with traditional project scheduling practices can provide a project manager with a thorough risk analysis for a project schedule. When analysing the schedule risk for a new project, information is entered for each of the five variables which in turn are used to calculate the required iteration input parameters (i.e. probability of iteration occurring and schedule impact). The general steps involved in the proposed modelling approach are:

1. Generate project schedule using traditional scheduling approach.
2. Input root cause information for current project being analysed.
3. Retrieve historical performance data for similar projects (i.e. observed project slippage etc.).
4. Based on information from steps 2 and 3, quantify potential project slippage due to iteration for current project.
5. Synthesise generic project schedule with iteration slippage calculations to produce overall schedule risk analysis.

An advantage of using root cause variables to model iteration slippage is that it can enable a firm to identify the biggest contributors to iteration in their process. Identifying which of the variables is contributing most to schedule risk can allow a manager to focus attention on the elements of a project which will potential cause the greatest amount of risk.

Additional validation of the developed methodology has been addressed by taking the approach to an additional case study firm and applying the general methodology. In this research study, the scope of this feasibility study was much smaller than with the primary case study firm. The emphasis in the second firm was on investigating the general problems which the organisation encounters in relation to iteration and NPD project slippage. The goal of this general investigation was to explore the feasibility of implementing the developed general methodology. This was achieved by conducting a series of semi-structured interviews with R&D management and staff within the organisation.

4 Lessons Learned

The impact that iteration has had on past NPD projects highlights the need for the company to address the issue. While unplanned iteration is not the only factor that causes project delays, it is the most problematic one. As the company consistently suffers from project delay due to iteration slippage, the successful modelling of iteration in the process will help to increase the accuracy of NPD project schedules. Having a means to predict the impact of all iteration scenarios can ensure more reliable planning of NPD projects from the beginning. Of particular benefit would be to know the risk of potential iteration for different types of projects. Being aware of the risk for a specific project type with certain characteristics would enable better upfront planning and more attention being given to the potentially most problematic aspects of a project.

A particular challenge for modelling potential iteration slippage in the company's process is the highly complex nature of their projects and NPD process. In reality any company that is producing technology based products will have complex and rigid NPD processes in place. As has been seen with the case study company, this complexity can prohibit the ability to dissect iteration in the process into well-defined feedback loops. This also restricts the effectiveness of more traditional methods for modelling iteration as they rely on the identification and re-organisation of individual iteration cycles.

Through the work done with the company, five variables that contribute to iteration in their process were identified: (1) level of virtual testing performed, (2) requirements definition, (3) new process/technology risk, (4) resources, and (5) required time to market. The proposed modelling framework presented in this paper uses these root cause variables as inputs for determining the iteration parameters required. The aim of this approach is that using these root causes as input variables will enable a more accurate representation of iteration that is reflective of the process being analysed. The outcomes of the various interviews with management as well as from focus groups with design staff indicated that these identified factors must be accounted for when modelling iteration in their process. Previous attempts at modelling iteration rely heavily on management experience to provide estimates for the iteration input parameters. Using subjective estimates for iteration probabilities and impacts does not provide the degree of accuracy and insight required by the firm.

While using estimates to determine iteration probabilities and impacts does create issues of reliability, solely using macro level project performance data would not provide a company with any insight into the contributors of iteration slippage. The proposed method is a hybrid approach where the identified contributory factors are used to calculate the estimates in conjunction with actual historical project performance data. The variables are used to drive the iteration input parameters for the model based on the type of project being undertaken but the model inputs calculated are bound by historical project data. For any given project the slippage associated with each of the variables will be dictated by the type of project being undertaken and the relevant historical data for that project type. The advantage of this is that it facilitates organisational learning regarding NPD projects and where improvements can be made to the process.

This approach differs from previous attempts as it uses the specific causes of iteration in a company's process. Using this method to model the occurrence of iteration rather than the use of subjective estimates helps to produce a more accurate representation of an iterative project. Previous models assume probability and impact inputs can be determined for any project with relative ease. However, based on the investigation into the NPD process of the case study company, the calculation of these input parameters is not trivial. Thus, providing a more descriptive approach will help to ensure that the model inputs used are as accurate and reliable as possible.

5 Conclusions

The problem of iteration in NPD projects is well established and can be a major obstacle from a project planning perspective. Modelling potential iteration in an NPD schedule is important in order to give a realistic view of how a project will perform. This case documents the work done to date with a high-tech company that has a long running problem of iteration occurring in their NPD projects. Evidence of the scale of the problems that iteration can cause in the firm was determined through analysis of past project performance data. For this company, on average, unplanned iteration is responsible for around 18% of all NPD project delay in any given year.

There are three main approaches which have been proposed to tackle the problem, (1) design structure matrix models, (2) pure mathematical/optimisation models, and (3) computer simulation models. Each method has advantages and limitations and the adoption of the most suitable approach will depend on the specific requirements of a company. In this case, the needs of the company result in computer simulation being the most suitable method due to the flexibility it offers.

The approach suggested in this paper is the identification of all factors that influence iteration in a company's process and the use of these variables to determine the probabilities and impacts to be used when developing an iterative project schedule. Information gathered from interviews with management and through focus groups with designers indicated that iteration could only be fully modelled in the process through the use of the identified contributory factor variables. The suggested approach differs from previous work as it eliminates the need for subjective estimates when attempting to model iteration in a process.

While some of the identified variables in the case study may be specific to this particular company, the approach of identifying the main drivers of iteration and subsequently using them in a model can be adapted for different circumstances. The contribution of this case is the proposed methodology of using the root causes of iteration in a process to drive the actual modelling of iteration in a project schedule. The use of this approach can ensure that the probability and schedule impact of potential iteration incorporated into a project schedule is accurate and relevant to the NPD process in question.

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A Study Analysing Individual Perceptions of PLM Benefits

Shikha Singh and Subhas Chandra Misra

Abstract PLM is the most desirable tool in the manufacturing sector these days. The offerings of PLM are still improving day by day in order to improve the cost, time, and quality of products. This case study discusses PLM benefits and individuals' perception of the existing benefits. Based on a survey conducted among Indian manufacturing firms, PLM benefits are ranked using t-test. This case study provides a general view of an individual's understanding and adaptability for PLM. On assessing the present status of PLM among users, top management may guide their subordinates to better understand PLM and improve the contribution of PLM for digitisation.

Keywords PLM · Benefits · Individual perception · Product cost · Time · Quality

1 Introduction

Product Lifecycle Management (PLM) is a collaborative concept which arose due to the limitations of previously existing design and manufacturing tools [15]. PLM is a collaborative approach which takes care of products from their conception, design, manufacturing and maintenance to their disposal [17]. Still, various practitioners utilise PLM as a design tool only [3] while ignoring other benefits of PLM. In order to reach the state-of-the-art of PLM, each individual of the firm must understand the PLM concept, only then will it be able to achieve the expected results [2]. Product lifecycle management collaborates people, processes, and technology [9] which takes a long time which led PLM to be considered as a '**long-term planned change**' [18]. PLM offers immense benefits to both the organisational and individual levels. PLM systems are the tools supporting the PLM approach. Institutionalisation of such new tools needs its persistent adoption by various users/stakeholders [8]. There exist

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multiple barriers to institutionalise PLM. Singh and Misra [15] studied the barriers to PLM institutionalisation and validated the identified barriers in a case study of an aircraft manufacturing firm. Further, Singh and Misra [16] worked to identify the core success determinants of PLM systems in an automotive firm. This chapter analyses the general perception of the PLM and its benefits among Indian PLM executives.

2 Benefits of PLM

The collaborative PLM concept helps to improve the quality of products due to improved design [1, 9], advanced manufacturing [1], and enhanced productivity [1]. Moreover, it reduces product delivery time [1, 2, 13], minimises the cost of new products [1] and digitises all the product development processes. Grieves [9] discussed and compared the PLM concept with 'Lean' thinking and emphasised it to be 'next generation of Lean thinking' as it reduces the waiting time for information retrieval [2, 18], minimises rework, and reduces to and fro movements by replacing the serial workflows. The information and communication technology (ICT) tools, i.e., PLM systems are developed to realise this concept and manage large volumes of data and information practically.

The collaborative approach removes the ambiguity related to product data and makes the product information 'cohesive', 'traceable', and 'reflective' [9]. Moreover, PLM suggests the improvements which lead to reduction in design changes [9], prototyping costs [11], product delivery time [2, 13], etc., in manufacturing firms. In addition to these improvements, PLM promotes organisational innovativeness [14] which ultimately facilitates the faster launching of new products [10] and digitisation of processes [7]. PLM systems integrate all of the different enterprise systems such as CAD, CAM, PDM, NC, CAE, etc. which contain knowledge about the products [18]. PLM systems provide an advanced interface for 3D design, simulation, and virtualisation which lead the organisations towards 'digitisation' [7].

The integration of all the data related to the different lifecycle phases of the product and the collaboration of all the stakeholders, provides coherent and cohesive product data throughout the value chain [9]. This improves communication with internal and external stakeholders. Such integration reduces information retrieval time and enhances innovativeness.

The three parameters viz. cost, quality, and time are considered to decide the effectiveness of PLM implementations [12]. Although these parameters are interwoven, the improvement in any of these parameters affects the other. Here, benefits of PLM are explained in terms of the suggested three parameters.

2.1 Cost

If we discuss the financial benefits of PLM in an organisation, it is evident that better data integration and collaboration reduce data discrepancy, thus helping each stakeholder to take better decisions about the product. Real-time data availability saves big money by a considerable reduction in wrong decisions and operations, which ultimately removes the reject and rework costs. This improves innovation in the firm by improving the product development and production costs. The virtual manufacturing on PLM systems allows virtually performing the manufacturing operations (including detail part preparation and assemblies) and deciding the best manufacturing process. The right process not only saves material but also time.

2.2 Time

The activities viz., integration of data, collaboration of stakeholders, and interoperability among systems, make the system robust and support all components of the organisation to work towards a common goal which reduces product delivery time

Table 1 List of benefits of PLM

Benefits of PLM	
Organisational benefits	
SuccOrg1	Reduced frequency of changes in product designs/processes
SuccOrg2	Reduction in waiting time to receive information from internal/external stakeholders
SuccOrg3	Decrease in rework
SuccOrg4	Increase in customer satisfaction
SuccOrg5	Reduction in product development and production costs
SuccOrg6	Reduce the product delivery time to the customer
SuccOrg7	Reduced time to launch new products
SuccOrg8	Leads towards digitisation
Individual benefits	
SuccInd1	Enhances innovativeness
SuccInd2	Improves individual productivity
SuccInd3	Facilitates a more comfortable platform to design the products
SuccInd4	Makes daily task performance simpler
SuccInd5	Reduces repetition of efforts

and faster launching of new products. The integrated PLM tools provide a more accessible platform to design the products. 3D visualisation and virtual manufacturing minimise the individual efforts of using different tools and make the PLM systems more useful for individuals. All the associated benefits, to be analysed in further sections, are listed in Table 1.

2.3 Quality

Through digitisation, PLM helps in reducing design changes, improving the quality, and achieving better customer satisfaction. Moreover, the collaboration aspects inform stakeholders immediately about the changes in different lifecycle phases. Such collaborations help to finalise the right design and process by considering the other phases of the product's life. PLM provides a standard bill of material (BOM) in order to give coherent product information across the value chain. The integrated data at one common repository reduces the waiting time for information retrieval. Availability of consistent data can help the organisation for further business activities which improves the individuals' innovativeness and productivity.

Various theories exist on technology adoption, such as Technology Acceptance Model (TAM) [5], Information systems success models [6], Diffusion on Innovation theory, theory of reasoned action, theory of planned behavior, social cognitive theory, unified theory of acceptance and use of technology [19]. All these theories are derived from the concepts of psychology and sociology. The individual perception of technology acceptance depends on various features of systems and the user's cognitive capability. Among all these theories, TAM was found to be the most suitable for this present study on the perception of PLM benefits. TAM notifies the two critical aspects of technology acceptance by users which are 'usefulness of system' and 'ease of use'. Considering these, the individual's perception on PLM benefits are recorded to get the current PLM status among PLM users.

3 Data Collection and Analysis

The PLM benefits were investigated as a part of the survey related to various aspects of PLM institutionalisation among PLM executives. The questions on organisational and individual benefits of PLM (Appendix) were a part of the survey on PLM institutionalisation. The online questionnaire was sent through the website of surveymonkey.com (https://www.surveymonkey.com/r/GXBJCBK) and Google forms (survey link: https://goo.gl/forms/0vAYJQMwRDeN3EdS2) to nearly 500 PLM executives. A total of 215 respondents reverted with valid responses, but only 207 could be used in the analysis after pre-processing of the dataset. Out of these 207 respondents, 27% were PLM systems users, 25% were developers, 23% were involved in PLM system implementation and deployment, 11% were PLM system solution providers, and the remaining 13% were engaged in different PLM domains such as consultancy, research, and testing.

The t-test was performed to check the hierarchy of all the benefits perceived by the users. On reliability check, the Cronbach's alpha was found to be 0.844 which shows the high reliability of the questionnaire [4]. Further, the t-test has been performed, with the test value 3, in order to check the importance of the PLM benefits and its impact on organisational and individual success. All the listed benefits are found significant and essential by the respondents. The ranks of the benefits are decided based on the mean difference with the test value. The positive differences show the acceptance of the benefits while its confidence interval indicates the significance level of the benefits. The t-test is performed in the SPSS 23 software, and the results are shown in Table 2.

As shown in Table 2, all the success factors were found to be significant to the respondents. Moreover, the factor 'SuccInd2 (improvement in individual productivity)' is at the top place. The following ranks are held by the factors 'SuccInd5 (reduction in repetition of efforts)', followed by 'SuccOrg8 (leads to digitisation)', 'SuccOrg2 (reduced waiting time for information retrieval)', 'SuccInd3 (easier platform for designing)', 'SuccOrg4 (increase in customer satisfaction)', and 'SuccInd1 (enhance innovativeness)'.

Table 2 One sample t-test statistics for PLM benefits

One-sample test

	Test value = 3						Rank
	t	df	Sig. (2-tailed)	Mean difference	95% confidence interval of the difference		
					Lower	Upper	
SuccInd2	34.391	206	0.000	1.60870	1.4094	1.6148	1
SuccInd5	32.840	206	0.000	1.56522	1.4577	1.6534	2
SuccOrg8	33.653	206	0.000	1.55556	1.4275	1.6256	3
SuccOrg2	31.331	206	0.000	1.55556	1.1728	1.4166	4
SuccInd3	32.148	206	0.000	1.55072	1.2078	1.4782	5
SuccOrg4	30.389	206	0.000	1.52657	1.3439	1.5643	6
SuccOrg1	29.026	206	0.000	1.51208	1.1691	1.4203	7
SuccInd1	29.711	206	0.000	1.50725	1.4644	1.6467	8
SuccOrg6	26.006	206	0.000	1.45411	1.4072	1.6073	9
SuccInd4	27.175	206	0.000	1.43478	1.5165	1.7009	10
SuccOrg5	19.578	206	0.000	1.34300	1.4556	1.6458	11
SuccOrg3	20.939	206	0.000	1.29469	1.3307	1.5389	12
SuccOrg7	20.325	206	0.000	1.29469	1.4712	1.6592	13

The analysis and results show that PLM is perceived by the executives as not only an organisational tool while it is perceived useful for the individuals also. The benefits such as 'improvement in individual productivity', 'reduction in repetitive efforts', 'easier platforms to design', are perceived as important benefits of PLM systems to individuals. Similarly, on the organisation level, it is recognised that PLM not only leads towards digitisation but also manages the product knowledge of the firm. The other organisational benefits of an increase in customer satisfaction and reduction in the frequency of changes in product designs/processes are also found more important than the remaining ones.

4 Conclusion and Future Suggestions

The available PLM benefits are listed to the best of the authors' experience and research studies. All the PLM benefits are found significant by the dataset of 207 respondents. Many more PLM benefits may be observed as its adoption and usage is propagating around the globe. The listed benefits can be tracked in any organisation, and such benefits may be checked as a success metric to PLM institutionalisation in an organisation. On realization of all the benefits, the successful implementation of PLM may be declared. Further studies and validation of the results can be done in other manufacturing organisations/countries in order to establish a broader perception about PLM benefits. This study will assist the future studies and development in this domain which will definitely improve the usability and adoption of PLM in organisations.

5 Appendix: Questionnaire on PLM Benefits

A survey recorded on 1–5 Likert scale, i.e., from strongly disagree to strongly agree.

1. Do you feel that the use of PLM systems reduces the frequency of changes in product designs/process in your firm?
2. Do you realise that the use of PLM systems plays a major role in the reduction of waiting time to receive information from internal/external stakeholders?
3. Does the use of PLM systems decrease the rework in your firm?
4. Do you feel that the use of PLM systems increases customer satisfaction?
5. Does PLM usage significantly reduce product development and production costs?
6. Does PLM usage significantly reduce the product delivery time to the customer?
7. Does PLM usage significantly reduce the new product launch time in the market?
8. Did PLM usage lead your organisation towards digitisation for designing, manufacturing, and repair and overhaul activities of products?
9. Does the use of PLM systems enhance your innovativeness?

10. Does the use of PLM systems improve your productivity/efficiency?
11. Do you agree that PLM systems facilitate an easier platform to design the products and understanding the product design?
12. Do you prefer using PLM systems in your daily task performance?
13. Did PLM usage reduce your duplicate efforts and make your work easier and comfortable?

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PLM Case Studies in Japan

Business Strategies and Key Initiatives

Satoshi Goto and Osamu Yoshie

Abstract It has been a quarter of a century since PLM system implementations began in Japan. This case study introduces PLM business scenarios of three Japanese manufacturing firms. They come from three different kinds of business situations. In particular, they describe the mindset of several senior operating officers in terms of business strategies and PLM positioning. For example, a factory head decided to address PLM ahead of ERP; a head of R&D group defined a PLM system for product designers as a digital working space, and a CIO strongly encouraged his employees to use standard PLM functionality as much as possible, and not implement heavy customization. Observing such executives' motivations on PLM promotion, the decision-making of management for PLM leadership is seen to be a critical success factor of PLM implementations.

Keywords PLM case study · PLM leadership · Decision making · Business scenario · Business strategy

1 PLM History in Japan

In Japan, PLM as a technical term was first seen in about 1995. At the time, concurrent engineering using 3D CAD data was booming, but the product design engineering style of Japanese firms was more focused on 2D drawings than on a 3D model data centric approach. Therefore, PLM was often positioned as a drawing data management system. Bills of Materials (BOM) that defined the product configuration were primarily managed by production management systems such as ERP/MRP systems rather than PLM systems. In the 2000s, Japan was facing the so-called "2007 Prob-

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lem," wherein it was estimated that millions of veteran engineers would retire by the year 2007. Due to this, there was a growing tendency to see PLM as not only a simple product information management system, but also as a knowledge management system for sharing the product engineering and manufacturing skill of veteran engineers. The role of PLM had evolved to support innovation in product development, even as a new generation of engineers came onto the scene.

However, in 2011, an unprecedentedly large earthquake struck eastern Japan, and the business strategies of Japanese firms became focused on the life-and-death problem of continuing operations rather than innovation in product development. It is undeniable that the desire not to halt production meant that management was more focused on maintaining supply chains rather than on new product development. In other words, strengthening supply chain management (SCM) and enterprise resource planning (ERP) systems had higher priority than PLM and CAD initiatives. Interest in PLM declined.

However, domestic demand for the coming 2020 Tokyo Olympics, along with expansive global strategies, has encouraged many Japanese companies to express their concerns about their current PLM systems not being able to cope with operational changes. In other words, as of December 2018, there is an increasing need in Japan to replace or rebuild aging PLM systems.

In addition, Japan is facing a rapidly aging society; one in four people is now over the age of 65. The Japanese government is encouraging digital transformation, with drastic reforms to the working practices of white-collar workers. Presently, an increasing number of companies are working with product development systems that make development highly productive, even with fewer people. Recently, in Japan, the fourth industrial revolution has caught the industry's attention. As if in response to this opportunity, Japanese manufactures are increasingly pursuing PLM systems combined with internet of things (IoT) technologies.

2 Case Studies

This section introduces PLM business scenarios in three Japanese manufacturing firms. These case studies are from three different kinds of business situation. In particular, they focus on the mindset of several senior operating officers in terms of business strategies and PLM positioning.

2.1 Case 1—"Implement PLM Prior to ERP"

Company A (anonymous) is an industrial machinery manufacturer. Recently, the company decided to renovate its aging PLM system. The intention was to support the design of similar products that account for more sales efficiency. The aim was for a speedy response to new product development.

In the past, Company A had major issues with creating a bill of materials (BOM) in the drawing work of the design phase. This work was time consuming as those responsible were required to manually input data. In addition, there was no data connectivity among BOM, 2D drawings, 3D models, and technical documents, as each of these was managed in disparate IT systems. Thus, much time and labor was spent on change activities, repeated or redundant input of information, and data queries made on an ad hoc basis. Moreover, all product data was not managed in an integrated fashion at the design stage, and this impeded the fluidity of designers and the balancing of the design work burden.

The first person to become aware of these problems was not a member of the design division. It was rather Mr. X (pseudonym), the head of the manufacturing factory. Mr. X was an employee who had spent most of his career on the shop floor. Later he was promoted to become a manufacturing manager, and then was appointed as head of the factory. As one of his business policies he, at that time, believed that implementing an ERP system would lead to improvements throughout the factory. However, he noticed that the data connections between design and manufacturing were extremely poor. For instance, when one veteran designer caught flu and was unable to go to work, no one was able to continue his design work, which resulted in a two-week delay in providing design information to manufacturing.

Presently, Company A is riding a booming economy and aims to use this opportunity to expand its business as much as possible. Mr. X became concerned that, given the current circumstances, sharing linked information between design and manufacturing would be too time-consuming. Mr. X feared that the factory would be overrun by the increased output of engineers in the product design process. He only became aware of such a problem after he was promoted to a position where he had to supervise everything including design processes. Mr. X began to wonder if the cause of this issue was a lack of functionality in the company's existing PLM system. Though he still believed that the ERP system was the most important IT system to influence production innovation, he began to realize that ERP alone was not good enough. This was why he accelerated the decision to renew the PLM system before addressing ERP.

Why was it necessary to implement PLM before ERP? As the factory head, Mr. X's reasoning can be summarized as follows. Various issues and troubles were beleaguering the factory. Among these, product design related mistakes were commonplace. For example, despite a design change, the drawings held by the manufacturing department were often obsolete. In addition, when it was discovered that some components used by the company were no longer being manufactured, it was extremely bothersome to pinpoint the scope of the impact, and search results often missed or left out items, or were inaccurate. When someone needed to find correct information, they were required to directly contact the designer responsible for the product. The designers tended to keep their own product drawings of the products for which they were responsible, but it was difficult for others to locate those drawings if the designer left the company. Mr. X's concerns grew, and he felt, "The situation is no good. If we don't integrate and manage design data properly in a PLM system, we will not be able to do design work. Our current management methods are at a breaking point."

His conclusion was that “ERP alone will not work. The upstream design processes are not sending down proper data. This means that we need PLM before ERP!”.

The PLM renovation project in Company A had only just begun, but the impacts were already being felt and noticed by the company, creating expectations for the future. First, data searches became faster. All design data were integrated within a single PLM system, allowing all necessary data to be found in one search. In addition, PLM’s access control function played a role in reducing the risk of mistakenly losing other people’s data. In the future, it is expected that expanding the rollout of new PLM functions will rationalize design work for similar designs, making sure sufficient labor is available for designing new products. Concerning design drawings, the PLM system promotes the distribution of 3D model data. This enables the design division to provide highly accurate 3D model data to the production engineering division. By doing so, the company expects to reduce manufacturing rework requirements and associated costs. In the future, the company aims to utilize production data though IoT technology and augmented reality for field service communicating with the PLM data.

2.2 Case 2—“PLM as Working Space for Designers”

Company B (anonymous) designs, manufactures and sells highly creative products for various types of urban office buildings and public facilities. In the last decade, this industry has faced severe competition regarding product development, and it has been challenging to generate products with fresh designs and functionality. Creating successful products requires an open, flexible work environment for product designers, and maintaining a corporate culture that respects innovative ideas.

First, let us go back to Company B’s situation in 2000. The product designers of the company were geographically dispersed, which resulted in none of them having experienced the benefit of digital engineering using 3D CAD and PLM. At the time, the groups with which product designers were affiliated were often the design departments within manufacturing factories. Working at a manufacturing factory site had a positive result in that they created product designs that showed an understanding of manufacturing requirements. However, these people were located far from the metropolitan areas that contained the company’s target markets and customers.

With that background, we now come to Mr. Y (pseudonym), who was responsible for product development at Company B. After joining the company, Mr. Y worked for a long time in the sales division. Though he had no knowledge of product technology, he was appointed the head of product development so that the company could develop products that were competitive from a sales perspective. One of his first decisions as the department head was to have product designers work near big city markets, rather than in manufacturing factories, because he felt they should work close to the sales department. Therefore, Mr. Y decided to move the designers to Tokyo.

What is an ideal work environment for product designers? Two to three years before considering PLM, Mr. Y began to feel the need for the kind of infrastructure favored by designers who seek to be creative. Infrastructure, in this case, does not simply mean having an IT foundation. Mr. Y emphasized that it means to first provide a "physical space" in which to work. For designers, the space must be comfortable or else good ideas are simply not created. When designers are not given a place to physically spread out materials and freely use their tools, thinking comes to a halt. When they worked in the factory, they could spread their things out across a wide-open space and repeatedly create product prototypes with complete freedom to move around. However, the Tokyo office space was congested. The product development done in that cramped and stressful place led to delays, generated higher costs, and worsened teamwork with the factory. These problems were later solved almost instantaneously by moving to a more spacious design-studio office. This meant that providing an open physical space was extremely important for the company's designers.

In order to produce hit products, is it good enough to only provide the right physical space? The members of the design team spent more time creating documents on word processors than they did with the CAD systems that were critical for creating great product designs. With his sales background, Mr. Y did not have much technical product knowledge, but he was doubtful that his designers were really able to focus on their design work. In addition, the version of CAD software in use at Company B was about four generations out of date, and nothing was being done for product data management. Mr. Y noticed that, "Designers need more than just a physical space. The work of design revolves around digital data, and a digital space is needed to manage that digital data!" This was a recognition that the design division needed the IT infrastructure of product information management.

Mr. Y began to study PLM seriously and came to understand its value. However, he was troubled by the question of how to convey its value to the board members, who would not be interested by appeals to the merits of reducing man-hours spent in design. Their corporate goals were to achieve sales goals and improve customer satisfaction. For example, talking with board members about the value of PLM requires an explanation of the "creating more new and original products than have been created to date." It was not easy to simply explain the effects of implementing PLM with respect to its financial impact. Mr. Y continued his appeals to the management team during executive meetings, and an agreement on PLM's value was finally reached by calculating it based on the management metrics favored most by the management team.

The company's source of business growth is its continual generation of hit products. Generating these hit products requires the creative work of designers. Providing a physical space alone is not enough. The company defined a key performance indicator—"Net Creative Time". In addition, assigning lots of people to create two-dimensional drawings by hand was extremely inefficient. One of the benefits of PLM is automatic generation of product variants. As the head of product development, Mr. Y came to believe that there was a need not only for a "physical space" but also a "digital space" in the form of PLM to really bring the talents of designers to full bloom.

In practice, the first steps in Company B's implementation of PLM were CAD data management and linking BOM with the ERP system. In other words, by rationalizing unnecessary work in detailed design, the company could focus on creating "Net Creative Time" for designers. The board members now understood the value of PLM, working on business process reengineering for development processes. The PLM revolution has not stopped with the simple implementation of an IT tool; rather, the company is beginning a fundamental makeover of its development processes. The future scope of PLM in the company includes a plan to create a decision system to give further feedback to the management team.

2.3 Case 3—"Don't Customize, but Use PLM as It Is"

Company C (anonymous) is a manufacturer of metrology equipment and related solutions. Most of the company's products are high-tech and controlled by software. Depending on the control programs, the company's products can be used for remote monitoring, and have captured market attention as digital transformation solutions for the era of industry 4.0. Mr. Z (pseudonym) has displayed leadership as the executive responsible for company-wide IT. While he was responsible for the implementation of all internal business systems starting from the strategy phase, he continually pursued optimal integration of software packages. For example, he exhibited a top-down leadership when it came to the various roles and business value of packaged business solutions used in the company, whether ERP, CRM, MES, HRM, sales management, or PLM.

Mr. Z always instructed his managers, "Use the standard functionality of packages as much as possible." He strongly asserts that, particularly in this current era of global competition, work that is not a factor in differentiation is a waste of time and money. In other words, he emphasized that work tasks that do not contribute differentiation of the company from others should be adapted to off-the-shelf IT packages to ensure that the package functions efficiently. Of course, whatever work that does enable company differentiation may indeed require customization, but Mr. Z recommends first using standard functionality provided by IT vendors for ERP and PLM systems in particular.

In the past, Mr. Z had accepted many proposals by external system integrators to customize systems when implementing systems. However, he later had an unpleasant experience because he was not able to back away from those customizations, which ended up being expensive in terms of system development and maintenance. He now feels that, if there is sufficient IT budget for investment, companies are better off rather investing in things that add value, such as technology development for product innovations, or production process innovations—and not customization of software.

Underlying his conclusions are major lessons gained from implementing an ERP system package at Company C. Mr. Z was successful in doing so without customizing the ERP system, using standard functionality as much as possible. With this success story, Mr. Z took the same stance with the company's PLM system implementation, namely the belief that standard functionality would be used when implementing the PLM system.

Predominantly, PLM is used in development and design to generate product innovation. When it comes to development and design processes, it was said to be difficult to standardize due to processes that vary by company and business unit. However, according to Mr. Z, there is almost no technological innovation in hardware development. Rather, there are many combinations of components and common designs, making PLM's standard functions effective for that area. Regarding the routine work of hardware design that is not a source of product innovation, he maintains that design processes should be rigorously rationalized. By doing so, Company C provides a very good example of a PLM implementation targeting so-called lean engineering.

Mr. Z worked closely with each of the operating divisions, and processes that at first glance may have appeared to be very different for each operating unit came to be seen as actually very similar. He had many discussions with end users. He was finally successful in getting an agreement that common processes could be used across the various business units. Often though, companies fail in this re-engineering process when implementing a PLM system, finding themselves unable to get user agreement on a vision for To-Be development processes that is common across the company. Instead, they tend to apply standard PLM functionality to specific partial As-Is processes within individual operating units. However, in the case of Company C, Mr. Z's strong beliefs and top-down style of leadership were successful in standardizing development processes for the entire company regardless of the operating unit in question.

In the end, Company C's PLM projects went live after an implementation period of 12 months. Afterward, the use of standard functionality in the company's PLM was still kept at 99%. This PLM system is clearly positioned as one piece of a company-wide IT strategy, and Mr. Z's top-down efforts were key to its success. In the future, Company C aims to create a single "trinity" system comprising PLM, ERP, and MES. This will be critical in helping them achieve their aim of becoming a leading smart-factory company in their industry.

3 Summary

This case study introduced the value of PLM technology for the benefit of corporate management and showed examples of the leadership of three senior executives. Each of these three individuals brought different backgrounds to their PLM strategies and implementations, but their proper directions for PLM, and their leadership as executives ensured the success of their PLM system implementations. It has been a quarter of a century since the implementation of PLM systems began in Japan. There is an increasing number of PLM packages available. They have many of the standard functions needed, along with good track records, allowing companies to achieve the value of PLM without undertaking any customization. Observing the executives' motivations for promotion of PLM, the decision-making of management for PLM leadership is seen as a critical success factor for PLM implementations.

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Developing the Requirements of a PLM/ALM Integration: An Industrial Case Study

Andreas Deuter, Andreas Otte, Marcel Ebert and Frank Possel-Dölken

Abstract The digitization of the industry, the drive towards smart factories as well as the Internet of Production (IoP) require rising smartness of products and services. Smart physical products are often mechatronic products that include increasing amounts of software. The development of software, however, comes along with new challenges for companies specialized in developing mechanical, electrical or electronic products. Some of these challenges address the product lifecycle management (PLM)-related business and work processes. The management of software lifecycles requires a much more rigorous requirements management. Furthermore, special solutions for management of source code in distributed development teams are needed. The build-process and testing activities need to be conducted in a systematic manner. The generation and provision of different licensing models need to be mastered and finally the issue of security needs to be addressed for any product that can be networked—which by the way is a strategic target of nearly any product developing company. Application Lifecycle Management (ALM) covers many of the above-mentioned issues. IT solutions for ALM are comparable to traditional PLM solutions, but focus particularly on software as a product. Thus, these systems have become widely used by software companies in the same manner as PLM solutions belong to the standard enterprise IT environment of companies developing physical products. With software penetrating traditional physical products, product managers, product developers, manufacturing staff etc. need to work with both, PLM and ALM, since neither solution is able to cover both domains sufficiently. However, ALM and PLM solutions feature redundant functionality. Thus, best practices for the systematic integration of ALM and PLM are required.

Keywords Product lifecycle management · Application Lifecycle Management · Smart products · Systems engineering

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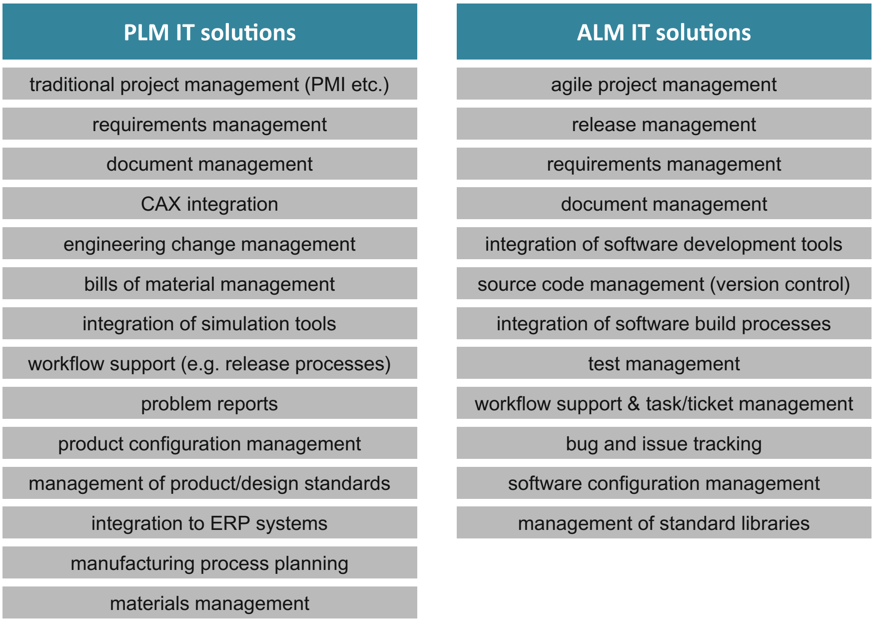
1 Introduction

Product Lifecycle Management (PLM) is defined as the business activity of managing a company's products across their entire lifecycles in the most effective way [1]. Traditionally, PLM addresses a product's hardware lifecycle. PLM is used, for example, to organize CAD drawings, to create different types of bills of materials (BOM), and to manage product variants. However, when developing mechatronic products, PLM capabilities reach their limits, because they do not address a product's software lifecycle. This is the task of the so-called Application Lifecycle Management (ALM). ALM organizes the software lifecycle by "indicating the coordination of activities and the management of artefacts (e.g., requirements, source code, and test cases) during a software product's lifecycle" [2]. Figure 1 outlines and compares typical functionality of standard PLM IT solutions and ALM IT solutions. Besides major differences, both system categories address many at least very similar tasks. Often the "logical task" is the same; however, the actual implementation of the IT functionality is different due to different perspectives on the same problem.

Hence, in smart product development, PLM and ALM coincide. Due to the rapidly advancing digitization of the industry, the product portfolios of industrial manufacturers are increasingly dominated by mechatronic products, which are also referred to as smart products. As many industrial manufacturers traditionally have a hardware-based product portfolio, they struggle to bring PLM and ALM together. They are



PLM IT solutions	ALM IT solutions
traditional project management (PMI etc.)	agile project management
requirements management	release management
document management	requirements management
CAX integration	document management
engineering change management	integration of software development tools
bills of material management	source code management (version control)
integration of simulation tools	integration of software build processes
workflow support (e.g. release processes)	test management
problem reports	workflow support & task/ticket management
product configuration management	bug and issue tracking
management of product/design standards	software configuration management
integration to ERP systems	management of standard libraries
manufacturing process planning	
materials management	

Fig. 1 Comparison of PLM and ALM core functionality

unclear about the use cases of a PLM/ALM integration, about subsequent requirements, and hence about the common process lifecycle landscape.

This case study demonstrates a practical approach to bring PLM and ALM together in a German manufacturing company. It starts with a brief theoretical overview on this topic. Section 2 introduces the case study and gradually explains the development of the requirements of the PLM/ALM integration. In order to provide a more general applicable view, Sect. 4 removes the company-specific elements of the case study. The article finishes with a concluding discussion.

2 Theoretical Background

Both PLM and ALM cover a multitude of business processes throughout the entire product lifecycle. As with any business process, they must be carefully designed prior to deployment. However, to manage them efficiently, appropriate tools must be applied [3]. For mature industrial companies with a portfolio of several thousand products, the management of hundreds of product development and product change projects at the same time in different locations all around the world becomes increasingly difficult and complex. To achieve competitive times to market and assure product quality as well as compliance with laws, regulations, and standards, IT-supported business processes are mandatory for PLM and ALM.

PLM and ALM are disconnected processes in today's industrial environments, because the management paths of the hardware development and the software development diverged in the last decades [4]. The hardware development dominated and still dominates the product development. Although the software became more and more important in the last years, the software teams and the hardware teams still work in parallel. They do not use the same tools and do not share the same mindset. However, it is nowadays accepted that smooth PLM/ALM integration improves product development and change processes due to better transparency and data consistency [3]. Based on this acknowledgment, all major global tool vendors enforce PLM/ALM integrations in their respective tool chains [5–7]. In addition, analysts have started to address the need for PLM/ALM integration [8]. A major improvement in a PLM/ALM integrated product development and change process is consistent traceability across all involved tools and data artefacts. Traceability is the ability to follow a requirement both forward and backward [9]. Active traceability management increases the quality of product development due to facilitated requirements fulfilment analyses [10]. Furthermore, ensuring consistent traceability allows the strength of both PLM and ALM tools to be leveraged, thereby benefitting from the best of both worlds. The strength of PLM tools lies in the efficient management of product structures including associated documents and files. ALM tools provide more sophisticated functionality for managing the product requirements, the related software code and the test cases [8]. Consistent traceability will ensure, for example, that a product requirement can be tracked down to the physical part structure in the BOM or to a specific software component in the source code.

As the industry has started to address the challenge, academia could increase the research effort in the field of PLM/ALM integration by providing general architectural patterns and reference models for integrated business and work processes [4]. Of course, both PLM and ALM are relevant to the well-covered research field of systems engineering. Systems engineering is an interdisciplinary approach used to enable the successful implementation of systems [11]. There are several concepts and methods guiding manufacturers in applying systems engineering in practice, such as the ISO/IEC/IEEE 42010 [12] or SYSMOD [13]. However, these concepts and methods do not address adequately the usage of IT systems. Since this is required to manage systems engineering efficiently, more efforts are required to outline how concepts from systems engineering can be implemented in integrated PLM/ALM environments. In [14], a systematic approach to create use cases for the PLM/ALM integration is proposed. However, this work lacks validation with real-world processes in industrial companies. The EU-funded project CRYSTAL addressed a complete tool chain with the focus on IT prerequisites [15]. Although PLM and ALM are addressed, concrete use cases and requirements from a user perspective are missing. To provide guidelines for system developers and industrial companies on the application of integrated PLM/ALM environments, more efforts are required to work out reference business processes and patterns, which match today's development environments.

In this case study, the term "requirements development" refers to the following three core activities of "requirements engineering" as stated in [16]: elicitation, documentation, and negotiation. Requirements engineering also includes the "requirements management" activity. This term describes the administration of the requirements developed, e.g., status control or the assurance of traceability. However, this case study does not include it.

3 The Case Study

3.1 Initial Situation and Cooperation Partner

Phoenix Contact is a leading supplier of electrical components and automation solutions for industrial applications, headquartered in Blomberg, Germany. In more than 50 worldwide subsidiaries, 16,000 employees develop, manufacture, and distribute more than 60,000 products to various industrial markets. The product portfolio includes pure mechanical devices such as connectors and cables as well as mechatronic devices such as PLCs or marking installation printers. As part of the Phoenix Contact digital transformation strategy, a global enterprise PLM project has been started to improve the future engineering environment. The objectives of the project include replacing a legacy PLM solution with a new one, namely Siemens Teamcenter [17], and the digitalization of all PLM-related processes. One of the processes in focus is the product development process (PDP), which describes the development phases and stage gates for mechatronic products.

The PDP follows the traditional development phases from product idea, conception, design, implementation, testing, and development release including the simultaneous development of products and the required production processes. Regarding mechatronic products, the PDP comprises guidelines for the design of the mechanical parts and the design of the electronic components. However, due to its different nature, different development guidelines were designed for the development of software, and this led to a split development process for hardware and software. For example, each domain manages requirements specifications, technical specifications, testing documentations, etc., in a different way. This led among other things to the rollout of an ALM tool, namely Siemens Polarion ALM [18], by the software development teams with just a low-level integration link to the existing legacy PLM solution. Consequently, the data in the ALM tool is only very tenuously linked to the data of the other domain specific tools, and in particular not to the legacy PLM tool.

One of the sub-tasks of the enterprise PLM project is the improvement and further integration of the PDP across all involved disciplines (development and production); this also encompasses improved harmonization between the ALM tool that has already been introduced and the new PLM tool.

Due to its competencies in that research field, the OWL University of Applied Sciences and Arts was asked to support in this subtask and a project called "PLM/ALM Integration" was initiated. The OWL University of Applied Sciences and Arts is one of the leading research universities for applied sciences in Germany. Currently, 173 professors teach and conduct research in the nine university departments. In addition, around 280 scientific assistants are employed in third-party funded positions. The third-party volume for the budget year 2017 was over 9 million Euros, an average of 53,000 € third party funding per professorship—which was above the national average of 31,990 € per professorship (2016).

3.2 *Project Motivation: Towards a New Understanding of Simultaneous Engineering*

Phoenix Contact's product portfolio comprises electro-mechanical products, electronic products, software products, traditional industrial services, such as engineering services, e.g. the design of solutions, as well as new software-based services, such as the support for the digital twin by providing product and product instance-related data as well as advanced cloud services. Furthermore, Phoenix Contact develops products and solutions on a global scale, which requires harmonized and standardized business processes and IT solutions in order to safeguard engineering efficiency.

Figure 2 outlines a product example (controller) that contains mechanical, electronic and software engineering. In the past, the software engineering usually focused

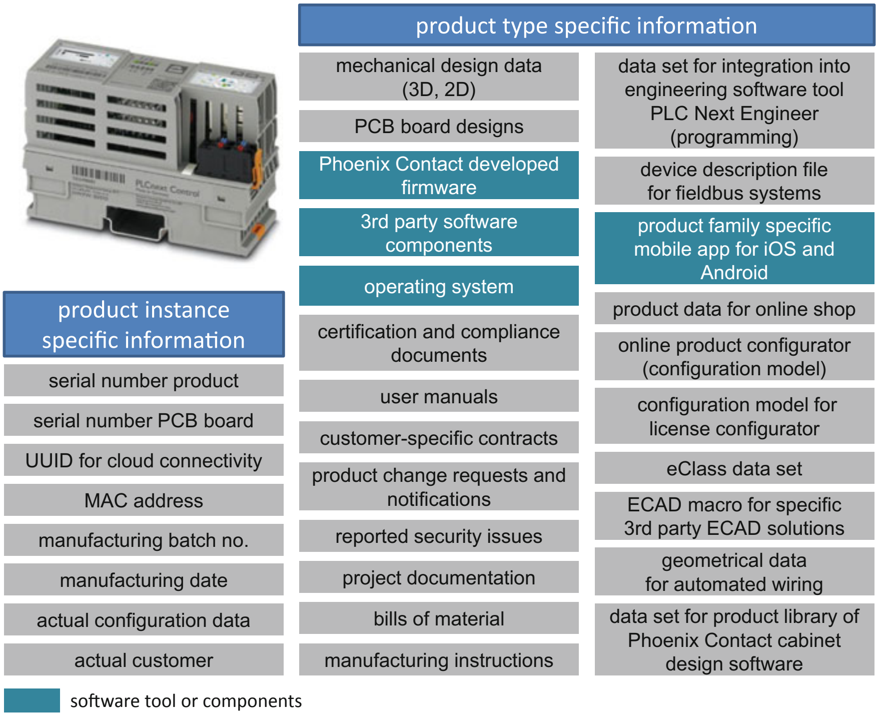


Fig. 2 Example product with typical product type and instance specific data and software

on the development of firmware. Nowadays, software development activities comprise:

- Product-embedded software
  - Internal operating system
  - Self-programmed firmware
  - Embedded third-party software components
  - Self-programmed standardized communication software, such as OPC UA servers, cloud connectors etc.
- Software related to “working with the product”
  - Functional libraries for engineering software tools
  - Domain or product type specific configuration software for different operating systems, such as Windows, iOS and Android
  - Related cloud apps for different cloud platforms, such as Phoenix Contact Proficloud
  - Sales configurator for online shops.

Therefore, the complexity of managing software throughout the product lifecycle has increased significantly. While it was possible in the past to separate mechatronic and software-related development and change processes, the interactions and dependencies between these disciplines have increased so far that an integrated working of the team and integrated working environments have become mandatory.

The classic product development or change process as depicted in Fig. 3 separates the development of hardware and software with regard to the used IT systems—for simplification reasons, we omit the fact that today a development process usually features the simultaneous development of product and manufacturing processes. The total set of requirements is split into hardware and software related requirements on which each domain can work independently. After reaching a defined maturity, product prototypes are built and tested until the final product can be released.

Figure 2 already suggests that today's product development requires many more activities than just creating the product itself. Thus, the future notion of simultaneous engineering will be much more inter-disciplinary than many product developers can imagine today. While the term 'simultaneous engineering' or 'concurrent engineering' usually addressed issues with regard of a deeper integration of product and manufacturing engineering, the concept of mechatronic engineering focused on the integrated development of hard- and software for one product. With current demands for speeding up times to market and the creation of new business models alongside the development of new products, the future product development and change processes at Phoenix Contact will encompass in many cases activities as shown in Fig. 4. Suddenly, disciplines, such as sales representatives, online shop responsible persons, corporate IT, corporate master data management, external suppliers of software tools among others, are needed to cooperate simultaneously in order to realize a new product family and associated business models and IT tools. This trend leads to two significant problems:

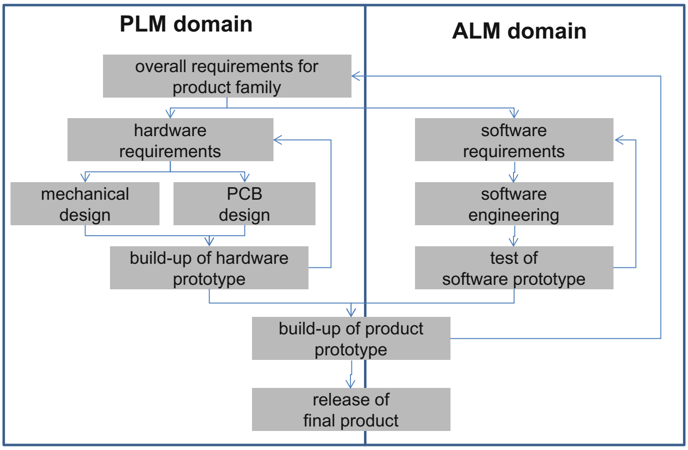


Fig. 3 Simplified model of separated cyclic development or change process

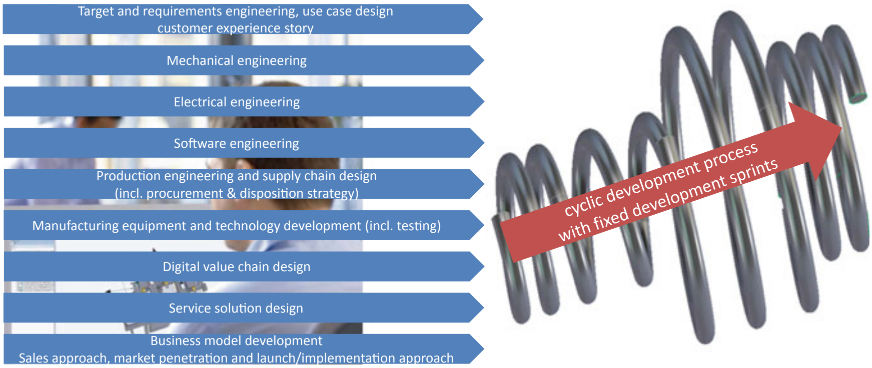


Fig. 4 New and broadened view on simultaneous engineering

1. Traditional project management according to standards, such as PMI, fails. Particularly traditional means of calculating project schedules and project budgets do not work anymore (if they ever did). Furthermore, new means for managing large teams across many organizational company departments and locations are urgently needed.
2. Working with different IT environments across different disciplines and departments significantly handicaps a close and meaningful collaboration and increases the probability of serious failures. Such failures are only detected throughout later stages of the product development and change processes leading to extraordinary delays in time and increases of budget. Furthermore, heterogeneous IT environments make the systematic application and use of defined and proven standards impossible.

Problem no. 1 can be mitigated by implementing components of agile engineering methods. Figure 5 depicts a spring model for development processes that outlines and summarizes needed changes for the operational management of complex projects:

1. The general project phases are not planned as a Gantt chart-like sequence of tasks, but by fixed cycles with defined cycle times (sprints). The definition of cycle times might vary over the project depending on the work to be done.
2. The stakeholders accept the incompletion of requirements due to limitations of knowledge as a matter of fact. Thus, the defined target state is not fixed.
3. Sprint teams need to be put together with regard to the interdependencies of their mutual tasks and competencies.
4. Tasks or work packages are grouped into stories based on their interdependencies, business processes or use case scenarios. Individual tasks are always assigned to a sprint. At the end of the sprint, the task has delivered a meaningful result. The sum of completed tasks allows a review of defined project targets. The target state might need to be modified based on gained insights or knowledge.
5. Milestones are still required. However, the meaning of milestones changes. A milestone does not define a fixed state for the solution (something is finally

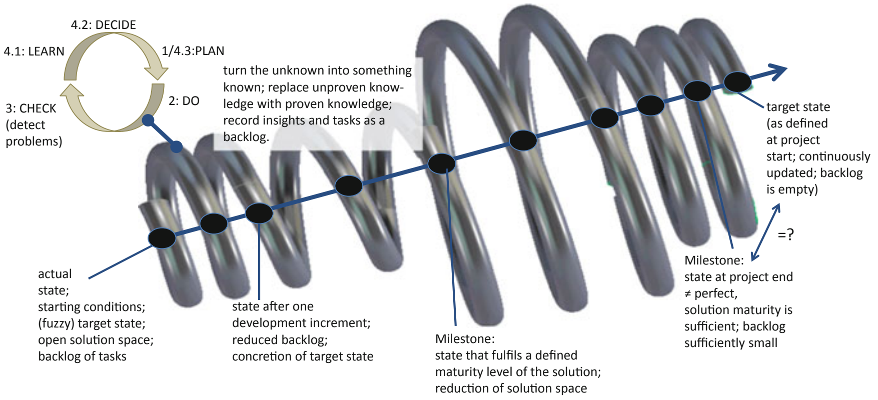


Fig. 5 Spring model of development processes

complete). It merely defines a meaningful level of maturity for the solution that is required to trigger other activities, such as e.g. the placing of orders at needed suppliers.

6. A final milestone defines the release of the project solution to e.g. sales, production etc. However, the solution is not perfect. It just reaches the required maturity level for the start of production, the introduction to the market or first customer applications.

This cyclic development further eases the gradual increase of product maturity. The increasing product complexity comes along with more "unwanted" and unforeseen technical problems. In order to assess this kind of challenge at early stages the systematic and excessive use of prototypes and samples is recommendable. Figure 6 outlines a general process from the first design samples of a plastics part via several functional samples to the start of series production. Each sample is part of the PLAN-DO-CHECK-LEARN-DECIDE-cycle as depicted in Fig. 5.

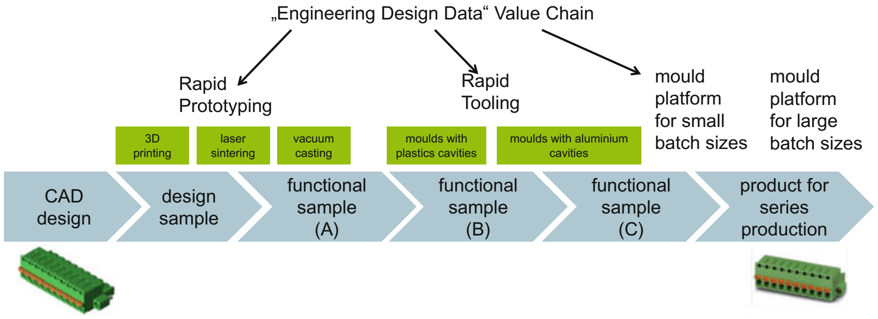


Fig. 6 Cyclic development process based on prototypes and samples

Indeed, a development process as depicted above is much better supported by ALM solutions than by PLM solutions. The latter usually provide support for traditional sequential project management methods, whereas ALM solutions provide more advanced support for agile methods that have first been applied to software development processes. Furthermore, processes, such as base lining, which support the development with samples, are more elaborated within ALM solutions. Thus, the application of ALM tools in standard product development beyond software engineering becomes meaningful and necessary if agile methods and tools shall be applicable.

With software embedded into hardware products and every product featuring network interfaces the issue of IT security emerges. Since software is never free of bugs, the management of security risks and problems becomes mandatory. IEC 62443 is an international standard focusing on IT security for industrial communication networks that defines requirements for reducing security risks throughout the development and manufacturing of products. Compliance to this standard requires sophisticated risk management as part of the requirements management. Furthermore, tracking of requirements with regard to product releases and a systematic patch and update management as well as communication of security issues to customers need to be implemented. Up to now, ALM solutions support these kinds of activities much better than traditional PLM systems leading to a coexistence of both system types within the product lifecycle management.

This need for coexistence of ALM and PLM leads to the above mentioned problem no. 2, the challenge for integrated cross-discipline teamwork on a non-integrated IT infrastructure. The single source of truth principle as well as the ubiquitous availability of information to any team member are mandatory in order to reduce the probability of failures. Thus, the approach as depicted in Fig. 3 needs to be replaced by a much more rigorous integration between hard- and software development across ALM and PLM.

3.3 Project Goals

Although the project team had a good understanding of PLM and ALM as standalone disciplines, it quickly identified that PLM/ALM integration is a rather imprecise term. To clarify the term, the project team needed to agree on the project objectives. It identified that before thinking about any implementation the requirements of the PLM/ALM integration had to be developed. Therefore, the project scope was set to include the following objectives:

1. Development of the requirements of the PLM/ALM integration
2. Validation of the requirements in the given tool chain based on the Phoenix Contact PDP

The tool vendor of Teamcenter and Polarion ALM, Siemens, had already implemented an initial integration of both tools, which was available for the project team.

The project objectives included a fit-gap analysis of the requirements, which will be identified in the case study, with the functionality already provided by the tool vendor.

4 Requirements Development

The project team started by analysing the current PDP (it should be said that any changes to the PDP were not within the project scope). The analysis included the identification of the involved roles, the data created, the data storage, and the links between the data. Regarding the management of a product's lifecycle, data management in Polarion ALM differs from data management in Teamcenter. In Polarion ALM, the software teams manage all data for all revisions of one mechatronic product, e.g., all versions of the firmware in a single Polarion project, called Polarion-Lifetime-Project. This is a central storage location in the Polarion ALM database containing requirements, design, implementation, tests, and defects. The data structure follows the principle of the so-called Sliced V-Model [19]. In opposition to this central data-oriented approach, in Teamcenter, there is a separate project item for each product revision. All hardware-related items, e.g., part items or CAD design items are linked to this project item. Initially, an item known as a TC-Development-Project item is created. With the support of this item, the first product revision is developed. The status of this item follows the milestones of the PDP. Once a first revision is released, each new revision is developed using what is known as a TC-Change-Project item. This item's workflow follows either the milestones of the PDP or the milestones of a dedicated change process, depending on the size of the change. Figure 7 shows schematically the general data organization.

After the data analysis, the project team developed a model for task distribution between the PLM tool and the ALM tool. This task distribution model allows the strengths of the PLM tool and the ALM tool to be leveraged without the need to create an interface between the two tools. This means that this activity clarifies which tool manages which type of data ("single source of truth" strategy). The task distribution model is illustrated in Fig. 8.

The model leverages the strength of Polarion ALM as a requirements management and test management tool as well as an issue tracking system. Therefore, the task distribution model proposes managing all requirements (hardware, software, and mechanics) and their test cases in Polarion ALM. Since BOM management and the management of hardware-related data are clearly the strength of any PLM tool, the different types of BOM and the hardware data remain at the heart of Teamcenter.

Once the task distribution model had been defined, work moved on to define in detail which type of data (e.g., a document) from the PDP should be managed in which system. We ought to mention that the engineering IT environment of the industrial partner consists of more tools than Polarion ALM and Teamcenter. Therefore, this stage considered other tools in addition to just these two, e.g. a specific Phoenix Contact project management solution.

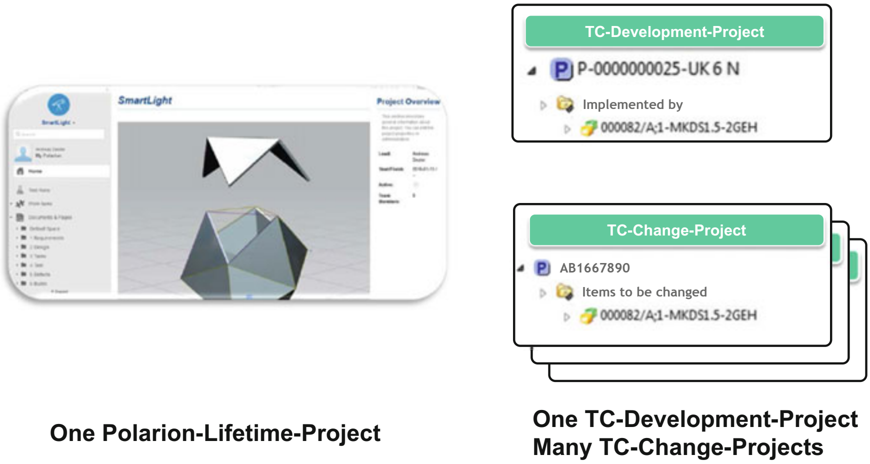


Fig. 7 General data organization between Teamcenter and Polarion

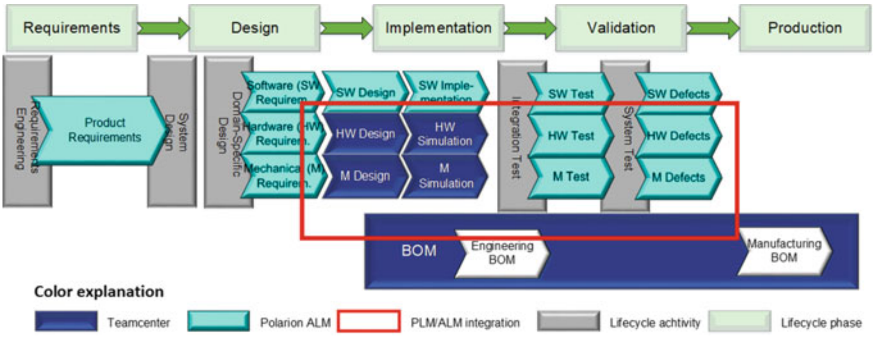


Fig. 8 Task distribution between PLM and ALM (inspired by Prendeville and Pitcock [8])

As Fig. 8 shows, even with a task distribution model in place, there are points of interaction between the PLM tool and the ALM tool. For example, the hardware requirements managed in Polarion need to be linked to design items in Teamcenter.

To identify the requirements of such interactions, the project team developed a set of use cases considering the above-described data structure containing Polarion-Lifetime-Projects, TC-Development-Projects and TC-Change-Projects. These use cases provide a sequence mapping how a specific actor works with both systems. Table 1 shows one example.

To realize this use case, the interface between Teamcenter and Polarion ALM must fulfil the following requirement: “It shall be possible to link a Teamcenter item with a Polarion baseline”.

Based on this principle, the project team created thirteen generalized use cases for integrated PLM/ALM processes and developed the corresponding requirements

Table 1 Use case "Linking Polarion baseline and Teamcenter item"

Actor	Project manager
Trigger	The project reaches the last milestone of the PDP
Goal	To create a link between a TC-Development-Project item revision and a baseline in the corresponding Polarion-Lifetime-Project
Post condition	The link is established
Normal flow	1. Revise the TC-Development-Project item via a workflow 2. Create a baseline in the corresponding Polarion-Lifetime-Project 3. Link the TC-Development-Project item with the Polarion baseline

of the interface between Teamcenter and Polarion. Table 2 shows the use cases and requirements. Two of the requirements merely address the usability of Teamcenter. Therefore, they are not listed. For a better understanding of the use cases and requirements, apart from the already introduced terms Polarion-Lifetime-Project, TC-Development-Project and TC-Change-Project, some more terms are explained:

- Item/work item: A piece of information containing a status and several attributes. Teamcenter uses the term "item", whereas Polarion uses the term "work item". The status is set via workflows.
- Polarion document: A WORD like document containing a set of work items and free text elements.
- Polarion project: A data storage in Polarion containing several information. A project contains folders and Polarion documents.
- Polarion baseline: A baseline remembers all data of a Polarion project existing at the time the baseline is set. Two different baselines can be compared.
- Polarion HEAD revision: Polarion creates a new revision of any artefact whenever the artefact is saved. Each revision has a unique identifier. The HEAD revision is the latest saved version of the artefact.
- Assignee: A person, who is identified in the corresponding attribute of an item/work item. This person is in charge for the item/work item.
- Traceability report: A view either in Teamcenter or in Polarion showing the relationship of linked items/work items as table or graph.

As one can see, all requirements refer to a specific type of traceability, e.g., linking a Polarion project to a Teamcenter item, creating comprehensive trace reports, and informing a linked item about a change to the partner item. Assuring traceability in a straightforward manner is the core requirement of any PLM/ALM integration.

4.1 Requirements Evaluation

As mentioned, there is an initial implementation of a PLM/ALM interface provided by the tool vendor Siemens. A subsequent step of the project team evaluated which of

Table 2 List of identified use cases and requirements

#	Use case (short description)	Requirement
1	1. A Polarion work item is created 2. This work item is being linked to a Teamcenter item 3. Polarion work item is being changed 4. Teamcenter item gets a mark/icon 5. Assignee or owner of the Item is able to remove the mark/icon *The same also in opposite direction*	It shall be possible to link a Polarion work item with a Teamcenter item When a Polarion work item is changed, the linked Teamcenter item shall get a mark
2	1. TC-Development-Project item or TC-Change-Project item is created by a user 2. A user creates a Polarion document in the corresponding Polarion-Lifetime Project 3. The user links this document with the TC-Development-Project item or TC-Change-Project item respectively	It shall be possible to link a Teamcenter item with a Polarion document
3	1. TC-Development-Project item or TC-Change-Project item is created by a user 2. A Polarion-Lifetime-Project is created by a user or it already exists 3. A user links this Polarion-Lifetime-Project with the TC-Development-Project item or TC-Change-Project item respectively	It shall be possible to link a Teamcenter item with a Polarion project
4	1. The last milestone in the development process is reached 2. TC-Development-Project item or TC-Change-Project item is set to a dedicated status via a workflow or is being revised 3. A user creates a Polarion baseline in the corresponding Polarion-Lifetime-Project 4. The user links this Polarion baseline with the revision of the TC-Development-Project item or of the TC-Change-Project item respectively	It shall be possible to link a Teamcenter item with a Polarion baseline
5	1. A user wants to set the status of a requirement work item in Polarion to “released” 2. Polarion checks automatically if all linked work items/items have the status “released” or similar 3. Only if all linked work items/items have the status “released”, then status of the requirements work item can be changed *The same also in opposite direction*	The status of a Polarion work item can only be changed if the status of the linked Teamcenter item has a dedicated status

(continued)

Table 2 (continued)

#	Use case (short description)	Requirement
6	1. Change process is started via workflow in Teamcenter 2. If a certain milestone in Teamcenter is reached, another workflow will be started 3. Teamcenter sets a baseline in Polarion 4. A baseline in Polarion is automatically created	When a Teamcenter item status is set via a workflow, a baseline in a linked Polarion project can be created automatically. The TC administrator can configure the rules for building the name of the Polarion baseline
7	1. A Polarion work item is changed 2. Polarion automatically creates a new revision of the changed work item 3. If a user adds a link from a Teamcenter item to a Polarion work item, the user selects a work item revision 4. A link between the Polarion work item revision and the Teamcenter item is created	It shall be possible to link a Polarion work item revision (not only the HEAD revision) with a Teamcenter item
8	1. Enter time into a Polarion work item. It is stored in the attribute “time spent” of a work item. 2. Save the work item 3. Transfer the times to a Teamcenter item	It shall be possible to access the data of any attribute of a Polarion work item from the linked TC item
9	1. A TC-Change-Project item is created in Teamcenter 2. In the corresponding Polarion-Lifetime-Project a requirements document is created to enable the requirements elicitation in Polarion	When a Teamcenter item is created, a document in Polarion shall be created. The TC administrator can configure the name and the folder of the Polarion document
10	1. Tracking defects in Polarion (Defects discovered by the customer or internal development) 2. Bulk edit defects: Selecting defects in the table overview of Polarion 3. Transfer selected defects as problem report to Teamcenter 4. Teamcenter takes over the defects as Problem Report	It shall be possible to link more than one Polarion work item with one Teamcenter item in a single action
11	1. Teamcenter items are linked with Polarion work items 2. Create a traceability report in Polarion 3. Report includes all links between Teamcenter Items and Polarion Work Items	When creating a traceability report in Polarion, all linked items shall be included *The same also in opposite direction*

the identified requirements the current tool chain already meets. The originally tested tool chain in February 2018 consists of Teamcenter V11.3, AWC V3.3, Polarion ALM V2017.1 and Connector V1.3.0. The project team repeated the tests in October 2018 with the updated tool chain: Teamcenter V11.5, AWC V4.0, Polarion ALM V2018.1, and Connector V4.0. (Remark: The Connector is a dedicated software linking Teamcenter and Polarion ALM.) The test sequences contained several test cases, which were derived from the use cases. The test execution showed that the given tool chain currently meets six of the identified requirements. It should be mentioned, that the tool chain fulfils more requirements. However, these were not identified from the use cases.

4.2 Project Wrap-up

The proposed task distribution model between PLM and ALM can be considered a valuable finding of the project, because it paves the way to PLM/ALM integration without connecting the tools via an interface.

Furthermore, it was not expected that all the identified requirements would already be implemented in the given tool chain. As Phoenix Contact does not expect the rollout of the PLM/ALM integration in a short term, this is not critical. However, before this rollout, which includes the connection between the tools, Siemens must implement the most important requirements. In order to identify the most important requirements, the project team prioritized the identified requirements by interviewing relevant stakeholders at Phoenix Contact.

To conclude, the project team contacted the tool vendor and discussed all the identified requirements. The tool vendor acknowledged that all requirements are comprehensible and most of them are usable for a broader customer audience. The project ended with an agreement between the project team and the tool vendor to manage the implementation of the identified requirements in the order of priority jointly.

5 Generalized Approach

Although the development of the requirements of PLM/ALM integration took place in the specific environment of a manufacturing company, one can outline a general basic project approach. If there is a product development process (PDP) in place, the following steps are generally applicable:

1. Create a data model for ALM and PLM respectively.
2. Identify all tasks of the PDP and assign these tasks either to PLM or to ALM.
3. Remarks: Some tasks will not be in PLM or in ALM as there are always other tools in use.

4. Identify the data (e.g., documents) and define its management place (PLM or ALM). Remarks: One can consider completing Steps 1–3 before working through the next steps. This will allow a smooth transition to a PLM/ALM integrated development process without the challenging process of creating a tool interaction.
5. Identify points of PLM/ALM interaction and describe these interactions with use cases.
6. Derive and formulate the requirements from the use cases.
7. Forward the prioritized requirements to the internal IT department and/or the tool vendor.

The following process of requirements management includes the implementation, monitoring, and evaluation of the requirements. All these tasks are specific to the environment used in a manufacturing company. The actual implementation depends on the given tool chain.

6 Conclusion

PLM/ALM integration relates to the field of systems engineering. It is increasingly required for smart product development to develop high quality products that can be brought to market quickly. Even if manufacturing companies are aware of this fact, they struggle to design and implement an integrated PLM/ALM environment. One of the factors hindering them in doing this is the identification of the corresponding requirements.

This article describes the development of the requirements of a PLM/ALM integration in a manufacturing company. It is a systematic approach, which starts with the identification of the task distribution between PLM and ALM based on defined data models without connecting IT systems. This step lowers the threshold toward an integrated PLM/ALM environment, because an interface does not need to be built between the IT systems. However, a major quality characteristic of any development—comprehensive traceability across all disciplines and tools—can only be assured if such an interface exists. In this industrial case study, the requirements of this PLM/ALM interface were identified by use cases. Although the article extracts a generally applicable process for the development of requirements, a manufacturing company needs to have a good understanding of PLM and ALM as stand-alone processes. The proposed process will be difficult to follow if this is not the case.

A potential threat to validity is that the described process ends without the validation of the implemented requirements. However, the tool vendor confirmed the usefulness of the requirements and expressed the will to implement them.

As mentioned above, academia could intensify its research activity in the field of PLM/ALM integration. A potential subject to investigate is the challenge of introducing an integrated PLM/ALM environment in different departments: a software developer will have to deal with PLM concepts, a CAD designer will have to handle requirements engineering following ALM ideas. This article did not address this challenge. However, it provides useful hints to help manufacturing companies to maintain their competitiveness in the age of digitization.

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Product Lifecycle Management at Viking Range LLC

William Neil Littell

Abstract This case study describes the strategy implemented by Viking Range, LLC as they implemented a PLM strategy to unify multiple engineering departments into one engineering organization. While the company was not burdened by as much legacy data as some implementations, considerable constraints existed within the company with respect to resource allocation and not delaying the launch of new products. The author addresses typical PLM challenges and change management strategies and how Viking Range overcame these challenges. The case study ends with advice to readers who wish to implement a PLM strategy within their own company.

Keywords Change management · CAD conversion · Configuration management

1 History and Context of the Company

Viking Range is a world leading kitchen appliance manufacturing company located in Greenwood Mississippi, USA. The company was founded in the late 1980s to fill the founder's niche desire for commercial appliance performance and style for home consumers. The company grew quickly through the 90s and 2000s, expanding the product line from only ranges to the full suite of home kitchen appliances, including products such as ovens, refrigerators, wine cellars, dishwashers and chimney wall hoods. Today, Viking Range is one of many companies owned by Middleby (MIDD), the largest commercial appliance company in the world.

2 Drivers for Improvement

The rapid growth of Viking Range during the 90s and 2000s led to a disjointed design engineering infrastructure within the company. Even though there are four manufacturing plants located within the same town, each plant was struggling to keep up with

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the market demand for premium performance products as well as design, launch and support products. The demand for commercial style and performance for the home market drove Viking to acquire a few other divisions, such as a refrigeration division from Amana and the purchase of the prestigious cabinetry company St. Charles. The rapid growth created an environment where the divisions worked diligently to launch new products, but did so in relative isolation from each other. Because of the rapid growth of the company, many engineering processes, such as engineering change processes, were manual, paper processes. This yielded an environment where extraneous paperwork led to uncertainty with respect to the timing of the process; where is it, and when will it be done. A lack of visibility to the changes with respect to the potential impacted models, and there was not a closed loop to implement the new parts on the line. At this point, the Viking Range portfolio of products was rapidly reaching into the hundreds of products, with thousands of both purchased and fabricated parts, and a newly formed commercial products division where products would be designed in Fullerton California and fabricated in Greenwood Mississippi.

The young Viking Range managed engineering data via network shares. 3-ring binders with prints for fabricated parts were distributed to the plant floor, which yielded an unending challenge to maintain the current version of the prints on the shop floor. Engineering Changes were processed via manual paper based processes, which could potentially become lost in the shuffle of daily work challenges and were difficult to trace. Maintaining service documentation was a challenge as well. The amount of nonvalue added processes required to process engineering changes thorough multiple departments combined with the volume of production and the desire to launch new products culminated in a strategic initiative to improve the flow of data within the company.

3 What to Achieve, and Why

During the early 2000s design engineering at Viking wished to modernize the efforts of the company to improve the flow of information within the company, reduce scrap caused by mistakes, and reduce the amount of time that people spent looking for information. A strategic task force was developed to attack these perceived sources of waste. The result of this task force was a charge to implement a product lifecycle management strategy to increase reuse at the company as well as increase the design efficiency of the company. Several key drivers were identified including: (1) Vaulting and revision control of CAD and supporting documentation (2) A release process to control the data (3) Workflow automation of tracking approval processes through the lifecycle of the data.

Vaulting of CAD data was required to actively manage the revisions of the CAD. We wanted a way for everyone to have access to all of the engineering data regardless of the division. We identified opportunities for improvement across the company through initiatives such as fastener reuse. The vaulting of CAD also enabled the engineering organization to better communicate with suppliers and service, because these departments could more easily access the information. One goal with respect to data management was also to control artifacts related to a part, such as test information and supplier specification sheets. Additionally, by standardizing the vaulting of data, we were able to standardize part numbers as well as the nomenclature of our parts across all of the plants. This enabled us to develop scripts to make it easier for our engineers to design parts correctly and consistently between each plant. Viking Range is very good at fabricating sheet metal parts. We made a conscious effort to implement the same type of fabricated part equipment at each of the plants as we expanded, which allowed engineering to develop custom scripts to automate the development of sheetmetal parts. For example, a designer specifies a standard material and thickness when they first create a CAD part. From this initial setup, the CAD system automatically applies the appropriate bend allowances for that material. Furthermore, because of how fabrication was implemented, we have the flexibility to move fabricated parts between plants if the volume of needed parts exceeds the capacity at one plant.

A standard release process was required to not only provide traceability of the processes, but also to control what is visible to the shop floor. We wanted to be able to track the current state of any process so that we could begin to gather metrics around where our bottlenecks exist within the approval process itself. Additionally, we wanted to ensure that fabrication could only access the latest release of the data on the floor, to take the guess work out of what was the most current version of the parts.

We also desired a standard process through which we could conduct our work that helped to take the guess work out of who should approve the data. At this time, the company had over 900 people working to create our products, with many people being assigned to a specific product family. As the organization grew, it became cumbersome to determine who needed to approve each engineering change, and so engineers were conservative with inclusion of people on changes. This yielded many people involved in the change process, no visibility of where the change was within the process, and general ambiguity concerning the timing of changes. Communication to the Service organization was stressed because Service was handled out of one separate and centralized location away from the manufacturing plants.

4 What Viking Range Decided to Do

Viking Range created a task force to evaluate the next generation engineering design tools and techniques. The charge of the task force was simple: What are the best tools for designing sheet metal appliances and managing the data available on the market today. The task force decided to make no assumptions concerning existing projects and data. The company invited the major CAD vendors to showcase their products onsite, and through this evaluation the company determined an optimal CAD configuration as well as a PLM system to provide management of CAD and company processes related to new product development.

5 Planned Activities

The task force determined the best suite of product definition tools to meet the requirements of the organization. An output of this task force was an implementation plan, which included these phases:

1. Standardize the engineering tools
2. Standardize the engineering processes
3. Optimize the engineering processes
4. Extend the infrastructure to other departments
5. Implement tools to automate product definition
6. Extend functionality through reporting and integration into other systems.

6 Actions Taken

Even though the project had a definitive plan, the development and deployment of the tools was not as straightforward. The engineering organization had many products that were being developed using the legacy CAD system, and so it was determined that we would implement the new PLM system and purchase connectors to allow us to manage both legacy and new data in the new PLM system. This compromise allowed the company to keep current projects on track, while allowing new products to be pursued in the new CAD system. The new PLM system was rather agnostic with respect to CAD data management, which allowed us to work towards standardizing and optimizing the engineering processes before we standardized the engineering CAD. Because we were able to develop the PLM in a way that was CAD agnostic, projects were not pursued in the new CAD system as quickly as we anticipated. Overall, it took several years to finally migrate all active CAD to the new system.

There was never a large project to convert all CAD at a particular time. Rather, we ended up converting projects, then platforms, then plants to the new CAD. There were typical change management issues which had to be negotiated with the users, but overall the process was less painful than a “big bang” CAD conversion project.

The strategy to implement the PLM backbone before migrating CAD was the correct decision for Viking Range. As the engineering organization became more homogenous, it was easy for the other departments to see the effect of a system to manage approval processes. We began to extend PLM to other departments to help them manage their own internal processes. In doing so, engineering was also able to become more integrated with those departments, which further drove process synergies.

Service was one of the first big beneficiaries of the new PLM system. Once the engineering organization began to process work using the same processes, we were able to connect Service so they could see the changes as they were being implemented, instead of after implementation. We quickly added a service approval point within the engineering change process, to bring Service even further into the engineering change process. This enabled the company to avoid costly changes early in the engineering design process before changes were implemented. For example, Service could review proposed engineering changes and then provide comments to the engineer with their concerns from a service perspective, which allowed us to address these concerns before the implementation of the change.

With the success of the Service approval within the engineering change process, we also included procurement, quality, fabrication, and manufacturing. The ability to add value to the process before it was released allowed us to reduce the likelihood of rework created by inadvertently implementing a change that negatively impacted a different department.

We were also able to track reasons for changes and rework because we now had a system to track our engineering changes. This yielded several other approval nodes, such as an agency approval (responsible for tracking changes to update certification paperwork) as well as a programing node, for input related to general manufacturability of the parts. We were able to implement many of these approval nodes in parallel with each other, which cut days out of the approval process. We further optimized the processes by adding routings, so people only see parts that are relevant to them. For example, procurement does not see engineering changes to fabricated parts, as these changes have no impact to procurement.

After several years of process and organizational optimization, we began to work together to optimize processes for each of the departments. Quality wanted to have a checklist of fabricated parts that needed to be checked. Finance wanted to be aware of the financial impact of new parts, as well as provide part costing earlier in the part release cycle. Procurement wanted a way to track new parts by commodity, as well as track Production Part Approval Process (PPAP) processes. Service wanted each engineering change to create a service change within the service organization. We were able to implement automated solutions to each of these opportunities through a combination of metadata manipulation and scripting. For example, we added a commodity classification to the metadata for each part. This allowed us to classify new parts generally upon creation, but allowed the system to automatically assign the appropriate procurement agent to the new part to acquire quotes and PPAP samples.

7 Results and Benefits Achieved

One of the unanticipated results of the PLM system was the evolution of our engineering change processes. When we started, we functioned as several engineering departments. Within a year or so, we had basically standardized our engineering change processes regardless of the division. Through working together, we developed and implemented best practices across the organization, which yielded a robust process that can be used by all divisions. Today, Viking Engineering uses the PLM system to schedule engineering resources as well as manage engineering projects. The system allows project team members to track the status of the processes related to their projects.

In 2009, the Viking Range PLM implementation was audited by an external organization. At the time of the audit, the implementation was about four years old and users were very comfortable with the new PLM processes. There had been several upgrade projects, several improvement projects as well as the implementation of some custom scripting to improve efficiency. As the implementation evolved over time, it was easy to lose sight of the total savings realized for the implementation. The audit attempted to retroactively baseline our implementation through old reports, interviews, and other artifacts. The results of the audit yielded $34,578,000 in savings through avoided costs either through new efficiency gained, or through projected savings in scrap reduction. The internal ROI for our implementation was determined to be about 7 years. Granted, it is very difficult to quantify cost savings on events that did not occur, but we do believe that the implementation has yielded many process efficiencies and capabilities which were not possible before the implementation.

8 Next Steps

The PLM infrastructure at Viking was implemented 12 years ago. The tools we use have become engrained in our way of doing business, and so we are working to determine the next generation of engineering tools. Since the original implementation, our company has changed significantly. Perhaps the most impactful change has been the inclusion into the Middleby portfolio of companies. Because Viking Range is now one of the dozens of appliance companies owned by Middleby, we have opportunities to increase collaboration and innovation. We are also actively working to include very advanced features into our appliances, which require closer connections with our suppliers and customers.

9 Lessons Learned

Viking Range quickly decided to implement more sustainable data management practices. Early on, the company used an "intelligent" part numbering nomenclature, which in theory helped the organization to manage parts. As the company grew, this nomenclature became unsustainable in that individuals in the company requested more information to be added to the nomenclature. If we did not move away from the intelligent part numbers, we might have ended up with very long part numbers which would have been more difficult to work with. One of the drivers for database driven data management was the desire to manage metadata with the part, which is more robust. The compromise for the company was to implement a 6-3 part number nomenclature, where the base 6 digits were generated sequentially, and the -3 was used to iterate against the PN. This allowed the engineering organization a very quick way to create a base part specification that could be iterated against (using the -3) without having to create a new engineering model or drawing. For example, a base part might be called 123456-000. In the PLM system, users search for the 123456* of the part specification to find the "base" drawing of the part. If this part was eligible to be a painted part as one of the configurations of our products, the part could be iterated in the BOM to be 123456-001. This allows our ERP system to track the painted versions of parts in the BOMs for different configurations, but allows engineering to only have to maintain one version of the part in PLM. The -3 suffix can also be used to control other related information as well. For example, Viking Range frequently includes French literature with our products. The base part number for the literature may be 234567-000, whereas the French version of the literature may be listed as 234567-100. This allows users of the PLM system to quickly search for the base of 234567* to see all languages of the literature for a particular product.

Culture and change management are perhaps the most difficult things to address with a PLM implementation. The active management of processes might require some people to perform additional work from what they are used to, which might make them feel as though the "new way" is slowing down processes. At Viking Range, we worked through this by creating a local user group, comprised of users from each functional area and department. This committee of stakeholders was developed using "power users" from the respective departments, who were used as a conduit between the users and IT/PLM administration. This helped the users find resolutions quickly, while also helping to give a voice to the different users across the company. The group worked together to understand the different business processes at each division and then standardize on one process which worked for each of the divisions. The ability to understand the perspective of each different department was critical to the success of identifying and eliminating nonvalue added work as well as developing requirements for new enhancements and processes.

With respect to the development of new processes, we worked very hard to ensure a balance between a lean process and one that was flexible enough to capture every scenario. Implementers of new PLM systems must make their users aware of the fact that it will not be possible to anticipate every scenario and attempting to do so is a losing battle. People must still communicate with each other instead of attempting to build a process that can capture every contingency. The way that we implemented this was through different dispositions of engineering changes. For example, if assembly requests that we move a hole in a fabricated sheet metal part 0.25 in. to make it easier to assemble, we probably do not need to go through the overhead of a full engineering change process. We implemented an expedited process for these very low risk engineering changes so that we can implement them quickly. Most of the time with this particular type of change, we can have updated parts to the line within one business day. This is powerful, because it yields a responsive engineering department as well as fostering communication and synergy between departments. The end result is a better product for our consumers.

10 Key Takeaways

- Change management must be a part of the PLM implementation plan.
- Consider changing your practices to leverage the strengths of PLM instead of trying to make the PLM system adapt to your company.
- Baseline your current state and build an audit into your project plan post-implementation.

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Management of Virtual Models with Provenance Information in the Context of Product Lifecycle Management: Industrial Case Studies

Iman Morshedzadeh, Amos H. C. Ng and Kaveh Amouzgar

Abstract Using virtual models instead of physical models can help industries reduce the time and cost of developments, despite the time consuming process of building virtual models. Therefore, reusing previously built virtual models instead of starting from scratch can eliminate a large amount of work from users. Is having a virtual model enough to reuse it in another study or task? In most cases, not. Information about the history of that model makes it clear for the users to decide if they can reuse this model or to what extent the model needs to be modified. A provenance management system (PMS) has been designed to manage provenance information, and it has been used with product lifecycle management system (PLM) and computer-aided technologies (CAx) to save and present historical information about a virtual model. This case study presents a sequence-based framework of the CAx-PLM-PMS chain and two application case studies considering the implementation of this framework.

Keywords Virtual models · Provenance · Product lifecycle management · Virtual models · CAx · Discrete event simulation · Meta model · Cutting simulation

1 Introduction

Virtual modeling and simulation tools are helping industries to speed up their product and process developments. Virtual models can be used to model and analyze a manufacturing system before it is constructed or put into operation. They also can be used for impact analysis of changes in existing manufacturing systems or designing non-existing ones. Since virtual modeling and simulations are time-consuming, reusing previously built virtual models, is extremely valuable for the users. In addition, the extra information (provenance information) can help evaluate the level of reusability of that model, when reused.

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Product lifecycle management systems (PLM) are the platforms for the management of product-related data. They manage product and production-related data such as virtual models by integration with different computer-aided technologies (CAx). For the management of provenance data and information, a provenance management system has been developed and used in the application case studies, which will be explained later. With the implementation of a CAx-PLM-PMS chain, both virtual models and historical information are available for users.

Two application case studies have been selected from the car manufacturing industry to demonstrate such a CAx-PLM-PMS chain. In the two case studies, two different CAx tools have been selected. The first case study employs a discrete event simulation (DES) model of a crankshaft production line and the second case study uses a finite element simulation in optimization of a metal cutting process.

Engineering tools and management systems used in the case studies are:

CAx: Case study 1. Plant Simulation as a DES tool

Case study 2. Deform 2D/3D as a metal cutting process simulation tool

PLM: Teamcenter as a product lifecycle management system
PMS: ManageLinks as a provenance management system

Siemens develops Plant Simulation and the Teamcenter software programs, and Scientific Forming Technologies Corporation develops the Deform 2D/3D software program. ManageLinks is an in-house developed application for managing provenance information.

In the next section, a short background of the actual models and the virtual models used in the two case studies will be presented. A brief explanation of PLM, virtual confidence and provenance data will also be given. In the third section, a sequence-based framework for the CAx-PLM-PMS chain will be explained. In the fourth section, the framework will be implemented in the two case studies, and the last section will cover the conclusion and future work.

2 Background

In this section, different areas of the CAx-PLM-PMS chain are introduced briefly. First, a definition of virtual models will be presented, and some information about DES models and metal cutting process simulation models, as the two types of virtual models in the case studies, will be provided. Afterwards, PLM as the second part of the chain will be explained, and finally, the virtual confidence concept and different types of provenance data will be presented.

2.1 Virtual Model, the Discrete Event Simulation Model, and the Metal Cutting Process Simulation Model

A model is a representation of an entity or a system of interest, and if a model is created by a computer program, then it would be classified as a virtual model. Simulation is the imitation of some real object or system. Simulation is a process of using a model to study the behavior and characteristics of a physical or conceptual system in which one or more variables of a model are altered in a simulation to see the results [1, 2].

Simulation models can be dynamic or static, continuous or discrete, stochastic or deterministic based on their characteristics. In one of the case studies, DES was used as a virtual model. In the DES, variations of the state variables have been tracked at a discrete set of points in time [3]. In the second case study, a metal cutting process simulation is used. The cutting process is a type of material removal process. In the material removal processes, the sharp cutting tool is used to mechanically cut the material to achieve the geometry [4]. The cutting process is simulated with a continuous finite element simulation in which some variables such as material removal rate, tool wear, cutting speed and chip formation can be analyzed.

2.2 Product Lifecycle Management

Anything that is produced and offered to the market is a product. Each product has a life cycle, which can be divided into different phases. The typical product lifecycle phases are: business idea, requirement management, development, production, operation, maintenance and disposal [5]. A product of a company can be managed in its lifecycle. The business activity of the management is the product lifecycle management [6]. This management has been done by managing the product and the production-related data, and the PLM systems are well-known for this kind of management [7]. As a need for product lifecycle management, PLM systems are integrated with different engineering software programs such as computer-aided technologies (CAx). The integrations provide PLM systems the capacity of transferring and managing data and information. However, these integrations can be made on different levels; depending on the level of integration, the data transition methods are distinctive. Regardless of the integration level, for the management of transferred data, they need to be structured and attached to the core of the PLM systems. The Bill of Material (BoM), Bill of Process (BoP) and Bill of Resources (BoR) are considered as the three main structures of a PLM system that manufacturers use to manage Product, Process and Resource (PPR) data [8–10].

BoM is the structure of different parts and assemblies of a product. BoR shows the structure of a factory and the resources required for production of a product, and BoP is a structure of different processes and their relationships for manufacturing of a product. The three above-mentioned information structures, provide connection points for linking the virtual models to the PLM system.

2.3 *Virtual Confidence, Provenance Data and Provenance Management System*

The last part of the CAx-PLM-PMS chain is the provenance management system (PMS). But what is provenance data and why does it need to be managed?

Managing provenance data can increase the reusability of virtual models and subsequently increase the level of trust and utilization of virtual models and tools in an enterprise. The level of virtual confidence in that enterprise can be measured by the level of trust and utilization of virtual models [11].

The 7W framework has been used as a basis for the data model of PMS. By recording the information of the answers to the seven different questions (Who, Where, Which, Why What, When and How), provenance data can be captured [12, 13]. This information about activities that are leading up to create a virtual model, identifies who creates this model, what the model is, where, when and why the model has been created, according to which criteria and how the model has been created [14]. For example, the purpose of a metal cutting simulation activity, which is stored in the PMS as the answer to the why question from those 7Ws, is to find the combinations of some input parameters such as cutting speed and depth of cut, to reach the acceptable or optimal values of some objective such as tool wear and chip size. This information is crucial for later reuse, and by managing them in the PMS, they can be sought, retrieved and validated for reuse.

As mentioned before, the provenance management system has been developed in-house to manage provenance data. It consists of a database (Link DB) which is a high-performance database (Caché) developed with the cooperation of InterSystem. It also contains a user interface named ManageLinks and an open-source ontology editor (Protégé) used to define ontologies. The PMS system is integrated with the PLM system through the API (Fig. 1).

With the PMS and through the user interface, whenever a virtual model is designed, the user can save extra information about activities that will lead up to the creation of that model. This information helps users in evaluating the possibility of reusing that model, in addition to how to use them later in other circumstances if they are applicable.

In the next section, a sequence-based framework will be presented to explain how the three links of the chain can be connected to each other for the management of virtual models and their related data.

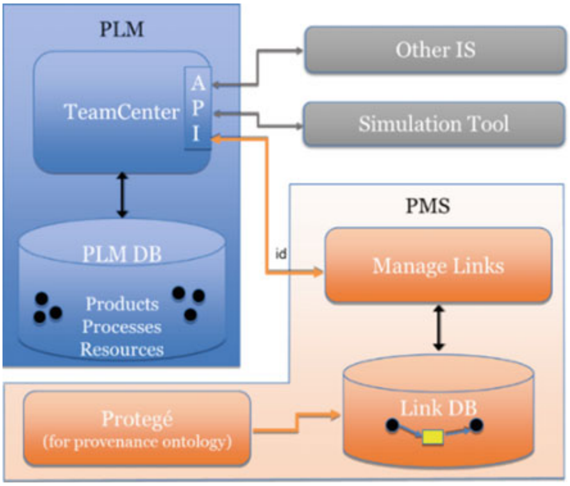


Fig. 1 Integration of PMS and PLM

3 Methodology

For the management of virtual models and their related data and activities, a sequence-based framework has been developed (Fig. 2). This framework explains the different steps of managing data in the CAx-PLM-PMS chain, and it has been divided into different areas.

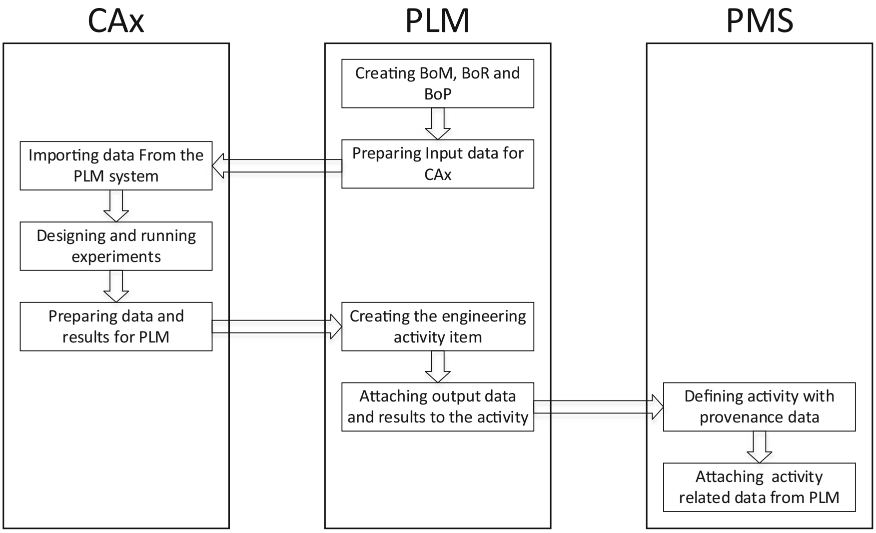


Fig. 2 The sequence-based framework of the CAx-PLM-PMS chain

For the management of the virtual models and their related data and activities, some steps needed to be fulfilled as specified in the framework. Depending on the type of integration between CAx and PLM systems, some of these steps can be eliminated or expanded to more sub-steps.

At the first step, three main structures of the PLM system (BoM, BoR, and BoP) have to be created. These structures can include some input data or the virtual models which are used by the CAx tool. Depending on the CAx tool and the type of integration, a number of other steps may need to be done for the preparation of output data for the CAx tool, such as creating export packages. Next steps are in the CAx area, and they are a number of engineering activities, such as virtual modeling, simulating, optimizing and analyzing. The related data of those engineering activities such as virtual models and results need to be prepared and in some cases exported to the PLM system. The second group of steps in PLM is about creating activity items in the PLM system and attaching the virtual models, their related data and results to those activities.

Moreover, in the PMS system, the provenance data of those activities can be recorded and managed.

In the next section, these steps will be explained for the two case studies with more details to clarify how the sequence-based framework of the CAx-PLM-PMS can be implemented.

4 Implementation

In this section, two case studies that used the sequence-based framework of the CAx-PLM-PMS chain will be explained. Both of them involve the production of crankshafts in an automotive manufacturing plant.

4.1 Case Study 1: Discrete Event Simulation of Crankshaft Production Area

In the first case study, a crankshaft production area has been divided into four production lines, and four DES models were created for each line. By using DES models of the production lines, a conceptual DES model has been designed for the entire crankshaft area. Finally, a detailed DES model has been generated from the conceptual model of the crankshaft production area. In each of the activities, a virtual model has been created and managed according to the sequence-based framework.

In the following, the implementation of different steps in the framework for one of the DES virtual models will be explained. The procedure will be more or less the same, for all other DES models and their related activities.

Creating BoM, BoR and BoP. PLM systems are working as a platform for the management of data. They are providing data for different CAx applications as well as saving the produced data from those CAx applications. As mentioned before, the core of the PLM system (BoM, BoR, and BoP) has to be defined as a backbone for the structuring of all data. For both selected case studies, some unique BoM, BoR, and BoP have been used. Depending on the activity, a different part of these structures can be applied for the data management.

A BoM is a structure of assemblies, sub-assemblies and different parts of a product. All the information related to the product is embedded or attached to this structure, such as different variants, part material, CAD models of the product, etc. In the two case studies, a unique part representing a crankshaft is considered as the product (top-left of Fig. 3).

A BoR is a hierarchical structure of the crankshaft production plant. The first level of this structure is the production plant, and it is divided into four main production lines (bottom-left of Fig. 3). In each line, there were a number of stations, and in each station, there were a number of different machines and transportation resources such as gantry robots and conveyors. On the other hand, the BoP shows different processes

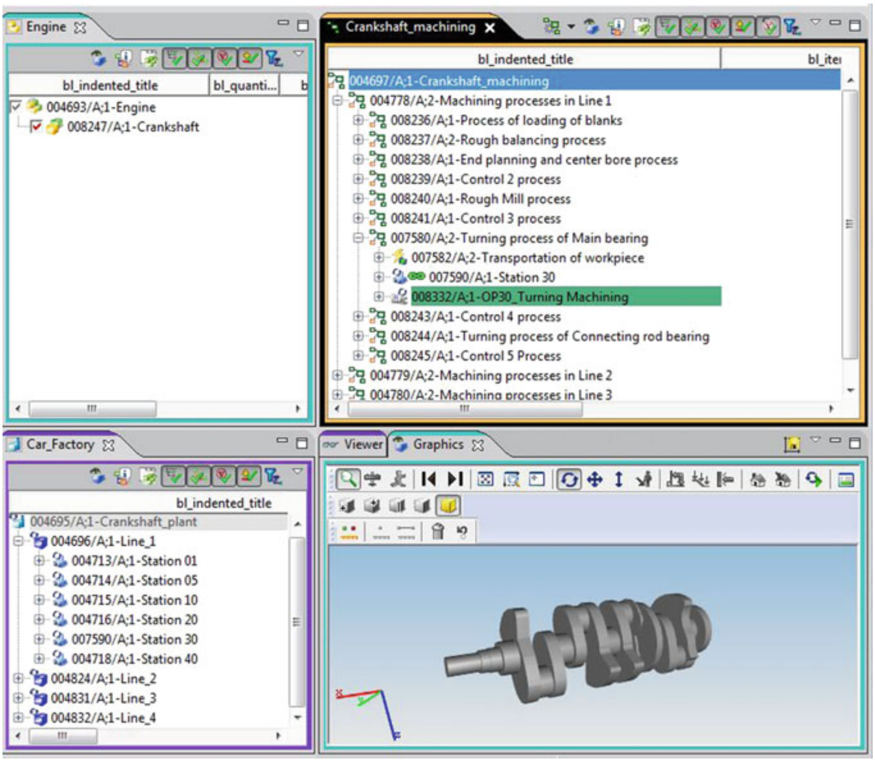


Fig. 3 BoM, BoP, and BoR for the crankshaft

of manufacturing a product. Here, in the case studies, the crankshaft machining process has been divided into four groups of machining processes in each line, and in each line there is a number of sub-processes that represent different operations and transportations (top-right of Fig. 3).

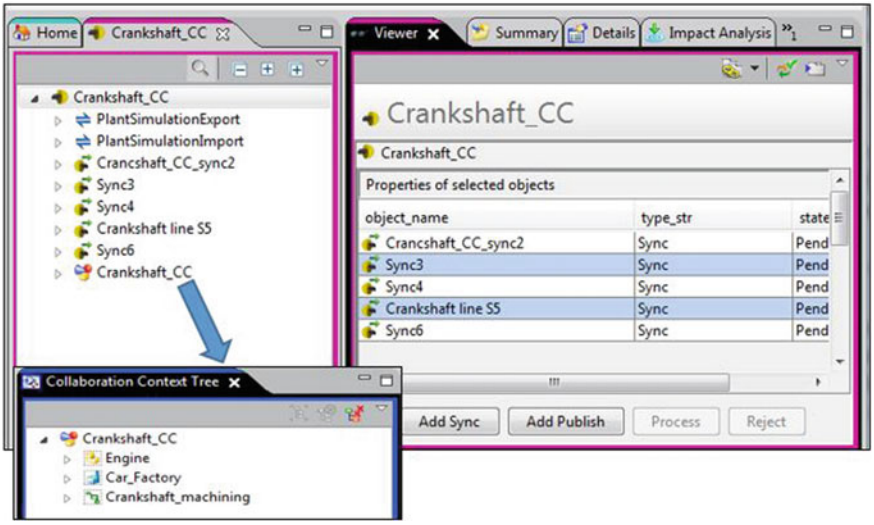
A BoP is a meeting point of the product and the resources. In a process or an operation, some resources are used for production or assembling of a part of the product. Therefore, BoM and BoR are connected to BoP at different levels, according to the relevant parts and resources to that process level. For example, the crankshaft as the product and the turning machine as a resource in station 30, have been attached to the turning operation of the main bearing in the BoP.

All the above-said structures are required for DES of processes and resources with their specification, but they should be prepared to be exported from Teamcenter.

Preparing input data for CAX. Based on the type of integration between Plant Simulation as a CAx tool and Teamcenter as a PLM system, for the use of PLM data in Plant Simulation, BoM, BoP and BoR structures should be gathered in a data package called "Collaboration Context" and later exported as PLMXML file.

Collaboration Context holds a collection of data which are contained in the structure and configuration contexts. Collaboration Context can be used to share these data with a third-party application. In this case study, a collaboration context has been created to gather BoM, BoP, and BoR of the crankshaft production line (Fig. 4).

After creating a collaboration context, for exporting data from Teamcenter, the "Application Interface" has been used to export data from Teamcenter. The Application Interface is a tool in Teamcenter and it has a business object that is used to



object_name	type_str	state
Crancshaft_CC_sync2	Sync	Pend
Sync3	Sync	Pend
Sync4	Sync	Pend
Crankshaft line S5	Sync	Pend
Sync6	Sync	Pend

Fig. 4 Collaboration context and application interface for exporting and importing data

transfer data between Teamcenter and an external application (Fig. 4). In Teamcenter, business objects are the fundamental objects used to model the business data.

The “Application Interface” item business object for Plant Simulation consists of the following three items:

- PlantSimulation Export: This item specifies the types of data which should be exported. For example, the MTTR (mean time to repair) of resources has to be exported to the PLMXML file.
- PlantSimulation Import: This item is used to specify the import process from Plant Simulation to Teamcenter.
- Collaboration context: the collaboration context item specifies PPR structures for the Plant Simulation software program.

By generating this business object, all available data in the PLM system for DES have been prepared and readily imported by Plant Simulation.

Importing data from the PLM system: This is the first step in the CAx area. The Plant Simulation software is the CAx tool in this case study. There is an object in Plant Simulation for communication with Teamcenter. This object can be configured for data transfer by setting the URL of the Teamcenter server and entering the Teamcenter username and password.

Plant Simulation can import and use XML files. Since Teamcenter exports data as a PLMXML file, it should be converted to XML, according to a defined “Style sheet” which is selected in the Teamcenter object in Plant Simulation. With the Import function, users can specify a table for structures and data, and also retrieve JT files from Teamcenter. In this case study, a table consisting of all data about product, processes, and resources from Teamcenter, has been imported and used within a frame in the model.

Designing and running experiments: For this case study, a DES model for machining processes in line-1 has been designed based on the data received from the PLM system. Afterward, a simulation of the production line has been run to find the bottleneck (Fig. 5).

Preparing data and results for PLM: The Plant Simulation software can generate an HTML report from the simulation results. This report is sent to Teamcenter by the export function of the Teamcenter object in Plant Simulation. The DES model also is saved in Teamcenter, but it could also be saved as a new revision in case the model is a modified version of an existing model.

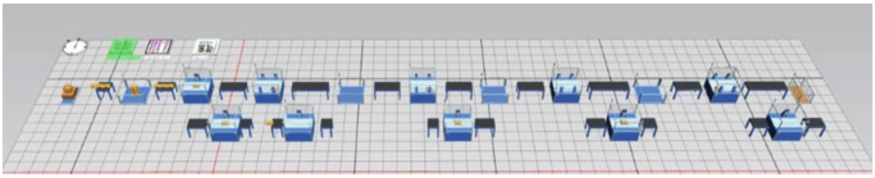


Fig. 5 Modeling and simulation of crankshaft production line-1

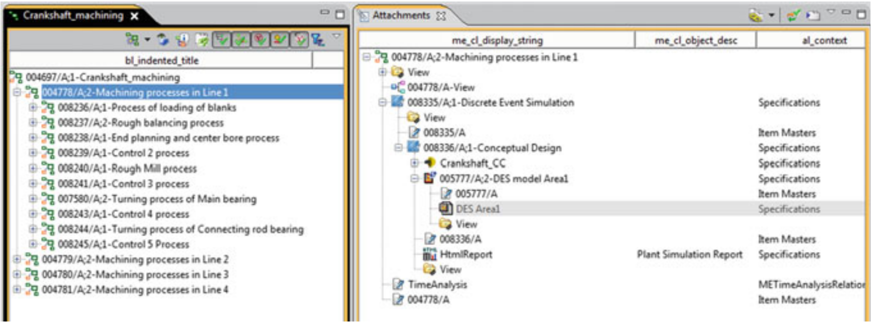
Creating the engineering activity item: In this project, a new business object (item) is defined to structure virtual models and all related data, in the Teamcenter data model.

An “engineering activity” of the DES is defined under the “Machining process in line 1” item in the BoP, to structure the DES model and its simulation report. Another “engineering activity” item is created under the “Discrete Event Simulation” item which is named “Conceptual Design.” The engineering activity has to be created on the same level as the manufacturing system is simulated. For example, if it is a line simulation, then it should be attached to the line level, and if it is simulating the area, then it should be attached to that area level, in the BoP.

Attaching output data and results to the activity: At this stage, all input data, the virtual model and output report, have been structured in the PLM system. The last part is adding the relevant provenance information of the simulation activity in PMS. Figure 6 shows how this structure is built in Teamcenter.

Defining the activity with provenance data: The last two steps are executed in the Provenance Management System (PMS). Whenever a user logs in with his/her Teamcenter login information to the ManagLink through the PMS user interface, ManageLinks connects to the Teamcenter server and retrieves the data from the Teamcenter database. ManageLinks consists of different tabs for data entering. The “Activities” tab is a place to see a list of all activities in the PMS. Users can also add a new activity in this tab. Items (business objects) can be searched and added from Teamcenter as entities to the list of entities in PMS, through the “Entities” tab by the users. They can store all ontological terms that are candidates to describe the classes (Entity, Purpose, Actor, Method, and Activity) in the “Concepts” tab. The ontological terms can be referred to where they are defined such as a link to a web page or a link to WebProtegé as an open-source ontology editor. “Location”, “Tools”, “Actors”, “Projects”, and “Methods” are other tabs to enter data about an activity and cover all 7Ws questions.

In this case study, an activity has been added to the ManageLinks, labeled as: “DES of crankshaft Line 1—Conceptual design”. All other provenance data about this activity have been entered to ManageLinks to clarify: What is the activity? When was

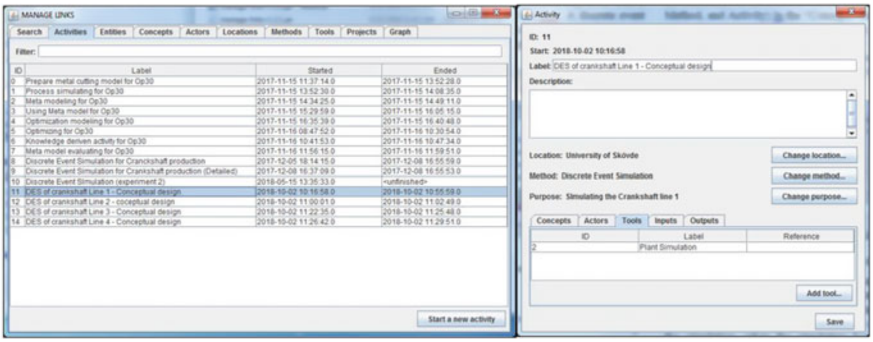


bl_indented_title

- 004697/A;1-Crankshaft_machining
  - 004778/A;2-Machining processes in Line 1
    - 008236/A;1-Process of loading of blanks
    - 008237/A;2-Rough balancing process
    - 008238/A;1-End planning and center bore process
    - 008239/A;1-Control 2 process
    - 008240/A;1-Rough Mill process
    - 008241/A;1-Control 3 process
    - 007580/A;2-Turning process of Main bearing
    - 008243/A;1-Control 4 process
    - 008244/A;1-Turning process of Connecting rod bearing
    - 008245/A;1-Control 5 Process
  - 004779/A;2-Machining processes in Line 2
  - 004780/A;2-Machining processes in Line 3
  - 004781/A;2-Machining processes in Line 4

me_cl_display_string	me_cl_object_desc	al_context
004778/A;2-Machining processes in Line 1		
View		
004778/A-View		
008335/A;1-Discrete Event Simulation		Specifications
View		
008335/A		Item Masters
008336/A;1-Conceptual Design		Specifications
Crankshaft_CC		Specifications
005777/A;2-DES model Area1		Specifications
005777/A		Item Masters
DES Area1		Specifications
View		
008336/A		Item Masters
HtmlReport	Plant Simulation Report	Specifications
View		
TimeAnalysis		METimeAnalysisRelatio
004778/A		Item Masters

Fig. 6 Discrete event simulation activity item, which is attached to BoP, contains data and model



ID	Label	Started	Ended
0	Prepare metal cutting model for Op30	2017-11-15 11:37:14.0	2017-11-15 13:52:28.0
1	Process simulating for Op30	2017-11-15 13:52:30.0	2017-11-15 14:08:35.0
2	Meta modeling for Op30	2017-11-15 14:34:25.0	2017-11-15 14:49:11.0
3	Using Meta model for Op30	2017-11-15 15:29:59.0	2017-11-15 16:05:15.0
4	Optimization modeling for Op30	2017-11-15 16:35:39.0	2017-11-15 16:40:48.0
5	Optimizing for Op30	2017-11-16 08:47:52.0	2017-11-16 10:30:54.0
6	Knowledge deriven activity for Op30	2017-11-16 10:41:53.0	2017-11-16 10:47:34.0
7	Meta model evaluating for Op30	2017-11-16 11:56:15.0	2017-11-16 11:59:51.0
8	Discrete Event Simulation for Cranckshaft production	2017-12-05 18:14:15.0	2017-12-08 16:55:59.0
9	Discrete Event Simulation for Crankshaft production (Detailed)	2017-12-08 16:37:09.0	2017-12-08 16:55:53.0
10	Discrete Event Simulation (experiment 2)	2018-05-15 13:35:33.0	<unfinished>
11	DES of crankshaft Line 1 - Conceptual design	2018-10-02 10:16:58.0	2018-10-02 10:55:59.0
12	DES of crankshaft Line 2 - coceptual design	2018-10-02 11:00:01.0	2018-10-02 11:02:49.0
13	DES of crankshaft Line 3 - Conceptual design	2018-10-02 11:22:35.0	2018-10-02 11:25:48.0
14	DES of crankshaft Line 4 - Conceptual design	2018-10-02 11:26:42.0	2018-10-02 11:29:51.0

ID: 11
Start: 2018-10-02 10:16:58
Label: DES of crankshaft Line 1 - Conceptual design
Description:
Location: University of Skövde
Method: Discrete Event Simulation
Purpose: Simulating the Crankshaft line 1

ID	Label	Reference
2	Plant Simulation	

Fig. 7 Defining the DES activity in ManageLinks system

the simulation started and finished? Who performed the simulation? What methods have been used? Which tools are incorporated? Where did the activity happen? What was the purpose of the simulation? Answers to all these questions can be traced as shown in Fig. 7.

Attaching activity related data from PLM: In addition to 7Ws data, specifying the input and output data is essential to complete the provenance data. In this case study, the “Crankshaft_CC” application interface item and the “machining process in line 1” process items are attached to the “DES of crankshaft Line 1- Conceptual design” activity as the input data. The “DES model Area 1” item and “HtmlReport” item are assigned to that activity as the outputs. Through the integration of ManageLinks and Teamcenter, these items can be searched and retrieved from Teamcenter and can be added to the activity. Figure 8 illustrates the “DES of crankshaft Line 1—Conceptual design” activity as one of the activities in the entity-activity graph of this case study with its input and output data.

Up to here, all steps of the sequence-based framework of the CAx-PLM-PMS chain have been implemented to create a DES model of the crankshaft production line-1. As mentioned at the beginning of this case study, the crankshaft production area has been divided into four production lines, and three DES models have been created for the other three production lines. All of the three activities were added to ManageLinks and Teamcenter, similar to the production line-1, which was explained earlier. The outputs of these activities are used as inputs for DES of the entire crankshaft production area. Similarly, DES of the crankshaft production area can be used as an input to design a detailed DES of that area (Fig. 8). Users can track sequences of related activities and identify how a virtual model is developed through different activities.

Figure 8 shows all activities and entities of the first case study. With the implementation of the CAx-PLM-PMS chain for all activities, each of the activities or entities can be analyzed according to its previous connected entity or activities and their provenance data.

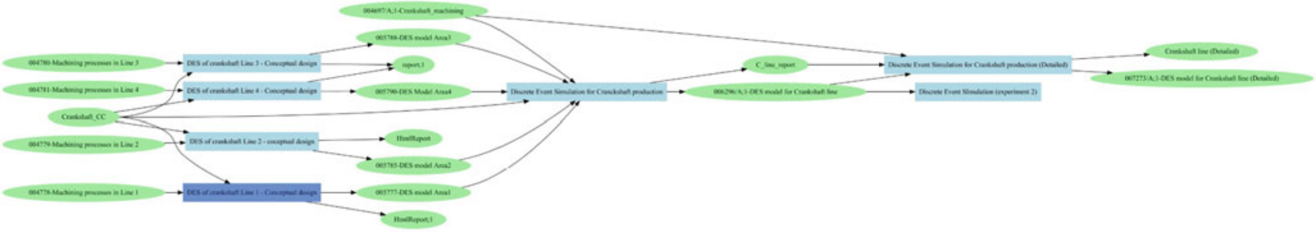


Fig. 8 The entity-activity graph for the chain of DES activities

In the second case study, the sequence-based framework will be used for a simulation-based optimization and knowledge extraction study.

4.2 Case Study 2: Cutting Process Simulation, Optimization and Knowledge Extraction

In this case study, a cutting process in operation 30 (machining of the main bearing in a turning operation) has been modeled, simulated and optimized by optimization methods. Simulations were replaced by meta-models, which approximate the actual simulation in a few steps to reduce the running time [15]. There were several activities in this case study such as simulation modeling, process simulation, constructing meta-models, using meta-models, meta-model evaluation, optimization, and knowledge extraction. In this report, the implementation of the sequence-based framework of the CAx-PLM-PMS chain for "simulation modeling" activity will be explained. In this implementation, the CAx tool was a Deform3D software program. Since some of the steps were done or described in the previous case study, they will only be explained briefly in the second one.

Creating BoM, BoR and BoP: In this case study, the same three main structures (BoM, BoP, BoR) that were prepared for the previous case study, are used. Unlike the previously described case study where the focus was on the line and area level, the focus in this case study 2 has shifted to the operation level.

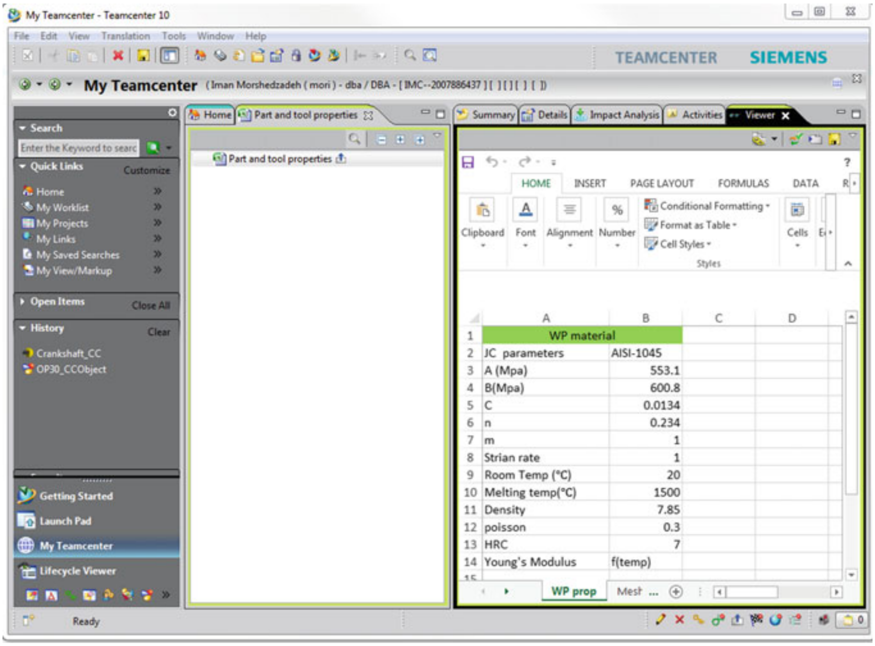
Preparing input data for CAX: Deform 2D/3D is the CAx tool in this case study. The integration of Deform 2D/3D with Teamcenter is at a low level. Files generated by Deform 2D/3D can be saved in Teamcenter and they can be opened through Teamcenter. An Excel file with all the data needed to generate the cutting simulation model has been created and added to Teamcenter. The Excel file contains data such as workpiece properties, mesh data, tool properties and process specifications (Fig. 9).

Importing data from the PLM system: The Excel file with the input data can be exported from Teamcenter and saved at the user's computer for designing the cutting process. These data have been used in the Deform 2D/3D application for modelling the cutting process.

Designing and running experiments: Within this step, the workpiece and the tool are modeled based on the data in the Excel file. Afterwards, the model is meshed and the simulation file in database format (.DB) is generated (Fig. 10).

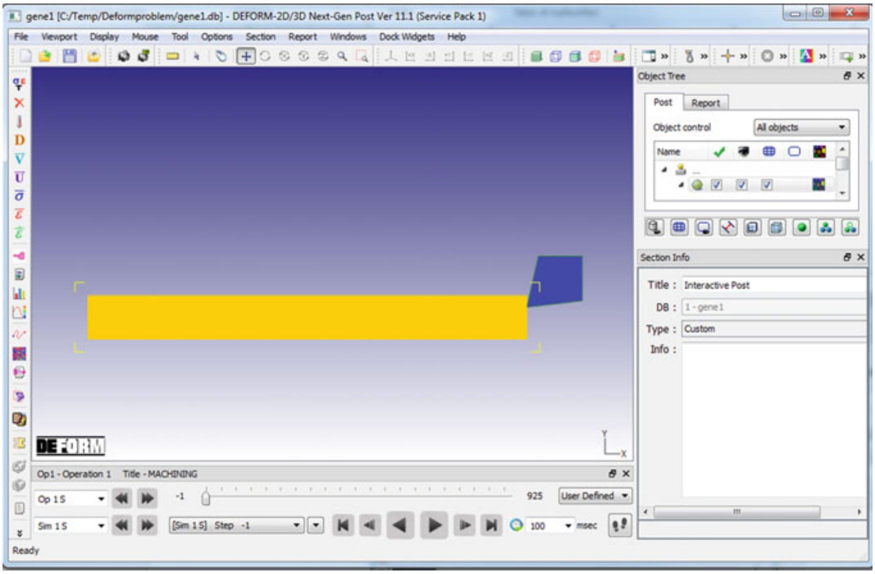
Preparing data and results for PLM: The output of this activity is a Deform 2D/3D database (.DB) file. This file is created by Deform 2D/3D after the simulation is completed. It contains the information for all finite element simulation steps, from the cutting operation of the main bearing in the crankshaft production. The simulations can be regenerated and the results can be analyzed by using this database file.

Creating the engineering activity item: As in the previous case study, an engineering activity item is created and attached to the BoP, but in the operation level.



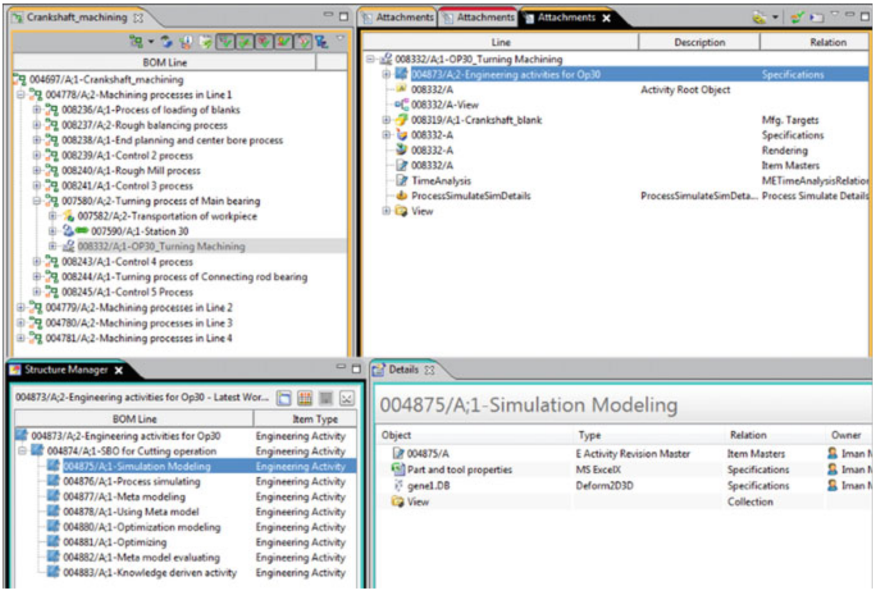
	A	B
1	WP material	
2	JC parameters	AISI-1045
3	A (Mpa)	553.1
4	B(Mpa)	600.8
5	C	0.0134
6	n	0.234
7	m	1
8	Strian rate	1
9	Room Temp (°C)	20
10	Melting temp(°C)	1500
11	Density	7.85
12	poisson	0.3
13	HRC	7
14	Young's Modulus	f(temp)

Fig. 9 View of Excel file in the Teamcenter environment



Title : Interactive Post
DB : 1 - gene1
Type : Custom
Info :

Fig. 10 The virtual model of metal cutting



BOM Line

- 004697/A;1-Crankshaft_machining
  - 004778/A;2-Machining processes in Line 1
    - 008236/A;1-Process of loading of blanks
    - 008237/A;2-Rough balancing process
    - 008238/A;1-End planning and center bore process
    - 008239/A;1-Control 2 process
    - 008240/A;1-Rough Mill process
    - 008241/A;1-Control 3 process
    - 007580/A;2-Turning process of Main bearing
      - 007582/A;2-Transportation of workpiece
      - 007590/A;1-Station 30
      - 008332/A;1-OP30_Turning Machining
    - 008243/A;1-Control 4 process
    - 008244/A;1-Turning process of Connecting rod bearing
    - 008245/A;1-Control 5 Process
  - 004779/A;2-Machining processes in Line 2
  - 004780/A;2-Machining processes in Line 3
  - 004781/A;2-Machining processes in Line 4

Line	Description	Relation
008332/A;1-OP30_Turning Machining		
004873/A;2-Engineering activities for Op30		Specifications
008332/A	Activity Root Object	
008332/A-View		
008319/A;1-Crankshaft_blank		Mfg. Targets
008332-A		Specifications
008332-A		Rendering
008332/A		Item Masters
TimeAnalysis		METimeAnalysisRelatio
ProcessSimulateSimDetails	ProcessSimulateSimDeta...	Process Simulate Details
View		

004873/A;2-Engineering activities for Op30 - Latest Wor...

BOM Line	Item Type
004873/A;2-Engineering activities for Op30	Engineering Activity
004874/A;1-SBO for Cutting operation	Engineering Activity
004875/A;1-Simulation Modeling	Engineering Activity
004876/A;1-Process simulating	Engineering Activity
004877/A;1-Meta modeling	Engineering Activity
004878/A;1-Using Meta model	Engineering Activity
004880/A;1-Optimization modeling	Engineering Activity
004881/A;1-Optimizing	Engineering Activity
004882/A;1-Meta model evaluating	Engineering Activity
004883/A;1-Knowledge deriven activity	Engineering Activity

004875/A;1-Simulation Modeling

Object	Type	Relation	Owner
004875/A	E Activity Revision Master	Item Masters	Iman
Part and tool properties	MS ExcelX	Specifications	Iman
gene1.DB	Deform2D3D	Specifications	Iman
View		Collection	

Fig. 11 Creating an engineering activities item and their sub-activities

Another activity item has been created which contains all activities of simulation based optimization for cutting processes. It contains eight activities and the first one is simulation modeling that has been explained (Fig. 11).

Attaching output data and results to the activity: As has been shown in Fig. 11, an Excel file which contains the properties of the workpiece and the cutting tool has been attached to the simulation modeling activity as the input data and “gene1.DB” file has been attached as the Deform 2D/3D output model. After structuring the data in the PLM system, they need to be connected to the activity with provenance data in the next steps.

Defining the activity with provenance data: In this step, an activity of “simulation modeling for Op30” is created in the ManageLinks and all other provenance data including time, location, method, purpose, actors, and tools are entered to the PMS.

Attaching activity related data from PLM: The last step for this activity was attaching related data from the PLM system to the activity as inputs and outputs. The Excel file of “part and tool properties”, the “op_30 main bearing turning” operation, the “Spindle_Late” turning machine and the “crankshaft” part are items from Teamcenter. They were attached to the simulation modeling activity in the PMS as input entities. The “gene1.DB” item from Teamcenter was the only output of this Activity.

The “Simulation modeling” activity was the first of eight activities of the simulation-based optimization and knowledge extraction process that has been implemented for the turning operation of the main bearing in crankshaft production.

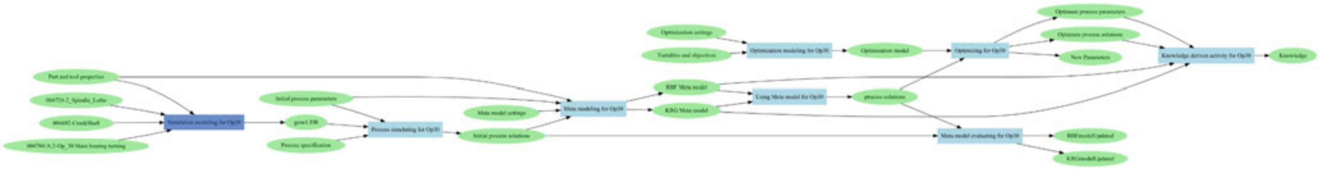


Fig. 12 Activity-entity graph of simulation-based optimization and knowledge extraction in operation 30

Figure 12 shows the entire activity-entity graph for those eight activities which are illustrated with rectangles in that figure. By managing the complete CAx-PLM-PMS chain, for all activities performed in the simulation-based optimization and knowledge extraction study, each of the entities that can be a virtual model can be analyzed according to its previous connected activities and provenance data (Fig. 12).

5 Conclusions and Future Work

In this case study, two industrial case studies considering the execution of the sequence-based framework of the CAx-PLM-PMS chain have been explained. It showed that this framework could be used for different engineering activities, and it connected different types of input and output data including virtual models to those activities in a sequential manner. Implementation of this framework to engineering activities and entities, makes all the related information available. In addition, it can help future evaluation of virtual models for their reuse. The information clarifies the conditions and the criteria behind any decision which later can be considered and re-used for new decisions.

For the future work, the developed sequence-based framework can be implemented for other application areas and other CAx tools for the applicability and compatibility evaluation of the framework. Another future work idea is to define an information structure in the PLM system for management of all input and output data, in a way that covers different projects and studies at different levels of the manufacturing system.

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How PLM Drives Innovation in the Curriculum and Pedagogy of Fashion Business Education: A Case Study of a UK Undergraduate Programme

Jo Conlon

Abstract PLM is increasingly understood as a strategic platform to facilitate business transformation through its dual role: firstly, driving operational excellence and then as a platform for innovation through providing an impetus for continuous engagement with emerging technologies. The three P's of PLM: process, product data and people, remind us that if the transformational potential of PLM is to be achieved, there is a growing need for professionals with an understanding of PLM as the backbone of the future enterprise facilitating an open-ended view of product lifecycle management. The retail sector, previously a late adopter of PLM, is now undergoing a period of significant investment. In parallel, educators within the associated higher education sector are challenged with maintaining a forward-facing curriculum and providing new learning environments that engage students to suitably prepare them for future professional practice. The argument that is advanced in this case study is that PLM provides a contemporary framework and alternative approach for establishing a collaborative, forward-facing pedagogy for fashion business. Further, the insight and energy of students and graduates at the periphery of practice or their "peripheral wisdom" (Wenger in Communities of practice: Learning, meaning, and identity. Cambridge university press, p. 216, [25]) has much to contribute to a sector in transition. This case-study reports on the first ever educational partnership to embed PLM in an undergraduate fashion programme in a UK University and seeks to encourage other educators to embrace PLM as a vehicle for educational change. This partnership was formed in 2014 with PTC for FlexPLM. The case study illustrates the initial implementation of product lifecycle management in conjunction with a shift from traditional lectures to collaborative learning practices to provide a powerful learning environment that equips future fashion professionals with a key differentiator that can drive the transformation of the industry.

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1 The Business of Fashion

> Study of the fashion system is a hybrid subject. Loosely defined as the interrelationship between highly fragmented forms of production and equally diverse and often volatile patterns of demand, the subject incorporates the dual concepts of fashion: as a cultural phenomenon and as an aspect of manufacturing with the accent on production technology. ([7], p. 93)

As the opening quotation explains, the business of fashion is a complex one and therefore learning to become a proficient professional within the industry is multifaceted. Fashion has significant cultural significance and economic weight as an industry. The textile and clothing sector is among the largest industries in the world; it contributes significantly to the economy of many countries, with a total end market worth over €2 trillion on a global level [23]. The global fashion business is a large and diverse sector that comprises traditional manufacturing as well as the creative activities typical of the creative economy ([1], p. 802). This fact: that the fashion business includes both the creative sector and traditional manufacturing industries sets up the inherent tension or paradox of the sector ([4], p. 5)—with *fashion* open and responsive to consumer trends and thereby inherently dynamic and uncertain contrasting sharply with structured *business* procedures established to generate a specific financial result. Fashion business professionals have to balance commercial success (meeting consumer needs) with financial performance ([4], p. 8).

2 The Seismic Shift in Retail Fashion

In the past the supply chain strategy of the apparel industry has been categorised as more of a push model as illustrated in Fig. 1 depicting the standard fashion design and production process referred to as “the buying cycle”. Competitiveness was previously based on achieving high volumes at low cost, however cost control and efficiency have now become standard. Today’s success is determined by the ability to be flexible and responsive [3] or the pull-model synonymous the ability to be responsive to consumer demand through product and process innovation based on a deep understanding of customers coupled with robust supply chain relationships throughout the extended enterprise. The shift from push to pull production represents a seismic shift in retail management ([15], p. 2) prompting a fundamental rethink of processes and practices that has been described as changing retailing from “transmit to receive” mode ([9], p. 1). Digital technologies are pivotal in enabling the shift as elegantly summarised by Crewe ([6], p. 761):

> The emergent computer – consumer – commodity nexus is thus of fundamental importance in that it holds the potential to reshape our understandings of organisations, consumers and the mechanisms through which fashion knowledge is generated and circulated.

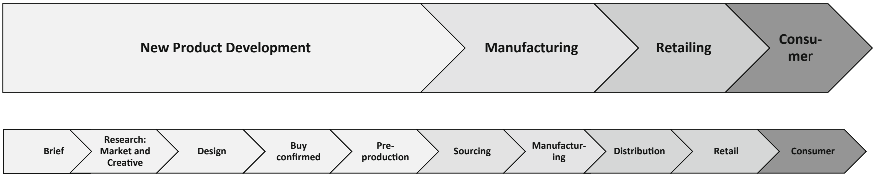

Fig. 1 The standard fashion design and production process. Adapted from Han et al. [8] and d'Avolio et al. [26]

3 Fashion Business in Higher Education

From the 1980s, degree programmes in "managerial fashion" ([13], p. 46) began to emerge alongside the more established and recognised fashion design degree programmes. This represented a new realism in fashion education and reflected the shift to global sourcing and growing importance of mainstream retail fashion. Within these fashion management programmes, most students conceive their education as vital to help them achieve their aspirations to work within a retail brand. One of the central positions within fashion retail brands is the buyer whose role is to ensure that the right products arrive in store at the right time and price from an analysis of consumer trends, current events, and previous sales with an in-depth understanding of consumer needs. The buying team translate this information into a product range that is negotiated with suppliers in terms of cost and delivery, supported by technical and sourcing specialists. Once the product is in store, product sales must be monitored closely in order to react to changes in demand. Industry demands graduates that can "hit the ground running", however, as educators, our job is to prepare students for the future not just train them for today.

Within higher education there is an ongoing shift away from passive learning through traditional lectures and a growing interest in integrating learning with experience in practice settings. Now, fashion institutions around the world seek to prepare graduates to succeed academically and be proficient in the ability to connect both ends of the value chain, i.e. production and consumption and balance commercial and financial performance ([1], p. 802). Central to this challenge, in an increasingly digital age, is learning how to manage the tension between creativity and commerciality. Further, increasingly researchers argue that education must reflect emerging global socio-political trends not just respond to commercial and economic demands from business. Current educational research asserts that it is important to preserve 'artistic freedom' within higher education as the source of critical, creative and innovative thinking to enable graduates to become change agents and manage demands for global citizenship [10, 11], sustainability [17, 18] and embrace technology [14, 19].

The pressures and complexities of our industry and working with a growing volume of information can be overwhelming for many learners, teachers and institutions alike. Therefore, it seemed appropriate to seek a digital learning environment

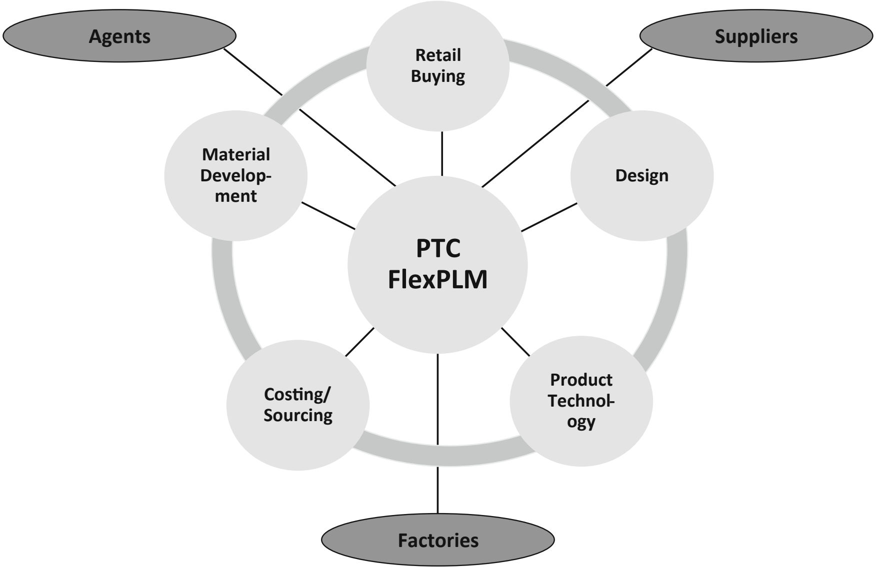

Fig. 2 FlexPLM as a central hub of function and process integration underpinning the educational programme (image courtesy of PTC)

to support and prepare students for roles in this complex, fast-paced and challenging creative environment. With the PLM acronym playing a 'holistic' role [20], the PLM framework can be utilised as a conceptual map and a mechanism to demonstrate the integration of diverse business activities throughout the product lifecycle as illustrated in Fig. 2. PLM provides a framework that permeates all aspects of the body of knowledge and provides a holistic view of industry processes, an up-to-date context for study that facilitates the opportunity to critique traditional practices and thereby generate new practices.

4 The Ambition Behind the Change Initiative

In 2011, with the increasing levels of investment in fashion-specific PLM solutions by retailers and brands it became evident that our future graduates' working environment would be within a PLM system and therefore we concluded that PLM should be included in our educational programme. The Department was keen to introduce PLM education at all levels in the programme to ensure that our graduates enter employment with a baseline of PLM knowledge, able to recognise the benefits it can generate, the problems it can solve and future opportunities it can stimulate. Our ambition for the BA Fashion Buying Management programme was to create a forward-facing curriculum that contributed positively to the sustainability and democratisation of the apparel sector. What was sought through the proposed intervention was the development of a mind-set capable of utilising technological innovations to critique existing processes and practices and create alternatives that respond to the demands and opportunities of new times, new needs and changes in circumstances.

An issue for the implementation of PLM into education is that there is no equivalent to the ROI calculations to support a business case for the investment. This is exasperated further by a conservative attitude towards software investment due to concerns over staff technical skills, packed curriculums and other educational priorities. It was only through the generous offer from PTC of an educational partnership where the first-year costs were waived that this intervention to integrate PLM into an undergraduate degree programme was made possible. This period allowed for a strong business case to secure budgetary support for subsequent years to be built from information relating to the scale of industry investments coupled with positive internal reports in terms of student engagement, recruitment potential, opportunities for wider research and funding opportunities.

5 Starting Our PLM Journey

This intervention, based on an educational partnership, builds on several previous failed attempts to secure funding for PLM software. Due to these funding constraints, before we had a live system we used PLM to frame teaching and used open source software to establish a collaborative team space [5]. Within the second-year programme there are three core modules; PLM was integrated into the global sourcing module. The PLM framework was utilised to clarify the processes involved and illustrate industry best practice. All second-year textile students (management and design students, $n = 95$) worked collaboratively in product development teams mimicking the processes and practices of industry. This shift to learning through practice, represents a pedagogy more closely aligned to the approach to teaching and learning in design [16, 22] and was an important precursor stage as it allowed for collaborative team-based learning to become established.

As PLM becomes the backbone of the modern industry, we recognised the importance of our students working **hands-on** within a PLM solution recognising the importance of an experiential and practical understanding of PLM. A combination of our previous interest, geography and good luck resulted in the educational partnership for PTCs FlexPLM system. Given the lack of PLM knowledge in the sector and that many core processes and practices within the standard fashion process model were developed before today's advanced technology there is a clear opportunity for our graduates to differentiate themselves in competitive job markets and make a positive contribution to the sector using the knowledge gained through their participation in this intervention. The significance of this statement to retail brands was highlighted by Suleski and Draper [21]:

> as adoption of PLM becomes mainstream in the industry, having the required talented employees in a business to challenge and overhaul legacy practices is a prerequisite to achieving the potential that the technology offers.

6 The Initial Implementation

We went for a phased implementation of FlexPLM, adding the creation of a "tech pack" within PLM to the earlier redesign. A tech pack is the industry short-hand for a set of documents that a manufacturer needs to turn the design into a product. A tech pack represents a convenient and recognised milestone that aligns well with my previous experience of sourcing and supply chain management and reflects the growing interest in supply chain transparency. As before, it was planned that the students would work in product development teams to develop a range with the addition of a "tech pack" generated in PLM for each product proposed.

At the time, several final year students returned from their industrial placements keen to know more about business improvements and the role of PLM. There was clearly an opportunity for second year and final year students to work together to share their experiences. Therefore, in addition to the year two teaching and learning programme, we utilised the mid-term reading week (i.e. no timetabled sessions) to organise a week-long PLM collaborative event where second and final year students would work in product category teams. Responding to a live brief from George at Asda, the students developed and presented an open-to-buy (OTB) range with a supporting tech pack for each product. In reality, a tech pack can be produced without a PLM system and therefore the authenticity of the task to work practice was generated by the live team brief and limited development time. The week's event culminated in a final presentation of the proposed ranges to a panel from industry and the university. This provided a valuable opportunity to "perform like" industry professionals and receive positive feedback and additional comments. The panel agreed the students had clearly demonstrated their competence as illustrated by these two exemplar comments from the panel member from George at Asda:

> I really like the level of detail you've gone into on your competitor analysis. I love the fact you mentioned: good-better-best which is something that we would benchmark against. I like the fact you thought to look to our website to find approved factories. I like the fact that you indicated that you have considered more than you have put forward for selection. That is something that we always do - this gives some flexibility to mixing and matching. I also like the fact that you had considered different size ratios for different products although this would always be open to challenge. It's good that you had considered what she would wear, although these are difficult conversations and decisions.
>
> … previously my background was senior merchandise manager for George, so I would have signed off that money on the garments that you've presented here, I'd have spent that cash with some extra information on the costing - I don't expect you to have done that level of detail here - I would have signed off on that and I think your comp shop work is easily comparable to what we would see back in the office, so thank you for that.

It might be imagined that the lack of live data in the educational setting presents a significant barrier to implementation of PLM. However, adding items to the library can be incorporated into the learning with notable benefits. The opportunity to apply knowledge in practice helps to develop an in-depth understanding of the black box of current processes and practices. Further, the richness of learning the "longhand" process yields a better appreciation of the automation of administrative tasks that PLM delivers. The task of working in collaborative product category teams to generate a bill of materials (BOM) and "tech pack" reveals the complexities and interconnectedness of product development and the strategic challenges for organisations better appreciated. The associated assessment task documents these processes and critically discusses the management of the relationship between new product development, supply chain management, retailing and the consumer in relation to industry practice in an illustrated report of 5000 words. The experiential learning has clearly overcome initial resistance and contributed to a rich understanding of the strategic management role of PLM:

> I was so sceptical of the whole PLM thing towards the start - I thought I don't want to learn this: it looks rubbish! And then I did it and I really, really enjoyed it! [The main part] for me was learning about PLM because I didn't know anything about it and thought it had nothing to do with what I want to do… But now I understand why retailers would use it for management. (Student feedback)

After the PLM event week, the students returned the final stage in the formal taught programme (Fig. 3), which focuses on using PLM as a platform or backbone for other technologies and included guest lectures, case studies, interviews. The second assessment was an individual case study assessment (5000 words), where students undertook primary research to understand current practice and research into innovative, strategic and applied opportunities for extended PLM technologies and proposed business improvements in diverse topics including 3D visualisation for prototypes, AR/VR in retail, sustainability, big data and IoT. Exposure to PLM has provided students with the impetus to solve problems and challenge legacy practices through their ongoing research. This further research is clearly underpinned by the provision of opportunities for students to develop and test their ideas and skills and gain industry insight.

Students are able to see that PLM will likely feature in the future workplace; one student saw the value of this intervention as a safe environment to experiment and learn before entering employment:

> In the actual business environment, the likelihood is, that by the time we come to graduate, the company that you do go to work for is going to have PLM. So rather than waiting till you're in the business, where the job that you're doing on the system actually has impact - you could mess up a SKU [stock keeping unit or product line], that's the reality of it – why would you not want to trial that in the University where it is not actually affecting real products? It's not actually affecting deadlines, the product arriving and stuff. It is a key industry tool that you are going to be so aware of when you graduate and go into the industry, why wouldn't you want to trial it before you actually could potentially (laughing) mess something up on it? (Student interview comment)

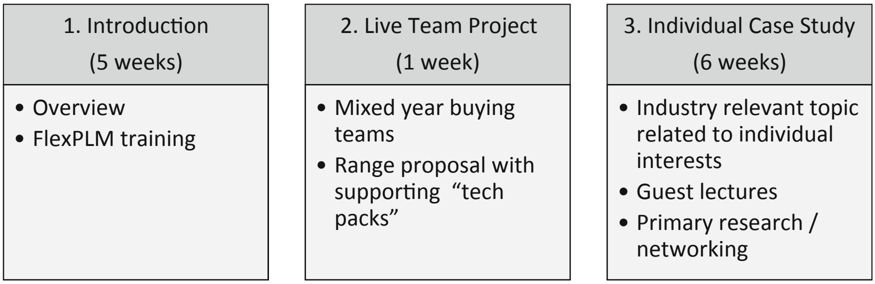

Fig. 3 Three main stages in the integration of PLM into the second-year module of the BA programme

7 The Benefits Achieved

There are many positive outcomes from the work to date. I came to be an advocate of PLM from a supply chain background, and uphold that there are many benefits in a greater connection and understanding of manufacturing. The PLM learning environment has helped bring the curriculum to life, made it more relevant to students' interests and demonstrated the need to work collaboratively to achieve the best results. It has also revealed a more diverse range of career opportunities to students. However, it is in its power to encourage innovation that I see as its core value to the industry. The students have an enthusiasm for the potential of technology and an eagerness to contribute to industry. They see technology as an enabler and are keen to experiment with new possibilities—for them, everything is possible, there's an app for everything, or certainly should be! One student expressed that she felt she has much to offer from her knowledge and experience and sees it as a position of strength for the future as implementation becomes more widespread:

> So, having that from an educational background as well, actually having dealt with in a classroom, is really good. I feel that companies aren't going to know what's hit them when us graduates come and join. We know all this stuff, I think it's really good. **I think this is where the change probably has to come from**. Some people, like when I was at [placement company], literally no one had even heard of it. Some people had been working there for 30 years or something, businesses like that who are doing good business, they are so ingrained in their old ways of working, it's like "if it's not broken don't fix it" so it needs to come from somewhere. The fact that we are being educated to know this is really great.…especially because of all these high-calibre implementations that are happening more recently, I think it will filter through.

8 Next Steps Foreseen

The initial intervention was in the 2014–15 academic year. This format has repeated with minor iterations; PLM is now an integral part of the teaching programme with some students taking this topic further in subsequent research and careers. The next phase will include costings and workflow management to give a richer experience of PLM. The openness of the structure (Fig. 3) allows for flexibility to respond to emerging themes in the industry and reflect students' interests. The intervention remains at course level despite efforts to disseminate further. In 2017, a similar event to disseminate PLM across the whole department of Fashion and Textiles was planned but this was not well-supported and did not go ahead. Promoting such optional events requires a significant investment in time to coordinate wider support and perhaps we had underestimated the reticence of design students to engage with business practice. However, learning from this, in 2018 we successfully hosted a digital storyboarding event open to all students in the department as an introduction to PLM and digital asset management.

This intervention mirrors the current industry focus of PLM around new product development. We seek to build a lifecycle perspective beyond ideation, design and manufacturing (beginning of life or BOL), to consider use (middle of life or MOL) and disposal (recycle) at the end of life (EOL) by demonstrating the potential of PLM to close the information loops in a shift to a more circular economy business model ([24], p. 278).

Taking this into consideration, it may prove more productive to engage with fashion management programmes externally such that students then benefit from academics sharing their expertise. Collaborations with interested parties with expertise to contribute, for example in sustainability, merchandising, data analysis and virtual prototyping would be welcomed. Collaborating internationally would also help students gain an insight working digitally across different cultures and time zones.

9 The Lessons Learned

This project has strived to foreground a forward-facing educational perspective that recognises the limits of "know-what" knowledge and the potential of learning through practice to broaden knowledge to also include know-how, know-why and know-who ([12], p. 136). Time and energy are needed for the shift away from the lecture and other forms of traditional higher education practice to a level of acceptance and proficiency in collaborative team-based learning through live briefs. From our experience, we believe a commitment to student autonomy and an openness in assessment tasks is required to promote active student engagement in their own learning (Fig. 4). The opportunity to learn with students from the same course, but at different levels can be a powerful motivator:

> It kind of puts in your head, that you will get to that stage - that didn't just happen, that didn't come out of thin air. They got there from doing the whole course…It made me feel like she's not just come on the course and known everything, she's actually learnt that. It gives you the initiative to push on, you can be at that stage. It pushes you to carry on… (Second year student)

Fig. 4 Summary of the main lessons learned (https://pixabay.com/en/teamwork-team-gear-gears-drive-2198961/, https://pxhere.com/en/photo/1451265, https://pxhere.com/en/photo/1450373, http://www.thebluediamondgallery.com/highlighted/e/experience.html, https://pixabay.com/en/cooperate-collaborate-teamwork-2924261/, https://pixabay.com/en/chaos-regulation-chaos-theory-board-1536612/)

As stated earlier, the educational partnership was fundamental to getting this project started. It helped to build a level of commitment and understanding on both sides. PLM is now at the heart of an evolving digital ecosystem and therefore the partnership provides valuable industry insight on how current practice is unfolding. As research practice develops, a balanced two-way communication can be established in the contributions of the partners.

It is important to recognise that ongoing funding will be needed to sustain the new programme. The reality is that in order to secure ongoing budgetary support, projects need to provide a business case which can be strengthened by communicating associated successes in recruitment activities, student satisfaction and the opportunities for funded research.

The industrial experience of the academic team should be considered to help to establish a useful entry point for PLM implementation into the curriculum. This experience should be brought to the project as a valuable resource for the students to access. This can help to counter concerns that relate to a lack of expertise in the technical aspects of the software. Although staff training will be provided, it is important to recognise this will only provide competence rather than expertise and therefore staff will need to join the PLM learning community as equal participants in a new digital environment and not to attempt to achieve any sense of academic "expertise" regarding the software.

A closer collaboration between industry and academia is imperative if the transformational potential of PLM is to be realised. This project accessed significant external support for guest lectures and seeks to establish a two-way traffic of ideas. To facilitate this, there needs to be a greater receptiveness to this interaction in the members of the industrial community, recognising the possibility to gain something of value from the students' alternative perspective and give them the chance to invest their energy, contrary to the experience of a final year during graduate position interviews:

> I feel that going in as a trainee, I know that for the older buyers and merchandisers, it wasn't around when they were at university, I think that perhaps they might not value it is as much. I know that's not what I should say but that's how I feel that I will be bypassed and not taken seriously…Even when I did mention it [PLM] in my interview, the Merch just looked blank, and didn't seem to follow the conversation, [because] the knowledge doesn't seem to be there.

Finally, our experience has led us to be strong advocates of practice-informed learning and we would recommend that practice precedes academic theory i.e. experience at the local (contextual) level precedes that at the broader (conceptual) level.

10 Advice—The Do's and Don'ts

As in industry, the appointment of a project lead is recommended. This person needs to commit to gaining a strategic understanding of PLM and accept the open-ended nature of the task.

Case studies, the blogs and websites of thought-leaders provide valuable information and insight that can be adapted according to the discipline and educational settings to support a successful implementation.

The next stage involves establishing a project team to develop and share a clear picture of "as-is" and "to-be". It is recommended that this is a cross-functional team and includes other academics, students and IT and reports regularly to a member of the senior management team.

It is important to emphasise the significance of including IT. Sadly, universities are prime cyber-attack targets and firewalls are in place to provide security, therefore IT need to be involved to manage an open experience within PLM. At the time of this implementation (2014) cloud and app versions of retail PLM were not as prevalent as they are in 2018. Accordingly, this project installed PLM to servers held on site. The evolution to hosted (cloud) systems with an open additive 'platform' approach to system architecture seems to offer many benefits in terms of security and also for modular adoption.

The project team needs to understand the typical time period of PLM implementations but it is advised that external partners are made aware of the glacial speed of change in higher education due to bureaucratic and extended quality procedures. It is also important to not let this inertia prevent further development and to use ongoing attempts to scale the intervention to provide a fresh impetus to continue.

Finally, many forward-thinking organisations are establishing a millennial shadow board as a source of innovative thought [2], therefore employ the energy of the students, those who have the most at stake in the development of future practice, as a powerful source of energy and inspiration.

11 Conclusion

This paper is the first to report on PTC's FlexPLM being embedded into an undergraduate fashion programme and can provide valuable pointers for how educational partnerships can develop both pedagogy and curriculum content. Through this type of partnership, the curriculum content can be developed to enable graduates to develop capabilities in closer alignment with the current and future needs of industry. This study used Product Lifecycle Management (PLM) as a vehicle for change to develop a new creative collaborative, participatory and holistic model of learning and teaching of fashion management in order to better prepare graduates to tackle the issues and challenges of industry in the 21st-century.

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Product Lifecycle Management Business Transformation in an Engineering Technology Company

I. Donoghue, L. Hannola and J. Papinniemi

Abstract The role of Product Lifecycle Management (PLM) in business transformation varies in scope and impact. PLM initiatives range from Information System (IS) renewal to strategic business transformation, where often the capabilities to implement PLM successfully are unclear. This case study explains, through a case company example, the PLM concept journey from definition to implementation. It explains the variables influencing PLM transformation in an engineering technology company. This paper is based on an example carried out from 2011 to 2015 when the company's strategy transformed it from an engineering company to a product and service company. The outcome show how a strategy-driven PLM transformation impacts a company at many levels, and also why the first PLM initiative had limited success due to focusing on IS driven process harmonisation. The case study also highlights the importance of the knowledge of the products, services and enterprise architecture, but also business models. The conclusions show PLM being at the core of business transformation, a cross-functional activity impacting products, services and customers.

Keywords Product lifecycle management · Product management · Enterprise architecture · Business model · Business strategy

1 Case Company Background

The case company provides leading technologies, engineering solutions and services to the mining, metal refining, energy, water and chemical industry. The solutions provided to the customers range from simple spare parts to operate and maintenance services, and the delivery of equipment and complex production plants. The company's history goes as far back as the beginning of the 20th century and its core business was the mining and refining of different kinds of minerals and metals. Over

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the decades the company developed and acquired different types of technologies to support its core business. These technologies were managed under a separate division that gradually became autonomous and the case company offered its products to customers around the world. Due to the company's decision to focus on its core business and diversify other areas, the technology division became an independent and listed company in 2000.

The case company had a comprehensive portfolio of customers, technologies, patents and solutions that ran as separate businesses with little in common about how products and services were defined and managed. In addition, the full business potential was not utilised in the different areas.

The company decided to define a new and independent business strategy that changed significantly the way business would be done in the future. The strategic goals for this transformation were to focus on customer experience and build a deeper and continuous partnership with customers to strengthen and increase the earnings of both. This also materialised as the need to be a lifecycle partner that could offer different kinds of services. The second area was the utilisation of existing technologies and the development of new technologies to remain at the forefront of its selected industry area. Product competitiveness was at the forefront of this change and the possibilities of strategic sourcing were seen as closely related to this area that could further improve competitiveness. Finally, the new way of working required a new operating model where the organisation, processes and information systems were aligned.

2 The Starting Situation: The Issue Addressed; The Objective

The business transformation initiative started in 2010 and the first steps to organise around Product Lifecycle Management (PLM) development started in 2011. The transformation was the responsibility of the dedicated internal development organisation that was hierarchically equal to the business lines and business areas.

This business transformation focused on developing and implementing the first operating model with the scope on core and supporting business process development and IT applications needed in these process areas. This led to siloed process and IT system development where different business process were not aligned and did not work together. In addition, the supporting IT development was independent from the processes that they were supposed to support. This first attempt to deploy PLM failed due to process and IT application uncoupling. Only limited capabilities from the operating model could be brought into use. A major challenge was the business lines' concerns that the new operating model did not support their business requirements. This concern was especially directed at PLM. The result was a way of working that did not support the business needs, and the deployment of the PLM system failed.

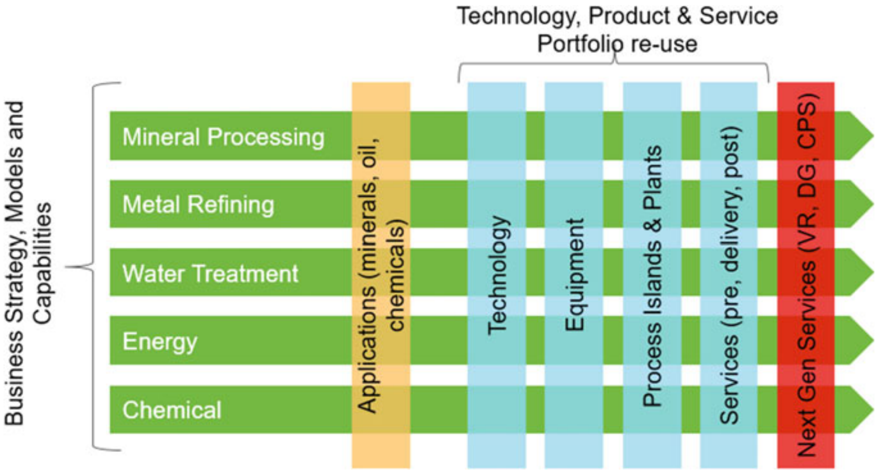


Fig. 1 Case company industry areas, technology, product, and service footprint

The case company's product, service and technology portfolio was heterogeneous and was managed independently by the product and technology managers. Most customer deliveries, especially plants and process lines were based on past project deliveries. Some product lines were using systems engineering and Configure-to-Order (CTO) principles and were found at the equipment level. Service products were managed as part of the product lines, but typically this was unstructured. Figure 1 illustrates the case company's different industry areas and technology, products and services that are to be managed over the entire lifecycle.

The case company's need to improve its product competitiveness was critical. It could be done in two ways where the first was to improve and align the way products were managed, and secondly the improvement of the products to be reusable for delivery and support services sales. The need for PLM was seen as a way forward. However, the agreement on the objective or goals of PLM was unclear, as was the scope of PLM. The situation was also difficult, because PLM system selection and development had gone forward as part of the overall business transformation initiative, but without agreement internally of common goals and scope.

Lessons learned from this first attempt to deploy PLM were the need to involve the business and have people working fulltime in PLM and product management development.

3 What Happened, What Was Done

To make this transformation successful, a Product Management and Product Lifecycle Management team was formed to focus on implementing these areas in the organisation. The following short- and long-term goals were set:

- Strategic goals for PLM to justify the change.
- Product and Service Audit to understand the feasibility of the change.
- PLM Audit to understand the feasibility of the change.
- Product and Service Definition initiative to align products and services.
- PLM Concept to show the new way of working, and the feasibility of implementing it in the case company.
- PLM Implementation program to bring the new way of working into practice.

Previously, one on the main challenges had been the ability to communicate the goals for PLM and what was its scope. Therefore, one of the first topics was to agree on the goals during the initial phase. They were defined as:

- Increase the reuse of products, services and their modules in delivery.
- Reduce the amount of engineering hours used in delivery projects.
- Increase service sales.
- Increase strategic sourcing to reduce the amount of supplier items used in design and delivery to support services.
- Reduce the cost and number of different items bought from suppliers.
- Build a supplier relationship with fewer strategic and key suppliers.

In 2011, the scope of PLM and Product Management were still under debate. This resulted in a productization audit to review the current state of the product and service portfolio. This audit highlighted risks in: (1) product management maturity and the variation between different product lines, (2) revenue generation in and between products that occurred as different pricing and revenue transfer models between product lines, (3) product and service definition was unstructured and missing in areas causing inefficiencies in deliveries that used products from different product lines, (4) product development carried out in delivery projects undermining the need for product management and development and creating in some cases customised solutions, (5) limited cross-product and service knowledge in the organisation to create reusable customer lifecycle solutions. From these observations, a development project was started that focused on the product definition development to support the business transformation.

A separate audit was carried out to determine the PLM maturity level and to review the business needs that PLM should address. This led to the first PLM Concept that tried to use and deploy the development already done. The focus of this PLM Concept was a simplified product management process and PDM centric adaptation of the business dimensions presented by Sääksvuori [1] and Stark [2]. This concept work resulted in an improved system and process alignment, but the limiting factor was still the applicability to the product and service lines due to the varying nature of the product portfolio. This resulted in a common product document management solution rather than a true PDM capability in all product lines.

3.1 The Strategy Driven PLM Concept

The decision to create a corporate-wide PLM Concept and nominate a PLM Concept owner was made in the spring of 2011. This decision made it possible for the first time to align the business needs and the strategic goals in a PLM concept and implementation program. The approach applied ideas presented in Sääskvuori's [1] and Stark's [2] PLM Models. The PLM Concept work also integrated the product and service definition work started earlier with the product lines that had applied a modified method from Haines [3].

The first task that was done in the PLM Concept work was to define the maturity model, levels and business logic of the different product lines in the case company. The maturity levels varied across the company as did the business logic. Therefore, a baseline and categorisation of the different products and services was made. Based on the mapping in Fig. 1, the case company's PLM Maturity Levels were categorised for the different product lines, for example, with Kärkkäinen's model [4] as shown in Table 1.

The result highlighted that the corporate wide PLM maturity was at a chaotic and unstructured stage. Also, it was evident that Equipment and Services were at a higher maturity level than the Plants and Process island. This meant that the business strategy would be difficult to achieve if investments in PLM were not made to achieve the goals placed on PLM.

The case company strategy was the driver and justification for the PLM initiative. The alignment to the strategy and the strategic PLM objectives was essential to progress in an organisation that was comprised of heterogeneous product lines. The strategic drivers were defined further to:

- Increase revenue 3-fold by the year 2020.
- Improve return on investment for customers through efficient operating costs and technology.
- Increase service business 4-fold from the current level.
- Reduce engineering hours in delivery projects.
- Increase the reuse of products, services and product modules in delivery projects.
- Increase the level of strategic sourcing to improve cost competitiveness.

The PLM initiative also supported several other strategic initiatives that were: (1) customer centricity and lifecycle partnership, (2) customer and company earnings logic, (3) leading technologies, and (4) product-service solution competitiveness.

Table 1 PLM maturity levels models in the case company [4]

Maturity	Description	Product lines impacted
Level 1: chaotic	Level of coordination is low	– Corporate wide – Industry areas with all technologies, products and services – Chemical—plants and process islands – Next generation services
Level 2: conscientious stage	Level of coordination is mainly at functional level	– Metals refining—plants and process islands – Water treatment—plants and process islands – Energy—plants and process islands – Mineral processing—plants and process islands
Level 3: managed stage	Level of coordination is reaching cross-functional and company level	– Mineral processing—equipment and services – Metals refining—equipment and services
Level 4: advanced stage	Level of coordination is dyadic in inter-organizational relationships	– None
Level 5: integration stage	Level of coordination is extensive, reaching inter-organisational networks	– None

3.2 *The Product Definition Work*

The audit on the state of productization revealed the need to create a common product and service definition within the case company. In addition, this work had to agree on the terminology that was to be used to describe the elements of the product and service portfolio. This led to the Product Definition concept that defined the information to unify the products and services across the company. The definition was divided in two dimensions. The first dimension being equipment product definition, service product definition and plant product definition. The second dimension was the productization maturity levels (A, B, C, D) that were defined for each product and service. A-level being productised more than 80% and fully managed by product management. D-level, where productization level was less than 20% and not managed by product management actively. In addition, product and service management defined what products and services were to be productised first based on business prioritisation.

Table 2 PLM maturity levels target example

Category	Productization level target	Products and services
Level A	More than 80%	– Mineral processing—equipment and services – Metal refining—equipment and services – Energy—equipment and services – Mineral processing—next generation services
Level B	Between 60 and 80%	– Water treatment—equipment and services – Mineral processing—plant and process island – Metals refining—plant and process island – Energy—plant and process island
Level C	Between 20 and 60%	– Water treatment—plant and process island – Chemical—equipment and services
Level D	Less than 20%	– Chemical—plant and process island

The Product Definition was a modified version of the concepts presented in Haines [3]. The productization categories that each product had to define for their prioritised products and services were:

- Product and Business Management
- Sales and Marketing
- Engineering
- Delivery
- Services (pre-delivery, delivery and post-delivery)
- Quality, Environment, Health and Safety

Each of the above areas has a set of deliverables that must be available for the products and services. Based on this available content, the product was given a productization level in the current-state-analysis and a productization target based on the product strategy (to-be). The productization work also prioritized what product definition areas were needed for each product and service based on the existing business priorities. For example, new product introduction products had different business priorities versus mature products focus areas. As an example, the productization target levels for the products and services, to support the product strategies, according to the Productization Maturity Level [3, 5] are shown in Table 2.

The decision to set different target levels also reflected the current and anticipated reuse-level of the products and services in each industry area, but also their application across other industries that the case company worked in. This is typical, for example, for automation systems that were applied to various business areas. This also raised the need to define the product management roles and responsibilities of the different products, services and the interfaces between them. The outcome was the mapping of the product-in-product-in-service relationships with clear boundary areas that each product and service included. For this to work in the case company, it requires a product architecture that supports both Engineering-to-Order (ETO) and Configuration-to-Order (CTO) approaches as presented in Forza and Salvador [6].

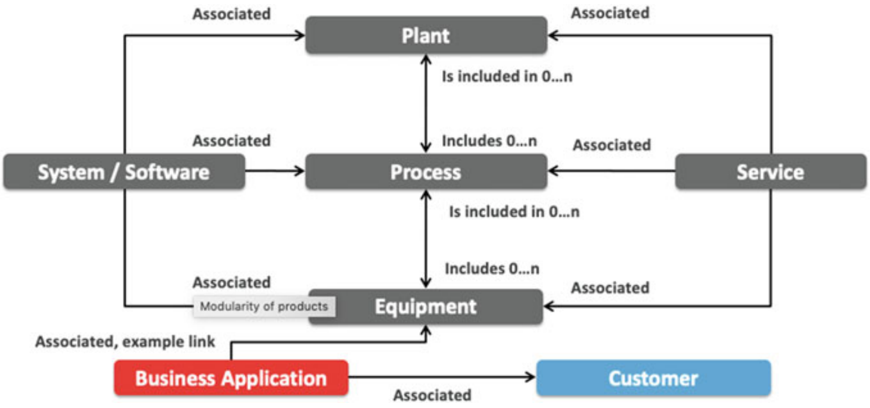


Fig. 2 PLM product-in-product concept

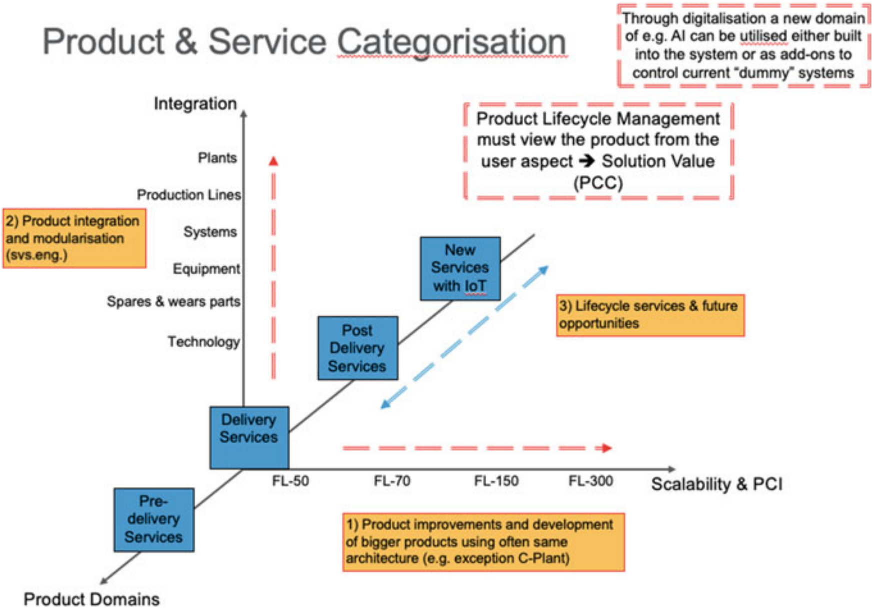


Fig. 3 PLM product-and-service time-dimension

Due to the nature of the solution business that the case company is in, the product definition and PLM concept created two addition definitions that were the (1) product-in-product concept (Fig. 2), and the product-and-service time-dimension (Fig. 3).

The first concept identified the relationships between (1) equipment and services, (2) equipment and production processes, (3) processes and plants. Additionally, the software system relationships were defined for the above products and services. The product-and-service time-dimension defined three things: (1) the product platform relationship to scalable products, for example, size, and continuous improvement to extend the product lifecycle. The second (2) defined the integration possibilities of the products to create larger system. Finally (3), the relationship between the physical product and the pre-delivery, delivery and post-delivery services.

3.3 Development of the Strategy Driven PLM Framework in Case Company

The first challenge was the role and scope of PLM in the case company's organisation and operating model. Initially, PLM was regarded as a function that was part of the Research and Development (R&D) Core Business Process. PLM was regarded as having only a role in the R&D Process organisation and it was placed between the Process and supporting IT systems. This position caused confusion and unclear responsibilities. Based on (1) the productization audit, (2) the PLM Maturity analysis and (3) the interviews carried out with the product and business line heads, it was clear that there was a business need for a corporate Product Lifecycle Management concept followed by an implementation project to change the current way of working. The business lines support for this need was clear, but their emphasis was on the business needs and benefits that should be achieved and the reluctance to have another IT software implementation.

The first objective was to position PLM in the correct place of the organisation and operating model under development. An overall framework was created to support the PLM initiative based on Osterwalder [7] and TOGAF principles (Fig. 4). This was used to argue the importance and organisational location of PLM, but it also gave clarity to the whole enterprise architecture development.

The key building element missing was the business model that formed the bridge between strategy and business capabilities that were needed to achieve the goals. The business model is used to identify the existing and missing business capabilities. For the PLM framework, these capabilities are categorised into three capability domains: (1) PLM, (2) products and services, and (3) customers. The products and services are core in the definition of the value proposition of the business model [8]. Similarly, customer knowledge is the basis of defining the Customer Segments [7] and channels how to serve the customer in the correct way over the lifecycle. According to Osterwalder [7], a company uses customer segments to understand what value is created and who are the key customers [7] and it also identifies how this value is created using internal and external resources. The existing and missing capabilities originate from the strategy and become evident in the business model. The capabilities of the business model defined what PLM must do in the operating model (Enterprise Architecture), and these PLM capabilities can be further broken down into PLM features and requirements.

The capabilities are the parts of the enterprise architecture that are divided further into convenient sized changes to the organization structure, processes, information

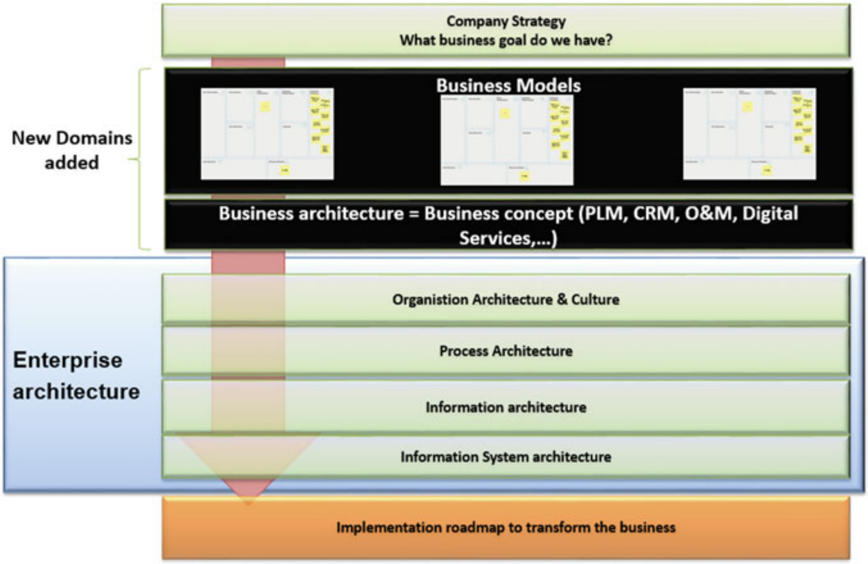
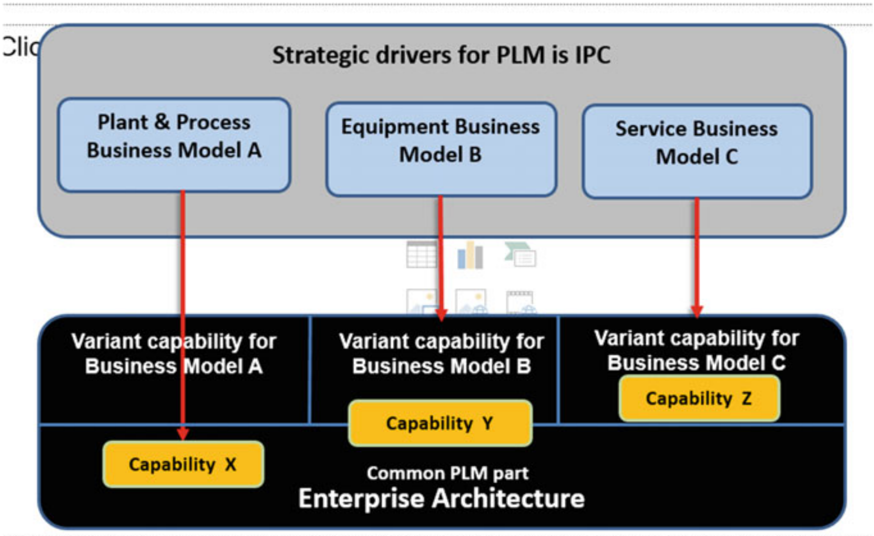


Fig. 4 PLM impact on the enterprise architecture

and IT architectures (Fig. 4). The capabilities that drove the PLM concept and model in the case company were: (1) product, service and module reuse, (2) increase service business, (3) reduce engineering hours in delivery, and (4) increase strategic sourcing through less manufacturing items. One of the challenges was the need to develop capabilities that were applicable for all or some business areas. The most challenging were those capabilities that were totally unique for a certain business line (Fig. 5). The identified business capabilities defined, for the case company, a PLM framework that had 3 lifecycles phases and the interaction between the different product layers that needed to be managed. The framework is an adaptation of the lifecycle phase presented by Stark [2] (Fig. 6).

Once this PLM Framework was defined, the development and deployment project could be scoped with understandable business capability sets to support prioritised business needs in one of the three PLM lifecycle phases, and product and service areas. The following stages from here were typical process, information and IT system development that also included the deployment and change management to on-board the organisations. The approach was a Minimum Viable Product approach that used agile development methodologies to ensure consistent feedback from the business organisation that would use the new operating model.

The implementation project focused first on the development of the capabilities for the equipment products and the deployment to the product lines verifying the solution with a pilot product. This was followed with development and implementation for services and plants. However, based on the equipment product and service product implementation, the need for a dedicated plant PLM Concept was identified. Even



Strategic drivers for PLM is IPC

Plant & Process Business Model A

Equipment Business Model B

Service Business Model C

Variant capability for Business Model A

Variant capability for Business Model B

Variant capability for Business Model C

Capability Z

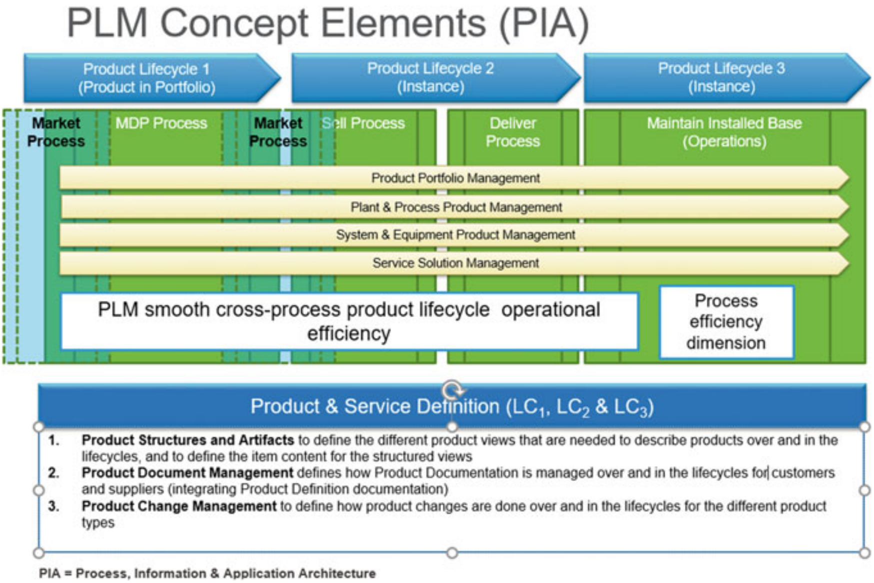
Capability Y

Capability X

Common PLM part

Enterprise Architecture

Fig. 5 Capabilities that define the PLM section of the enterprise architecture



PLM Concept Elements (PIA)

Product Lifecycle 1 (Product in Portfolio)

Product Lifecycle 2 (Instance)

Product Lifecycle 3 (Instance)

Market Process

MDP Process

Market Process

Sell Process

Deliver Process

Maintain Installed Base (Operations)

Product Portfolio Management

Plant & Process Product Management

System & Equipment Product Management

Service Solution Management

PLM smooth cross-process product lifecycle operational efficiency

Process efficiency dimension

Product & Service Definition (LC$_1$, LC$_2$ & LC$_3$)

1. **Product Structures and Artifacts** to define the different product views that are needed to describe products over and in the lifecycles, and to define the item content for the structured views
2. **Product Document Management** defines how Product Documentation is managed over and in the lifecycles for customers and suppliers (integrating Product Definition documentation)
3. **Product Change Management** to define how product changes are done over and in the lifecycles for the different product types

PIA = Process, Information & Application Architecture

Fig. 6 Product-in-product lifecycle model though this was based on the equipment and service product concept, there were significant addition to methods for example how the plant structures were defined using system engineering logic to a higher degree to include inter-linked feature, logical, physical and location structures. A key success factor was the time used on training and supporting the product lines hands on from the beginning of the piloting to ensuring that the product lines can continue independently the productization work to fully adopt the PLM operating model.

4 The Results and the Benefits Achieved from the PLM Concept

The objectives that were set on the beginning of the new PLM concept were to:

- Increase reuse of products, services and modules
- Reduce the number of engineering hours in delivery
- Increase services
- Increase the role of strategic sourcing

A product definition that covered all product types from equipment, service to plants was achieved. The evidence of the reuse of the products and services was based on the structure flow that could be used over the 3 lifecycle phases starting from offering structures that led to sales and delivery structures to finally installed base structures that can be used to maintain the installed base. Once the structures were in place that were used to base the offer and delivery on, the time to create quotations that led to sales order reduced.

Based on the availability of the agreed product definition and product structures, the amount of engineering hours was reduced and one significant factor was the existence of a common component library with approved items. In addition, the possibility to send approved manufacturing bills of materials to manufacturing shortened the purchasing order cycles before manufacturing started. Another significant improvement that was possible was the interface between equipment products that formed the process lines that comprised the plants. The need to redesign the equipment is not needed from the plant and process engineers, but only the equipment specification to fulfil the process requirement.

One of the main improvements occurred through the effort the whole organisation put on the service business development. Through the service definition work done in the program, the case company was able to structure its services and categorise according to how they supported the different lifecycle phases and product and process types they supported. This PLM implementation was not solely or even directly responsible for the service business growth however, it played a role in supporting the continued growth that reached the investment market expectations.

The foundation for sourcing to succeed was the introduction of a common item concept that defined how to manage all items in the case company. The implementation of this concept made it possible for the organisation to eliminate duplicate items and identify competing manufacturer items that were previously purchased based on delivery project needs. The concept also started the discussion internally about which suppliers should be strategic and key suppliers. This consolidation to selected items through the different product lines also made it possible for services to better support customer spare part and other service needs in the future.

In addition to these achievements, the implementation of the PLM concept played a fundamental role in creating a common way of working within the case company and it served as the platform for product management functions and roles to gain recognition as a career path. Finally, the improvement to the response times to the customer, for example, quotation times, validated that PLM played a role to improve customer satisfaction.

5 The Foreseen Changes and Disrupters to the Existing PLM Concept

How can PLM development succeed with the emergence of new business models and technologies, or how will PLM roles change in the future?

When the PLM Concept was defined (c. 2012–2103) for the case company, the impact and the opportunities of these emerging technologies was unclear and could not be incorporated due to the risk of creating a too complex concept based on immature and unproven technologies. The emergence of the Industrial Internet of Things (IIoT), digital twins, multibody full physics real-time simulation, or machine learning based artificial intelligence offer great possibilities today at the concept level, and they open new areas that the case company's PLM concept must include in the future revisions. It is evident, not only for the case company, but other companies in the same industry that the adoption of these new technologies will disrupt this industry sector.

6 The Lessons Learned in the Case Company

In the case company, PLM was started solely as an Information Management PDM initiative to improve the operating model that supported only the R&D business process digitalisation. After limited benefits were gained with this approach, the decision to move to a PLM business transformation initiative that implemented the strategic drivers through product and service definition and corporate wide PLM strategy, created value by realisation of the corporate and business unit strategies.

The most important aspect that was learned in the development and implementation of the PLM Concept, in the case company, is the misconception that one concept defining a common operating model with one set of processes and IT systems will work in a company that has multiple business models that have differing value propositions to the customer based on a heterogenous product and service portfolio. This initial vision of a simplified One Company concept set the transformation program back by 12 months and involved loss of considerable IT development resource and funds.

One of the main challenges was also the lack of senior and middle management understanding of what PLM is and what in can do for a company in a business transformation. In hindsight, the education and briefing around PLM should have started much earlier and it should have been even more visible throughout the case company. The initial decision to separate the PLM concept and the product definition work from each other was a decision that created misalignment, but luckily this was changed early in the work, but it still caused overlapping work and misalignment in the team. The PLM organisation must be a business-critical initiative and have the support and involvement of a cross-functional team that has the mandate to proceed from the executive management team and should report directly to senior management.

The case company's PLM drivers were efficiency orientated and drove PLM from an inside-out view point of view. This approach does not focus on the customer's voice or insight to understand the customer's business need and selection of the correct solution to achieve their business objectives over a sustainable lifecycle that was already emerging in the service business. The inside-out approach creates an environment where PLM is seen to implement short-term benefits rather than long-term benefits through sustainable and evolving customer relationships. By nature, PLM is a strategic initiative and the improvements it creates are realised on the long term. Benefits from PLM work are measured in years, and effort and commitment must be constant, systematic and along an evolution path from one maturity level to the next.

Therefore, we believe that the PLM Concept cannot succeed without understanding of the relationship between strategy, business models, products, services, technologies and how the enterprise architecture is built. PLM can drive product excellence and innovation, but the case company did not have an internal structure and execution framework that included the customer dimension aligned with strategy and business models. However, we see that the addition of these dimensions is essential for PLM to support future needs. As a theoretical contribution of the study in Donoghue et al. [8], a rough framework was proposed as shown in Table 3. This framework includes these missing areas. This model also introduces the relationship with strategy and business models.

7 Recommendation and Advice

This case study focused on the models that were applied to the case company where the business is complex solution deliveries that require deep technology and engineering capabilities. This low-volume high-mix solution is typical for many European manufacturing companies. The challenge that these engineering and technology companies face when implementing PLM are dependent on the product, service and PLM maturity level. The business characteristics are often project driven Engineering, Procurement and Construct (EPC) solution deliveries. The case company applied and implemented PLM to transform to a product-service company and the approach should be applicable in certain part to other companies of the same nature.

PLM is a key initiative for many companies, but methods used, and results achieved from PLM initiatives are most often conflicting. The promised value from PLM initiatives is not always realized or even evident after the PLM implementation. Due to the rapid pace of digitalization and the emerging services and platform economy, PLM is under pressure to deliver on its promise and go even further in the future due to the emerging technologies of industry 4.0 [9].

From a practical point-of-view, PLM can have two different approaches in companies. The first is the traditional approach where PLM is information system centric, and very often only PDM centric. In this case the benefits are typically efficiency focused. The second approach is business-driven where PLM is a strategic initiative that covers the operating model, products and services from the customer lifecycle point-of-view, and this offer the possibility to create a disruptive business model.

It is important for a company to understand what their PLM maturity level is, and what type of change they are trying to achieve, not only with their products, services

Table 3 The extended global PLM model for manufacturing [8]

	Operating model (PLM)	Product-service	Customer	Dependency
Strategy	Strategy alignment and PLM strategic goals	Strategy alignment and product and service strategic goals	Strategy alignment and strategic customer goals	All
Business model and business capabilities	Business model PLM capability identification	Business model product/service capability identification	Business model customer capability identification	All
Operating model dimension	• Management and control • Organisation architecture and culture • Process architecture • Information architecture • IS architecture	• Product and service definition [5]	• Customer definition • Segmentation • Channels • Customer relationship management	All
Maturity model	Sääksvuori [1]	A, B, C, D model [5]	Kärkkäinen [4]	
Implementation	Stark [2]	Stark [2]	Stark [2]	

and PLM management system, but also the customer segments and customers. All of these areas must be developed together, and the products and services are at the core of this work. This leads us to the question if PLM should be driven from an outside-in approach that starts from customer insight and strategy. If the approach is changed to outside-in, then the needs and insight of the customers would drive PLM over their lifecycle. This would lead to products and services that better fulfil the customers evolving requirements and improve the customer experience over the complete lifecycle. This would also lead to better understanding of how services and digitalization could be implemented in companies, and how service design and customer experience could be integrated with PLM.

For a PLM transformation to succeed, it is important to understand the different areas that must be taken into consideration before and during the PLM initiative. Therefore, the current state, the company's objectives and readiness need to be mapped from the following viewpoints:

1. What are the strategic objectives for the PLM change?
2. What is the definition level of the products and services?
3. What is the current state of the company operating model (enterprise architecture)?
4. What are the products and services definition change that is needed to achieve the objectives?
5. What are the changes that are needed in the operating model (enterprise architecture) to achieve the business capabilities?
6. How to implement change in an organization (program and change management)?

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PLM Strategy for Developing Specific Medical Devices and Lower Limb Prosthesis at Healthcare Sector: Case Reports from the Academia

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Abstract The study aims to present advances made by the academia in terms of multidisciplinary work among groups formed by industrial designers, industrial engineers, physiotherapists, and physicians, related to a University Hospital in a local environment in order to consolidate a collaborative strategy that allows the development of specific medical devices. *Methodology* A product portfolio consolidated by surgical devices and lower limb prostheses was the outcome of undergraduate projects, master and medical-surgical specialization projects working together. The baseline of surgical devices contains virtual pre-planning, biomodels, surgical guides, and implants according to requirements from different anatomical areas, predominantly skull and knee treatments. The baseline of lower limb prostheses presents cases developed and tested with users who had transtibial or transfemoral unilateral amputation. *Results* As the number of actors who shared data and limited resources increased, a gradual implementation of PLM strategy was established by building collaborative databases based on an established conceptual framework proposed by previous tool selection, so that the roles for project execution were defined in terms of access according to the role. To achieve comprehension among participants, a visualization model was adapted to involve workflows, roles, capabilities, and resources. Several data were collected from study cases to be stored and retrieved for further development according to stage development, understanding time and resources implemented to respond to a short period request when schedule uncertainties demand those requirements. Regardless of those results, the further project needs biocompatible materials as well as machines capable of transforming this raw material in order to achieve high-quality standards.

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1 Introduction

Technological changing promoted by the digital era has merged with the real world, integrating physical and biological systems. This situation has created opportunities to alter the shape and reality of the environment around us. Our reality has been built by new materials studies that apply to personalized issues and bioprinting, redefining the way of conceiving processes, products, and value creation according to the World Economic Forum [1].

Specific cases are related to the development of orthopedic surgical medical devices. Instead of the traditional approach of mass standard device production, some products have emerged from new manufacturing concepts such as flexible factories [2] and Direct Digital Manufacturing (DDM) [3]. These advances have granted process flexibility for developing Medical Devices (MD) obtained via 3D printing such as Patient-Specific Implants (PSI) [4], surgical guides for cutting, guiding or drilling, 3D printing from skin cells for tissue replacement and even printing organs. Those are pieces of evidence about the way how technological change has impacted on the new medical devices conception [5]. It was by far demonstrated that Medical Devices have been effective for patient functional recovery and also improvement in health professional performance [6].

The development of these Medical Devices requires the integration of a large amount of data that must be kept updated and traced through the process. Those systems are heterogeneous and allow the exchange of data between different roles, processes, communication tools and digital visualization apps [7]. Healthcare organizations face new challenges that are derived from a greater focus on controlling health system costs regarding increased expectations on treatment efficiency and personalized medicine [8]. It must be oriented to create and improve value throughout collaborative strategies for the organization and patients [9]. A correct strategy must integrate the patient's profitability with successful care. Therefore, financial success would be a desirable consequence instead of the most relevant strategy in healthcare treatment [10].

In the light of this approach, it was identified that implementing product lifecycle management strategy PLM grants value creation [9]. The studies on literature review showed positive results to PLM implementation by improving processes acceleration [11] that allows reduction of information access time, number of errors, improvement of communication between actors and reduction of design time and product costs [12].

Just a few studies carried out on the PLM approach in the medical sector have been able to identify three intervention topics: implants, biomedical imaging and product portfolio in medical device companies. Likewise, it was possible to identify development issues from Medical Devices, mainly focused on information exchange and the relationship among roles [13]. Another difficulty reported has been obtaining relevant data for raw biomedical images [14], as well as handling the transmission of patients' data between collaborators [15]. Finally, technology integration deals with different processes. From reverse engineering RE to computer-aided design CAD, computer-aided engineering CAE, rapid prototyping RP, computer-aided manufacturing CAM and other data files that must be integrated in order to ensure interoperability [16].

On the other hand, despite the fact that PLM strategy is known and implemented by automotive and aeronautics in countries with emerging economies since the 90s [17], the PLM strategy applied to the orthopedic medical sector is still uncertain and needs to be explored in more detail. To our knowledge, a few studies on PLM in Latin America in the health sector have been oriented to osteosynthesis implants [18–20], and no studies on socket development for lower limb disabilities have been found. However, in order to execute a management strategy, it was found that some researches approximate to the data control on early design stage in sockets for inferior members [21–24] and customized implants [13, 16].

Different authors recognize the importance of health technologies for value creation in surgical innovation to improve patients' life quality within industries 4.0 framework, to configure a System of Systems based on CAx. Those technologies spin on design and manufacturing labor, supporting patient-centered activities, applying the principles of flexible manufacturing by using a PDM system integrating virtual technologies and low-cost 3D printing. Those isolated systems were selected by technology assessment. Based on these criteria, authors designed the PLM strategy in order to enhance the development of medical devices, articulating process areas, tasks, and roles with the technologies mentioned above.

The following sections describe the background, the methodology implemented to define the strategy and the procedure in which the PLM reference framework was established for surgical and prosthetic medical devices development. Finally, the results, discussion, and conclusions are presented.

1.1 Background

Almost 1.5 million different medical devices, a vast variety of artifacts, integrate Medical Devices [25]. Since 2002, the global market was calculated at US$14 billion [6], but four years later this value increased around US$260 billion [26]. In 2014, the orthopedic medical devices world market was estimated at US$375.2 million [27] from standard devices produced by countries such as Australia, Canada, The United States, The European Union, and Japan, which belong to The Global Harmonization Task Force GHTF. Comparatively, Europe was just the third worldwide market, which was led by the USA with the 50%, although emerging countries such as China and India have also risen [28]. In Latin America, Mexico and Brazil were the largest manufacturers of Medical Devices in the region [29].

Due to the fact that medical devices have been so profitable, they have had two drawbacks during exportation. First, medical devices in developed countries are not suitable for contextual, anthropometric and epidemiological needs for the Third

World population [26]. Second, technological dependence and weak regulations in developing countries had already opened the door to adulterated and even degraded products [30].

In contrast to this trend, personalization in product development [31] is a correct path to generate solutions that correspond to patients' real needs, applying technologies to value creation in clinical practice [32]. The technologies involved in medical devices development come from the integration of architecture systems defined by the inclusion of Reverse Engineering RE [33] or CAD systems [34]. These systems implement segmentation techniques such as tomography to obtain soft tissue or hard tissue virtual models as bone geometries; or by point cloud techniques to generate the use of a light scanner or contact reconstruction. These systems integrate the application of virtual CAD technologies for modeling, CAE for evaluation by simulation, 3DP printing [35] or CAM for the fabrication of final devices [36].

Recent studies on new technologic products for specific patients apply RE based on image segmentation technique to create implants adapted to bone geometry for reduction or restitution of complex fractures in: skull [37], jaw [38], spine [39], knee [40], ankle [41], elbow [42] and shoulder [43]. Apart from implants, other related technologies have also been developed as temporary guides to assist surgeries [44], virtual pre-planning [45] and use of physical Biomodels [46]. At the same time, the application of RE by point cloud has allowed the generation of reference models from residual limbs that serve as a reference for the design of customized prostheses for lower limb amputation [47] and upper limb, [48] using virtual technologies and additive manufacturing for socket generation.

Despite the successful evidenced applications, there were identified three drawbacks to achieve technology implementation for medical devices. The first one is related to equipment and specialized software cost. Although different tools have been proposed, communication difficulties between reverse engineering activity and CAD/CAE software remain [22]. These difficulties arise due to the investment limitation on commercial PDM licensed from robust use, as well protection and migration of data [49]. The second drawback refers to the complexity represented by the development of these devices, corresponding to compliance with regulatory requirements, clinical requirements, established monitoring processes and treatment [50]. Finally, insufficient knowledge management causes the third problem, since specialized processes depend on tacit knowledge that only few people have.

Based on the previous approach, the health sector requires solutions focused on creating robust and reliable design methods, which involve flexible manufacturing articulated with low-cost systems. That purpose could be attained by means to defining workflows that allow a reliable implementation of virtual technologies [51], oriented towards compliance by quality, safety and efficacy criteria. Not less important is to guarantee that knowledge is transferable and becomes explicit by routines and practices from organizational knowledge, to guide and supervise each role performance during the lifecycle phases of the process development [23].

2 Methodology

A conceptual framework was established based on the PLM model visualization, and Martinez's definition of process areas involved in each phase [52]. Strategy construction methodology was designed as established by Stark [53], since the design of the strategy aims to meet the user's expectations quickly and sustainably. The implementation objective was defined on the basis of the need to organize the basic data related to the product portfolio, as aimed by Schuh et al. [54]. Thus, goals were defined accordingly as follows. On the first stage, two objectives that brought together the key activities to carry out PLM strategy implementation were defined. Namely, the aims were:

- To define a System of System (SoS) or an integration model related to flexible manufacturing technologies based on low-cost health techniques to obtain surgical Medical Devices (MD) and orthopedic prosthetics MD for specific patients.
- To define a reference framework that integrates the stages and process areas with technologies, establishing practices and diagnostic tools, process protocols and quality verification for results generated in each case in order to contribute with the fulfillment of the quality criteria in the processes associated to the stages of ideation, definition and implementation, by means of case studies.

The fulfillment of first objective was executed by means of two stages. The first one was concerned about the strategy configuration, for which was to be required to define the software architecture to be able for developing medical devices. In accordance with the SoS theory, RE-CAx-3DP systems were defined, selecting potential technologies to support health software as well as low-cost hardware. From this study, the inputs and outputs of each system were defined as measurable milestones throughout the entire workflow [55]. The measurement of performance and interoperability between technologies were identified. To do this, user requirements were defined on software and hardware capabilities such as file weight, virtual volume, final part weight, virtual and physical processing times, affordability and compatibility of CAx file formats [56, 57]. The definition of the types of technologies was conducted while projects were oriented and addressed to medical devices design, which allowed defining activities by stages and alternatives to support RE-CAx-3DP architecture.

In the second stage, requirements were established to configure data management and government system. Like the SoS from low-cost RE-CAx-3DP, this system was made up with PDM low-cost product data management platforms. Three sorts of data were set up to frame the PDM. First, the file storage of RE-CAx-3DP that is a primary line to support the product development process. Second, for documents concerned to process management that allows traceability to be carried out in terms of progress, quality and compliance with product requirements in accordance with the operational line advance. Third, supporting materials for training and research such as catalogs, tutorial videos and design guides. These three types of data were the ones required to administer in any case study.

According to the second objective and based on the model established by Martinez [52], the SoS was articulated in a conceptual framework of the PLM strategy, delimiting the development process to the first three stages of the product life cycle: ideation, definition and implementation. The process areas derived from conceptual framework guidelines are fuzzily involved in different lifecycle stage. We proceeded to define a reference framework to adjust a PLM strategy to medical devices that was supported by the development of research projects for undergraduate, masters and doctoral studies that contribute to do more research and configure both SoS, for RE-CAx-3DP and for cloud storage and documentation. On this strategy, workflows, roles, activities, and tools were integrated within the strategy.

Finally, a strategy was defined for two kinds of cases, surgical medical device and a prosthetic medical device. Those involve flexible manufacturing technologies and SoS, RE-CAx-3DP and Storage documentation by low-cost resources. The strategy incorporated workflows, stages, process areas implemented, actors involved and sort of information generated through product development.

3 Results

This section describes the main results related to the guidelines for the PDM platform, the selection of technologies for the SoS RE CAx 3DP definition, the conceptual framework of the PLM strategy, the description of case studies and the PLM strategy of health technologies for the development of orthopedic medical devices.

3.1 Guidelines to Build a PDM Framework

The four areas proposed by Schuh et al. [54] were considered for the configuration of the strategy: data management, basic product data management, project data management, business administration and system integration. The first area is product data management, which involves tools for the storage of source files, planning, hierarchy, information coding, document creation and editing, file management and change and configuration management. The selection of the platform for information management required the identification of the capabilities of the system. It was established that the platform should first allow the administration of the technical and operational information associated with the device development process, as opposed to the storage of DICOM formats and the generation of CAx files: RE CAD CAE RP [58]. Second, the platform had to include office tools for the creation and edition of documents for administrative processes and quality management. Third, the platform should allow the storage and administration of audiovisual material, created for learning processes [59].

The second one is the project management area, where formats were organized through planning tools, quality assessment and maintenance support documentation. The third area, business management, is related to the management of multiple projects, tracking and document backup, change control, process performance indicators (time, cost, quality), access levels and workflow management. The fourth area, collaboration and integration, concatenating each system into a single storage and data exchange interface. Since commercial PDMs of a robust type require a considerable investment [60], it was decided to evaluate isolated technologies that in an integrated version make up a SoS with the capacity to support the basic features described above [61].

3.2 Technology Selection

A matrix of capabilities of software tools was generated in relation to the type of software and possible actions to be carried out. This matrix was built for the preliminary selection of software tools, to be used in the configuration of the software architecture in order to develop medical devices and PDM platform setting oriented to storage, configuration and changes of files derived from process development, data management and knowledge transfer.

Regarding the actions required to perform in these software, criteria such as file editing, CAD volume visualization, storage, office documents edition and data management creation of CAx files for product development processes are described in Fig. 1. Based on this matrix, it was identified software with greater capacity to respond to the requirements. We identified public software that allows us to perform 5 actions regarding the 6 requirements; however, information is uploaded to a cloud service. This is followed by educational software that allows performing 4 types of actions in respect of the file size, the learning cave, its cost, its accuracy, availability of supporting material and data security; these are the six requirements proposed. This procedure can be carried out once the software typology, the selected systems and typology of low-cost integrated software tools have been identified.

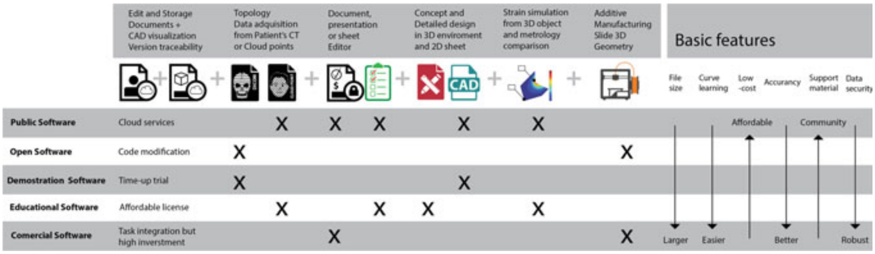

Fig. 1 Comparative analysis between capabilities and software selection

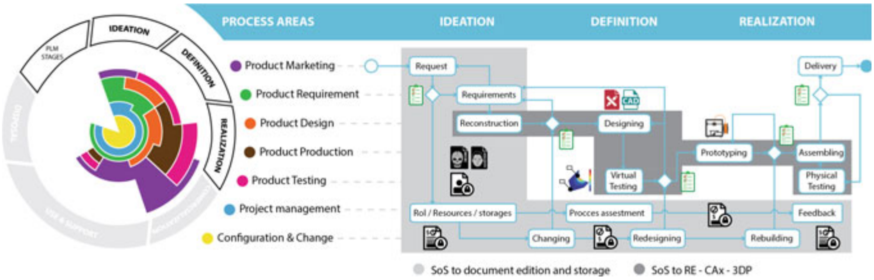

Fig. 2 Workflow and activities based on system integration

3.3 Strategy Conceptual Framework

The main requirement for the development of these devices is to respond to the need to generate personalized products, tailored to the patient. This feature has implications such as order of production by customer demand and generation of production requirements based on the clinical case typology. Consequently, the development of each product generates a geometry adjusted to a specific patient and product.

The way these products should be developed requires the definition of a flexible manufacturing model, appropriating the use of technologies that can be implemented in the health area. In accordance with the above, since the conception of 4.0 industries in the integration of the virtual world materialized physically by 3D printing manufacturing techniques, a conceptual framework for the construction of the PLM strategy could be configured. The visualization model proposed by Martínez [52] was taken as reference due to its contribution in the definition of process areas involved in the development of new CAD-CAM products and the correspondence of this visualization model with regard to the development process to obtain a variety of products through SoS RE-CAx-3DP.

Figure 2 describes the conceptual framework of product development processes according to the process areas and the general workflow involved. In addition, it entails the definition of two parallel SoS that respond to the capabilities requested by user requirements, which are the platform related to document editing and storage, and the RE-CAx-3Dp system for the project definition and implementation according to the needs of the multidisciplinary team.

According to Fig. 2, the process areas and the stages of the product lifecycle generate a matrix in which SoS are included. Based on this structure, the workflow of the process is configured. It starts in *Product Marketing* area, where the service request is made. By approval, it is then taken by *Product Requirement*, where the product specifications of the portfolio to be developed are defined.

Then, in the *Product Design*, *Product Production* and *Product Testing* areas, the software tools defined in the SoS RE-CAx-3DP are distributed to get the product requested. Meanwhile, the work plan is defined from the *Project Management* area and consists of assigning roles, tasks and quality formats to meet requirements such as delivery times and availability of resources. In the *Configuration and Change* area, storage, management, and change management are formalized according to the client's request or the assigned roles. Finally, the *Marketing* area receives the result generated in the *Production Product* area in order to deliver it to the client, the one who provides lifecycle feedback.

3.4 Case Studies

3.4.1 Technologies for Specific Patients

The development of different projects was made according to the relevant area of knowledge for the development of medical devices. Different multidisciplinary teams were formed between Industrial Designers, Physiotherapists and Surgeons. This synergy allowed the exchange of technical knowledge and facilitated access to clinical information, as well as the opportunity to generate solutions on real cases and situations, based on clinical cases of patients with pathologies of congenital, trauma or oncological origin.

Ethical principles practices were defined and carried out, as well as precautions such as the codification of the information to maintain the patient's data anonymously were taken, as established by the ethics committees. Once the level of information security was guaranteed and the interaction roles between the actors involved in the device development processes were defined, the data were shared through public platforms, editing and 3D visualization. The working groups were divided into those responsible for specific medical devices projects and those in charge of lower limb prosthetic devices.

Figure 3 describes the main workflow with digital manufacturing defined for the development of Patient-Specific Implant PSI. The process was carried out through data acquisition via Computer Tomography CT established as input data. A reverse engineering process was performed to obtain a virtual reference model. Subsequently, once the specifications of the clinical case by the specialist surgeon are defined, the list of requirements is stablished and the PSI is modeled in a CAD model. Virtual simulation tests are performed in CAE by Finite Element Analysis FEM and finally, the biomodels and PSI are taken to 3D printing.

A pilot study was carried out and structured in two stages. In the first stage, diagnostic and planning cases were developed. In this phase, clinical cases are addressed for diagnosis of tibial plateau fractures, pre-surgical planning for craniosynostosis, orbital-malar region trauma, PSI design process for cranioplasty, reduction of type B hemipelvis fracture or replacement of mandibular edentulous areas. In the second stage, cases were submitted on verification processes by geometry matching between device and tissue, namely a surgical approach of LeFort 1 type to reduce cleft lip LPH sequelae and maxillary retrognathia, segmental mandibulectomy for reduction of sequelae of mandibular fracture, multiple reductions in pseudoarthrosis and severe facial trauma.

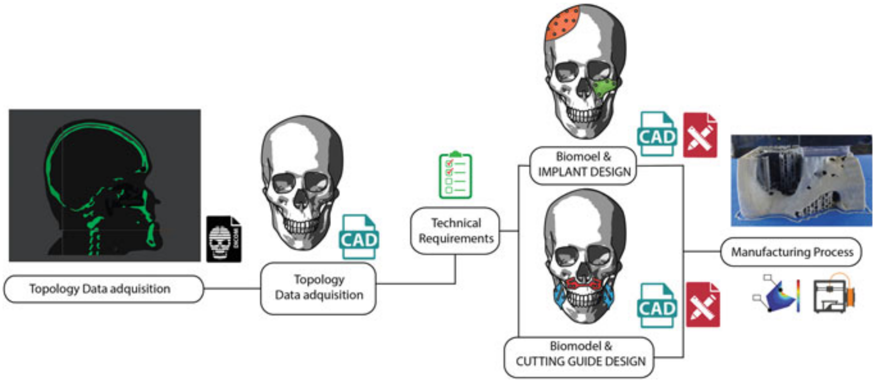

Fig. 3 Process and typology of specific medical devices with digital manufacturing technologies

There were 10 cases of skull and face trauma, 2 of jaw, 1 of hip damage, 22 of knee and 1 case for dental PSI. Derived from these cases, according to the service requirement definition, four kinds of products were generated. Virtual biomodels that were used as a reference for diagnosis in order to define surgical pre-planning processes. In complex cases, the decision-making process was also supported by pre-surgical or post-surgical physical biomodels, the design of PSI to replace blemished zones and the design of template guides to assist activities such as cutting, drilling, and repositioning a bone tissue during surgical activity. All the obtained 3DP virtual products were developed on a natural scale, and the scope of the results allowed them to be implemented in surgery.

3.4.2 Lower Limb Prosthesis

Another type of tailored medical devices is the lower limb prostheses. This device works as a support structure to replace the amputated anatomical region, allowing the rehabilitation process to recover its ability to walk [62]. These devices are made up of the socket, the cane, the ankle and the foot [63]. The socket is the main and most important component of the prosthesis since it is the interface between the stump and the prosthesis and therefore, it must be adjusted to the stump anatomy [64]. Problems in the development and manufacture of the sockets obtained by the traditional technique have been identified in the literature; these problems are associated with factors such as development time [65–67], information management [24, 68–70] and product quality [24, 66, 70].

A process based on digital manufacturing, is a SoS RE CAx 3DP, was proposed in the framework of the PLM strategy. Figure 4 describes the process flow defined for the development of lower limb sockets. This process starts with reverse engineering obtaining input data by means of a 3D scanner for the generation of the virtual reference model of the stump.

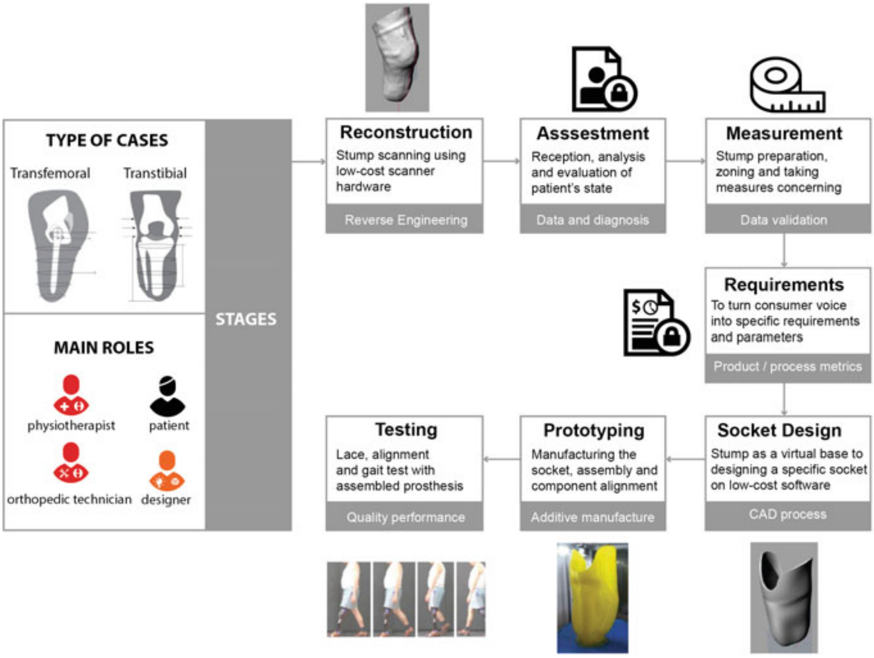

Fig. 4 The development process of lower limb sockets

A process based on digital manufacturing was proposed, that is a SoS RE CAx 3DP, within the PLM strategy framework. Figure 4 describes the workflow defined for lower limb sockets development. This process starts with reverse engineering, obtaining input data through the 3D scanner as a virtual stump reference model. Subsequently, the list of requirements are defined based on prosthetic technician's specifications and a traditional mold definition technique was performed by emulation. Thus, the socket was modeled in CAD software based on this reference model. Finally, the sockets are taken to 3D printing. To carry out the verification of the socket, adjustment and walking testing on the patient must be done.

There were 4 cases of sockets for lower limb, patients with amputations due to accidents and victims of war. It was supported by the treatment of a case of a female patient that required a transfemoral socket of quadrilateral type. The remaining 3 cases presented in adult patients requested transtibial sockets of type PTB and KBM. These devices were assembled with standard mechanical components according to the designation of an orthopedist and the concept of the prosthetist. The sockets were prototyped in 3D printing. In the framework of the pilot study, the lace tests and the walking tests were performed, obtaining satisfactory results from the first iteration.

During the pilot study, it was possible to verify the applicability of the conceptual framework for the PLM strategy proposed in Fig. 2. According to this framework, each case was developed from specific requirements in order to achieve a suitable product. Different formats were created for the evaluation and verification of the outputs of each activity, since in socket design it is necessary to verify patient measures. This procedure was implemented in order to manage all the information generated and control each one of the activities.

3.5 The Proposed Strategy

The strategy reference frame was defined relying on the experiences in the case studies described in the previous section. The development of this research was

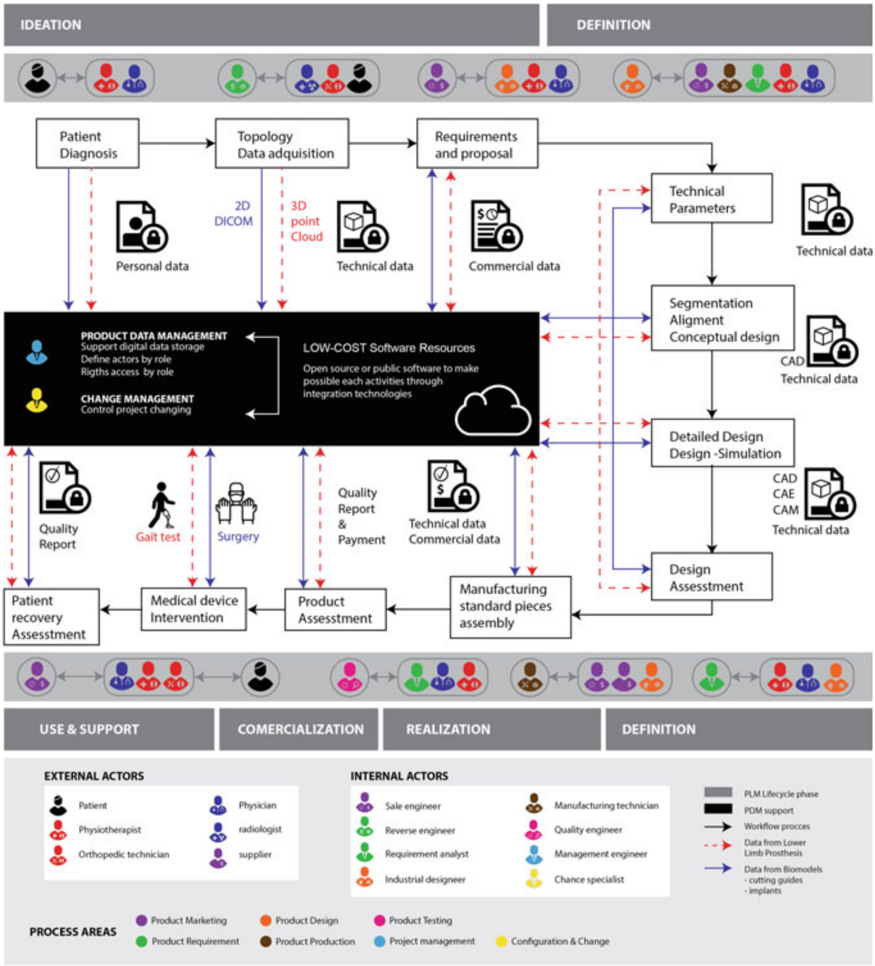

Fig. 5 Process and typology of specific medical devices developed

based on Martinez's visualization model [52] and the general process detailed by Ngo et al. [13] represented in the framework conceptual of Fig. 2. The strategy was concentrated in the first three stages of the product life cycle, establishing workflow for the different specific medical devices, organizing the type and level of interaction of the different roles according to the active process areas in the cycle development stage. The structure flexibility of the strategy facilitated the development of the two types of cases: lower limb sockets and specific medical devices [71].

Figure 5 shows that the different types of products (PSI and sockets) are guided by a common general workflow. However, there are differences that lie in the inputs and outputs that the products generate in the topological data acquisition activities and in the intervention activity with the specific medical device. According to each activity, a responsible role must interact with other roles to obtain or verify the information needed to achieve each task. Those roles can be internal and external roles to the organization and intervene in different stages of the life cycle of the product. Patient data were derived from interactions. These data should be collected and safeguarded as they are shared among the different areas of the process. In this way, the pieces of information are centralized in a database that acts as a repository and a visualizer.

All the information generated and shared in each activity is managed, stored and shared through the use of a web platform that permits different actors to be able to edit or visualize the data according to their role. The technologies implemented and integrated in the SoS RE-CAx-3DP are some tools of public access, free software, or licensed for educational and demonstrative purposes, which has allowed the consolidation of an integration model that evolves as open type tools are developed and adopted. This is evidenced in Figs. 1 and 2.

Although a general PLM strategy was proposed, different factors influenced the generation of operational differences to obtain the products and the respective results. Table 1 shows comparisons between two case types according to the process stages in which the SoS RE-CAx-3DP are involved. The differences and similarities were identified through four main components: actors involved, technologies, generated information and verification formats in each stage.

The reconstruction stage contains differences between the 4 components. It was observed that in terms of sockets, the patient and the prosthetist technician are present in order to obtain data by means of 3D scanner technology. On the other hand, the designer obtains patient's data from computer tomographies or DICOM images in specific medical devices. Verification by simulation could be another example. In the case of implants, it is carried out by Finite Element Methods, but in the case of sockets, the evaluation protocol has not yet been implemented. The similarities presented in the two cases were found in the stage of modeling in CAD and 3D printing, in which the role component does not exist since it is carried out by an industrial designer in both cases.

It was possible to verify the applicability of the conceptual PLM strategy framework proposed in Fig. 2 throughout the pilot study. In accordance with this framework, each project was developed from case requirements to obtain a product.

For that purpose, different requests were received: definition of diagnostic protocols using virtual biomodels for pre-planning and complexity analysis for surgical

Table 1 Case differences according to stage process

Stage	Item	Patient specific devices [71]	Lower limb prosthesis
Reconstruction—reverse engineering RE	Role	Design team	Patient Design team Technician
	Technology	Image segmentation from CT	Cloud points by a 3D laser scanner
	Information	To generate and clean the biomodel	To generate, repair and clean the stump
	Verification	Surgery—post-surgery	Measurement form activity verification form
Design by CAD—computer-aided design	Role	Surgeon requirements	Technician or physiatrist requirements
	Technology	CAD software to virtual pre-planning	CAD software to emulate traditional technique
	Information	Topology biomodel as reference	Virtual stump as biomodel
	Verification	Requirement accomplishment	Design assessment form
Simulation CAE—computer-aided engineering	Role	Development team	Under definition
	Technology	Software CAE	
	Information	Requirement accomplishment	
	Verification	Mechanical behavior by material and static loads	
Manufacturing	Role	Manufacturer-supplier	Technician-supplier
	Technology	Additive manufacturing—commercial fixation—sterilization	Additive manufacturing—commercial items for assembly
	Information	Technology and material selection by compliance	Technology and material selection by performance
	Verification	Surgeon satisfaction—requirements fulfillment	Lacing and walking testing

procedure, the design of PSI to evaluate biomechanical behavior by simulation. Furthermore, there were personalized surgical guides for cutting, drilling, or positioning in order to verify the capability to generate precise devices and therefore evaluate the fit in the bone tissue during the surgical procedure. However, 3D virtual reference biomodels were obtained regardless of the type of request in all cases and virtual surgical pre-planning was carried out according to the surgical technique selected for treatment implementation.

4 Discussion and Conclusions

In this chapter of the book, it was evidenced how it was possible to build a PLM strategy integrating a digital manufacturing SoS for production in flexible factory contexts. In fact, the development of the devices through digital manufacturing was selected regarding the advantages presented by Jones in relation to: the decrease in the cost of the additive manufacturing machinery, going from the industrial sector to the desktop, the release of designs and open source programs RepRap for manufacturing by using fused deposition modelling, and the connectivity that makes the design, modification and exchange of virtual information possible [72]. Thereby, the final products can be manufactured anywhere, according to the user's requirements, obtaining a specific final product [36].

Hence, in the development of a complex product such as custom medical devices, the process involves the exchange of ideas from multiple sources, digital data volumes and decisions that require administration [73]. In addition to collaboration between distanced actors, different organizations try to configure their value proposition to be more efficient when solving problems, using fewer resources, implementing new technologies for product development and administration [74]. That is why industries 4.0 seek to digitize the supply chain that provides personalized treatments to the patient in the health sector [75], taking advantage of additive manufacturing such as reduction in distances, production times, material consumption, energy consumption and part complexity [76].

In the present study, the evaluation of technologies allowed the identification and selection of technological tools, following the vision proposed by Schuh et al. [54], on the contribution of technologies to the PLM implementation objective, considering the processes, roles, availability and centralization of product information [77] and the activities required to be performed, the control of engineering and quality requirements [78], the complexity and technological maturity of the prototype or final product. In accordance with the above, when considering the importance of implementation costs, the low-cost strategy is highly relevant for countries with emerging economies, as well as the reduction of development times and costs to guarantee applicability, especially in the initial stages of development, where the organization has more control [79].

The authors' strategy is based on a close communication with the specialists generating interactions and solutions in co-creation, involving the health expert, as an actor who is part of the solution. This strategy is related to the model proposed in this book chapter, unlike Zdravković et al. [16] who articulated a network of providers between the clinical system, the common or pre-planning system, the design system and the manufacturing system specialized by request.

The decisions made regarding the definition of process areas, workflow, technologies, roles and defined tools to guarantee the control of the results and obtain precise products, show that low cost PLM strategy built for the development of these devices in specific patients and prostheses, meet the expectations. However, as Allanic et al. [14] and Pham et al. [15] proposed, when given the volume of cases developed up to now as shown in Table 1, it is necessary to continue working to increase the PDM capacity in order to generate greater control in the interoperability between roles and the data generated. So that with the proposed base strategy, it is possible to achieve higher levels of maturity and control strategy processes in relation to the performance of the roles involved, amount of information, information custody and data traceability generated during the process.

The implementation of the PLM as a strategy based on the visualization model proposed by Martínez [52], facilitated the definition and detailed organization of the operational guidelines, both, process and information flow. This action involves functional departments, activities, inputs and outputs. This is how the activities were distributed [20] within 7 of the 8 visualization model processing areas. However, four of these process areas are: *Product Requirements*, where the guidelines for the device design were established*; Product Design*, where these parameters were converted into virtual or physical objects; *Production Area,* where the products were obtained in 3DP; and *Testing Area*, in which the fulfillment of requirements was verified by means of different tests. These were the areas of higher level of development in the current strategy defined by the authors to guarantee the development of the precise medical devices.

Nonetheless, other process areas were also intervened. From *Marketing*, a proposal is prepared to delimit the scopes, delivery times and products requested, also monitoring product satisfaction from a consumer. *The Management Area* is responsible for synchronizing activities among the execution of different projects, while the *Configuration and Changes Area* coordinate many change requests during the product development from different sources. These previous departments functioned as *Cross-Cutting Areas* and assumed a key role in the management of compliance with requests at an appropriate development time. Mainly in the area of configuration and change processes, from the defined low-cost SoS, the storage, management, evolution, and traceability of the project data were guaranteed in a safe manner to provide information integrity and personal data anonymization from medical records.

The digitization of information and the use of 3D printing tools tie in with the concept of Industry 4.0, with PLM defined as the strategy to orderly consolidate the required procedures according to the product profile. The way in which the cases were supported by the resources shared between the design, engineering and medicine teams within the framework of the PLM strategy, allowed obtaining specific medical devices and precise sockets according to clinical requirements. The previous statement is supported by the results obtained in the second stage of pilot studies.

The tests implemented in surgery were the evidence of satisfactory results. These tests verified if the implants and the guides fitted in during the surgical procedure. On the other hand, there were socket and walking tests for the case of the amputations, which meant good results as well.

Further projects require to strengthen manufacturing capabilities to comply regulatory procedures that permit to obtain end-user medical devices. It is necessary to continue exploring low-cost software alternatives for obtaining or programming a centralized PDM, in accordance with the needs of surgeons, orthopedists, prosthetists, designers, and engineers. In this way, the process performance in the product development could be controlled, obtaining key performance indicators while different case studies are carried out. Similarly, it is important to address the observations of Ahmed, et al. [80] on collaborative work and linking in hospital centers through PDM platforms and PLM strategies. This could improve articulation and coordination to access and monitor data from patient treatment, in a way that it facilitates decision making in real time with respect to device design requirements.

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Use of Industry 4.0 Concepts to Use the "Voice of the Product" in the Product Development Process in the Automotive Industry

Josiel Nascimento and André Cessa

Abstract The world is going through rapid and deep technological change. With advances due to new uses of the Internet and electronic devices, the relationships between companies and their customers will be improved in a way never seen before. These changes will allow products to communicate with their manufacturers (the Voice of the Product) so that they can be improved in future generations and can also be supported with updates made remotely, without user intervention. Productivity increases, continuous improvement and improved customer relationship are the objectives of this paradigm shift. Products from all durable and non-durable segments will have a high level of customisation, with the customer being responsible for specifying which characteristics will satisfy them.

Keywords Industry 4.0 · Product development · CAN bus · Continuous Improvement · PLM (Product Lifecycle Management) · IOT (Internet of Things) · Connected Products and Services

1 Introduction

The first three industrial revolutions led to mass production, electric energy and the use of information technology making technological competition the centre of economic development. The first revolution, around 1780, involved the use of machines, the second, around 1870, the use of electric energy and the third, around 1969, the use of industrial automation [6]. In the fourth industrial revolution, often called Industry 4.0, the impact will be more profound and exponential as it is built on a set of technologies that allow the combination of the physical, digital and biological worlds. The fourth industrial revolution has the potential to increase economic growth and to alleviate some of the major global challenges we face collectively. We also need

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to recognise and manage the negative impacts it can have on inequality, employment and the labour market.

The impact of the fourth industrial revolution on economic growth is a divisive subject for economists [6]. On one hand, the techno-pessimists argue that the crucial contributions of the digital revolution have already been made and that its impact on productivity is almost over. On the other hand, the techno-optimists say that technology and innovation are at a turning point and will soon trigger an increase in productivity and higher economic growth. They believe that the use of Industry 4.0 concepts will bring a new level of integration and interaction with users and/or customers of any type of service, whether public or private.

The discussion of the potential value and results of use of Industry 4.0 concepts raises the question of creating incentive projects to boost studies and applications, and resume economic growth in Brazil. With this in mind, the Ministry of Industry, Foreign Trade and Services (MDIC) established a working group, called Working Group for Industry 4.0, also known as GTI 4.0, to discuss the subject and create a national agenda. The Group is made up of 50 representatives from government, industrial companies, non-governmental organisations, and so on. The objective is to promote debate on the application of Industry 4.0 technologies for the advancement of Brazilian industry [2, 3].

With the increased popularity of portable, mobile electronic devices and the use of the Internet, both for domestic and business purposes, conventional forms of developing products and services are also undergoing change. It should be noted that there is an increasing number of services on the Internet for the most diverse purposes, from public offices to private financial entities.

Based on these considerations, this case study presents a proposal to change the management of the product lifecycle of a motor vehicle, specifically in the phase of use of the product by the customer, a phase in which today there is usually little interaction between the customer and the manufacturer. Currently, information about the condition of the vehicle and its components is only known at a few specific times from scheduled services, satisfaction surveys and warranty events.

The intention is to propose a change in the current manufacturer/customer relationship that will generate benefits for both parties.

2 Theoretical Reference

According to Piaget's theory of cognitive development, competence is built in the articulation and mobilisation of knowledge by mental processes (physical or mental actions on objects that are modified and become increasingly refined by successive steps of assimilation and accommodation), while the skills allow the competence to be put into action [5]. For example, the skills of a Production Engineer allow them to analyse processes and results, and develop strategies so that they can, through an evolutionary and continuous process, achieve excellence.

2.1 Electronics Embarked on Vehicles

The use of electronics in vehicles has revolutionised the automotive world and considerably increased the number of options available to the market. Electronics has, in many cases, helped to simplify both the manufacture of components and the assembly of vehicles. There are clear technological advances in the automotive environment, ranging from keys that control the ignition to entire systems such as Anti-Lock Braking Systems (ABS) [8] and Traction Control Systems (TCS) [7].

The growing number of electronic artefacts caused the number of wires, modules and connections to increase considerably. The traditional method of interconnecting all the components became a bottleneck since the routing of wires had to be done point-to-point, that is, from the control module to the component that would receive the electrical signal. To help simplify this activity, the systems were subdivided into smaller systems. Figure 1 illustrates the amount of electronic subsystems in an automotive vehicle. (Source: http://telecompk.net/2009/06/30/telematics-in-pakistan/ Accessed on 18/11/2018.)

All these systems are connected by a common physical means called the Controller Area Network (CAN) which manages access to particular functions of the vehicle.

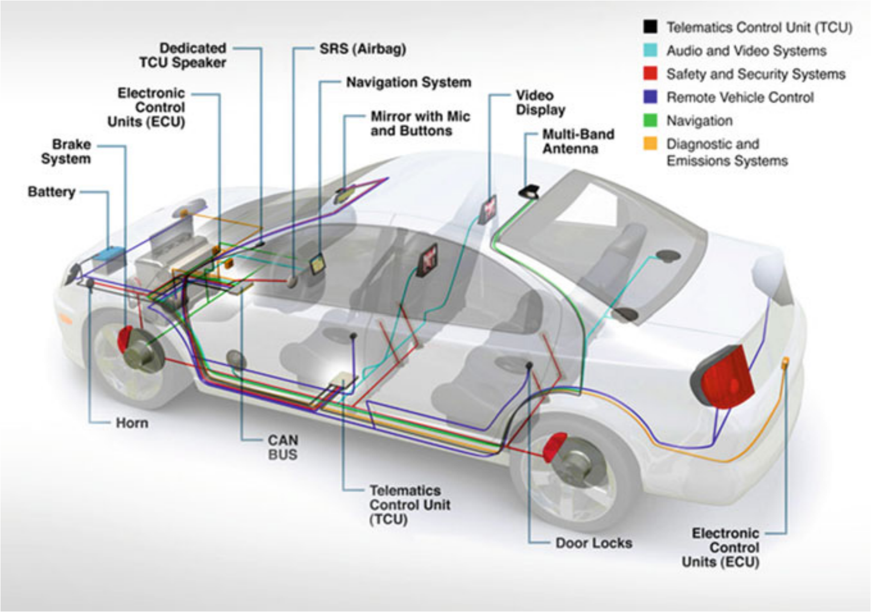

Fig. 1 Subsystems of a motor vehicle

2.2 CAN Network

The CAN network was developed by the German company Robert Bosch and made available in the mid-1980s. Its initial applications were in the bus and truck sectors. Today, it's used among others in the automotive vehicle, ship and tractor industries. With this network, the modules that control the various vehicle systems can exchange information with each other [7].

Module information is shared on the transmission line. The encoding of the information is digital, the data transmission is serial and there is a strategy of priority management in the diffusion of the information in the network. For this, the message that is sent must be in a universal standard. Through this standard, the CAN network is able to define which information has priority to pass through the network [7]. Normally the information that has highest priority is that which groups safety items such as brakes, engine, transmission and air bags depending on the manufacturer's specification. Also, information from the entertainment, comfort and guidance modules, currently called infotainment by the market, travels through the CAN.

2.3 Industry 4.0-concept

The term Industry 4.0 appeared at the Hannover Fair in Germany in 2011. On that occasion employees from Bosch and academics from the German Academy of Sciences and Engineering led a study of the implementation of this industry model for the German Federal Government. Published in 2013, the study addressed the connections between machines, systems, and assets that enable industries to precisely control every step of the value chain to make their plants intelligent.

Some companies use different terms for this type of approach [1]. General Electric uses the term Industrial Internet. Cisco refers to it as the Internet of Everything. The difference between these terms and Industry 4.0 is their application.

According to Gilchrist [1], application in the industrial environment characterises the name of Industry 4.0, whereas Internet of Things also applies to things outside this scope.

For Schwab [6], the question for all industries and companies, without exception, is no longer the question, Will there be disruption in my company? But rather, When will there be disruption? How long will it last? and How will it affect me and my organisation? That leads us to understand that Industry 4.0 is not just a temporary movement, but a trend that is already changing the way we live today.

2.4 Applied Technologies

Industry 4.0, contrary to what many think or imagine, is not only a technology, but a set of Information Technology tools applied to the industrial environment in order to, in principle, improve the production processes and achieve better quality and productivity.

The main technologies are:

- Additive Manufacturing: Also called three-dimensional printing (3D Printing), this is the addition of material in thin layers to form a complete component.
- Artificial Intelligence: A segment of the field of computer science that seeks to simulate human intelligence to reason and solve problems. It can be used by software platforms and robots.
- Internet of Things: Represents the possibility that physical objects are connected to the Internet and can receive and send information, and perform actions.
- Synthetic Biology: A combined effort between various areas of knowledge such as chemistry, biology and computer science for building biological parts, and also modification of existing biological systems.
- Cyber-physical systems: fusion between the physical and digital worlds. This concept can be applied to every object and process in the factory. For a physical object there is an equivalent digital model, called the digital twin.

In addition to the elements mentioned above, there is also the Information Technology architecture that commonly exists in the industrial environment, including components such as data communication networks, computers, servers, Internet and programming languages. Also included in Industry 4.0 are technologies such as mobile devices, Big Data, Analytics and electronic elements such as sensors and actuators.

This range of technologies used together forms what Gilchrist conceptually characterises as Industry 4.0. [1]

The next section focuses on one of these technologies, the Internet of Things.

2.5 Industry 4.0 in the Automotive Industry

The automotive industry is undergoing a profound transformation in both its products and processes. The processes are gaining more and more technology which brings with it a significant improvement in quality and operation time using cyber-physical systems. Cyber-physical systems are those that can be integrated using computer technologies and physical processes [1]. An example of a cyber-physical system is an intelligent assembly line, where the machines can perform several operations by consulting specifications electronically described in the component that is being manufactured, remembering that this all happens in the manufacturing process of the component.

Prototyping using 3D printers, supported by the concept of Additive Manufacturing, also helps to reduce development costs since it is not necessary to develop corresponding tooling. According to Stratasys, it is possible to print from PP (Polypropylene) [12], a type of plastic, to metal in a process called DMLS (Direct Metal Laser Sintering) [11]. In addition to prototypes, small parts can also be 3D printed for emergency repair of machines and equipment.

The use of artificial intelligence can provide gains in all spheres of business ranging from chatbots (which are instant communicators between humans and artificial intelligence technology), through product development, to the use of cognitive systems that try to simulate human reasoning in decision making.

These changes also reach the final product. Motor vehicles are increasingly loaded with technology. The biggest transformations in the on-board technology are due to the high demands of laws and international treaties that demand the reduction of carbon dioxide emissions in the atmosphere and also a demanding consumer market that at all times seeks products that bring convenience and agility to our daily lives.

In addition to meeting legal and market requirements, manufacturers can also benefit from the use of the Industry 4.0 set of technologies by capturing information from their products and then using this information to improve their products.

With the use of sensors and the CAN network, the manufacturer can, through a data connection, capture sensor data and use it to analyse the behaviour of components and systems of the vehicle. Examples include: tracking the number of kilometres travelled; checking fuel quality; remembering the geographic regions travelled; and monitoring of parts that affect safety.

All this information provides the manufacturer with the ability to monitor the product very precisely and even to contact the consumer if necessary in case of an emergency. The information can also be used in a knowledge base for use in continuous improvement and new product development projects.

The product lifecycle has five phases: Ideation, Definition, Realisation, Use/Support and Retirement/Disposal [10]. One of the main challenges for a company is to manage its products from their conception to their withdrawal from the market, in other words, to accompany them from cradle to grave.

2.6 Challenges Faced

Traditionally the main information channels between the manufacturer and the customer have been through car dealers, through the manufacturer's Customer Service Department, and through customer satisfaction research involving direct contact with the customer. All these depend on the presence, availability and commitment of the customer.

The high prices charged by manufacturers for so-called "scheduled services" have driven many customers away from dealerships. As a result, a lot of information about the condition of the vehicle is lost to the manufacturer.

In the case of the customer satisfaction survey, even with a high degree of satisfaction, the customer can refuse to answer the researcher's questions.

In view of the above, it is clear that the manufacturer has only partial access to quality data about its products in the Use/Support phase of the product lifecycle. As a result, when the customer is the main agent in the provision of information, the manufacturer may have the false perception that everything in the product is behaving correctly during use, when in fact the true information has not reached the manufacturer because the information channels mentioned above are not working.

In an attempt to find and trace a new process proposition for this stage of the product lifecycle, several hardware and software suppliers were consulted, in the automotive segment, for initial information gathering.

2.7 *Proposed Model*

The current model for the product lifecycle has five phases: Ideation, Definition, Realisation, Use/Support and Retirement/Disposal [10].

We propose adding to the current model a feedback flow from the Use/Support phase to the phases of ideation and definition, and inclusion of this information in a knowledge base. According to the Project Management Body of Knowledge (PMBOK), such integration of information from a project may be referred to as a knowledge base of lessons learned [4].

Figure 2 illustrates the proposed model.

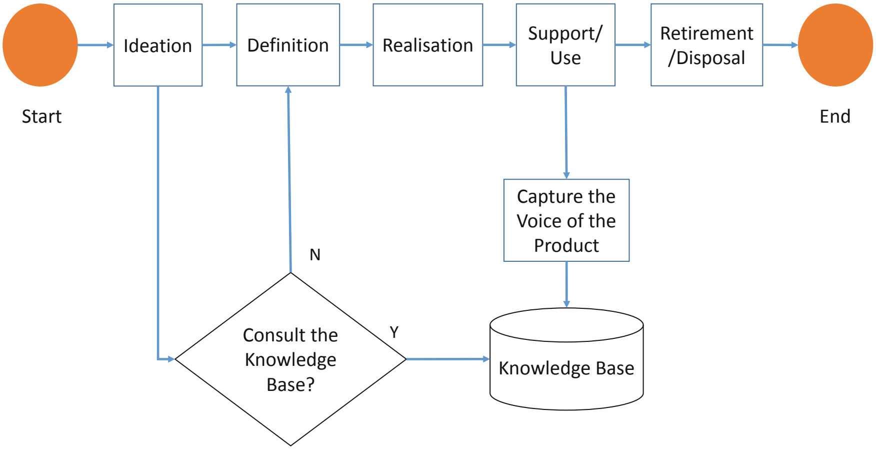

Fig. 2 Phases of the product lifecycle

During the Use/Support phase there will be regular capture of information that will be stored in a database and used as a key decision-making element for new product development activities and for improvement of products already developed by the manufacturer. By analogy with the frequently used term of the Voice of the Customer, this information may be thought of as the Voice of the Product [9].

2.8 Technical Approach to the Objective

As a first step, it's necessary to get alignment between the business expectations and the technical requirements of Engineering, clearly stating which data about the product will be captured.

Then the targeted monitoring points on the vehicle will be evaluated, to identify those which are already monitored. If any components are not yet monitored, a study will be launched to show how best to connect these new components.

For access to the sensors on the components, it is proposed to use the vehicle's auto-radio device, which must have the capacity to access the Controller Area Network to collect information.

Once the equipment provides support for the required function, the manufacturer can develop software applications that will work in background mode (so that the driver/customer will not be aware the software is running) on the car stereo.

When the customer connects their mobile device to the car stereo equipment, or even connects the car stereo to their home network of wireless computers, the applications will start collecting information and send it to the knowledge base (Fig. 2).

To avoid concerns about invasion of privacy, the customer will be informed, through a clearly presented document, that the manufacturer may have access to the information in their vehicle. This document will be kept for later reference in case of any legal dispute, protecting the manufacturer.

The manufacturer will need to know the technical description of all the messages that travel in the Controller Area Network and their respective values so that there is full understanding of these parameters when this information is analysed.

Big Data tools will be used to graphically present information on predetermined parameters, for example, kilometres travelled by the vehicle at the time of a failure. This data will make it possible to make an analysis of the causal factor of the occurrence.

The application that captures this information can also provide it to the customer, for example, informing the customer that the number of kilometres travelled is approaching the value set by the manufacturer for a scheduled service.

With this type of integration into the product, the number of possibilities is almost infinite, transforming the use of Industry 4.0 tools into a strategic and market differentiator.

3 Research Methodology

The methodology used in this case study was literature search.

This type of research offers tools that help in the definition and resolution of problems already known, as well as in directing thoughts and studies to new areas where there is not yet a solid concept.

Literature search also opens up the possibility of a subject being analysed from a new perspective and using other approaches, thus producing new conclusions and results.

Aiming at the implementation of this new "Voice of the Product" approach, the following steps were proposed:

1. Search of bibliographic sources: books, journals, specialised websites and academic publications.
2. Preparation of a proposal.
3. Presentation of the proposal to the Management Board.
4. Running a pilot project with representative production units.
5. Implementation of the new approach in series production.

4 Conclusion

Industry 4.0 has the potential to make processes more efficient and thereby enable the production of products with high quality standards and in a very short time. The number of applications and benefits is almost immeasurable. Many potential benefits can be highlighted: cost reduction; energy savings; increased safety; environmental conservation; error reduction; no waste; business transparency; improved quality of life; unprecedented customisation and scale.

All the above-mentioned benefits add to the consolidation of electronic systems in vehicles, fruit of the third industrial revolution. They enable the automotive industry to expand its research and development centres, encouraging the study of new technologies and their integration into existing and future product lines.

In view of the many possibilities identified during the initial investigation, a proposal was made to develop an automotive vehicle application based on the Internet of Things, one of the technologies of Industry 4.0. Its main characteristic is the capacity of the component and/or product to send and receive information through a data network.

The proposal to implement this new approach was accepted by the senior management of the automotive company in question. At the time of writing this case study, the project has started. It's at the point of selecting technology suppliers. The suppliers targeted would have the "… capacity and openness for technology transfer in order to train the employees involved in the process."

With the total implementation of this proposal it is expected to add competitive edge to an increasingly demanding market. Return of Investment (ROI) is seen not only as the intellectual capital captured by the product, but also the development of a harmonious and trustworthy relationship with customers.

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PLM Applied to Manufacturing Problem Solving: A Case Study at Exide Technologies

Alvaro Camarillo, José Ríos and Klaus-Dieter Althoff

Abstract This chapter presents a case study of a prototype Knowledge Management system that supports the process of Manufacturing Problem Solving in a multinational company. The prototype system allows capturing and reusing knowledge generated during the resolution of Overall Equipment Effectiveness (OEE) problems in multiple locations at shop floor level. The developed system was implemented in Exide Technologies. The system integrates the 8D method, Case-Based Reasoning (CBR) and Product Lifecycle Management (PLM). The PLM system is used as the source of extended problem context information (i.e. Products, Processes and Resources) that will enrich the similarity calculation of the CBR application. Process Failure Mode and Effect Analysis (PFMEA) is used as the source of the initial set of cases to populate the case-base. From the development perspective, the system comprises a multi-agent architecture based on SEASALT (Shared Experience using an Agent-based System Architecture LayouT) and programmed in Java. The development infrastructure comprises: Eclipse, JADE (Java Agent DEvelopment framework) and AML (Adaptive Mark-up Language) studio. The selected software applications are myCBR and Aras. The prototype system was tested and validated in three main steps with an increasing level of complexity. The results demonstrated the feasibility of the adopted approach. An overall description of the system, results, lessons learned, and recommendations are provided.

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Keywords Product lifecycle management (PLM) · Manufacturing problem solving (MPS) · Fault diagnosis · Process failure mode and effect analysis (PFMEA) · Case-based reasoning (CBR)

1 Case Study Company

Exide Technologies (www.exide.com) is a global provider of electrical energy storage solutions, batteries, and associated equipment and services for transportation and industrial markets. It has about 130 years of industry experience and operates in more than 80 countries. Leading car, truck and lift truck manufacturers trust Exide as an original equipment supplier, and Exide serves the transportation and industrial aftermarket through a comprehensive portfolio of products and services.

For this case study, two plants of Exide Technologies, one located in Germany, and a second one located in Spain, were selected. The selection criterion was that they produce similar products with similar processes. In particular, they produce motive power batteries for the industrial market (i.e. forklifts or similar applications), and both of them use the Wet Filling process to manufacture the positive plates of the batteries. A second Casting process was also selected for testing purposes in the German plant. Casting is used to manufacture the negative grids. More details about these processes are not relevant for this work, and due to confidentiality issues, they are not presented.

Exide Technologies, as most of the manufacturing companies in the world, faces issues related to knowledge management. This work aims to address a few of them, which can be summarised as follows:

- The continuous pressure to reduce costs, and with this, to ensure competitiveness in the market, pushes manufacturing companies to apply Lean Manufacturing methodologies. In some cases, this implies moving the spotlight from highly educated, but expensive staff, to blue-collar employees (i.e. line operators, group leaders, and quality inspectors) as key drivers of the Continuous Improvement Process (CIP) [1, 2].
- The point above is reinforced by the Research Global Manufacturing Study conducted by Deloitte [3]. This study shows that manufacturing has nowadays a negative image in the eye of many young workers when compared to the new technologies business. This creates thus a talent attraction problem of highly educated staff and gives even more relevance to the inputs from blue-collar employees.
- When blue-collar employees dedicate time to tasks different from producing parts, it means that the targets at the end of the shift will be missed. Therefore, even when management encourages them to participate actively in the CIP of the company, they are also put under pressure when the production targets are not accomplished.
- Knowledge sharing is a relevant issue, particularly in multinational companies. Most of these companies have different manufacturing plants, distributed geographically in different locations, and with similar processes, but they suffer from

communication barriers due to multiple reasons such as distance, language, or belief in knowledge as power or a survival tool [4, 5].

- Potential failure modes of the manufacturing processes can be identified during their development phase by using preventive methods like PFMEA (Process Failure Mode and Effect Analysis). Nevertheless, this information is seldom used on the shop floor. The literature shows that the industrial application of PFMEA is complex, time consuming, and inefficient [6]. Additionally, it provides a low outcome, its results are not revised during regular continuous-improvement activities, and there are issues to keep an efficient feedback. Part of the problem with PFMEA relates to its documentation being very often based on a spreadsheet approach, which makes it difficult to reuse results and identify similarities.

2 Proposed Approach

Despite the application of preventive techniques, such as PFMEA, unforeseen failures can still occur during the operation of manufacturing systems. A manufacturing failure occurs in a specific manufacturing context and generally implies that some part of the manufacturing system does not perform according to its operational specifications, as a consequence, production targets can be missed. To address this kind of situation, a systematic approach is needed to reach and exceed the defined production targets. Typically, manufacturing problems are analysed and solved by teams, following a Manufacturing Problem Solving (MPS) process and working directly at the shop floor. The process comprises the use of different techniques and methods. Although training is generally provided to team members, the process only brings good results when it is driven by people with enough experience and with access to additional support knowledge, e.g. by means of a software tool [7, 8].

The proposed approach aims at capturing and reusing knowledge generated, across multiple locations, when executing a Manufacturing Problem Solving (MPS) process at shop floor level. It is specified in three models: an MPS process model, an MPS knowledge representation model, and an MPS system architecture model. These models represent the specification to develop a prototype application where the proposed approach is implemented [8, 9].

The proposed approach integrates the 8D method [10], Case-Based Reasoning (CBR) [11], Product Lifecycle Management (PLM) [12] and PFMEA [13]. The 8D method is a structured method to guide the resolution of problems step by step. Case-Based Reasoning (CBR) is used as a repository of cases and an artificial intelligence application to search for similar manufacturing problem cases collected previously in multiple locations, and it is implemented on an agent-based distributed architecture. A Product Lifecycle Management (PLM) system is used as the source of extended problem context information (i.e. Products, Processes and Resources (PPR)) that will enrich the similarity calculation of the CBR application. PFMEA is used both as the basic reference to create an ontology, on which the system is built, and as the source of the initial set of cases to feed the CBR application. The specific knowledge to be managed is the one recorded in the PFMEA during the process development phase, as well as the knowledge generated during the daily CIP activities linked to the Overall Equipment Effectiveness (OEE) improvement. Among the different topics considered by OEE, the focus is set on quality issues with product and processes (i.e. quality claims and scrap), abnormal production speed, and breakdowns. Information available in the company, e.g. in a PLM system, can be used to improve the efficiency of the knowledge sharing.

From this perspective, this work presents the case study conducted to evaluate a prototype development that implements the created models. The main constraints for the development of the prototype application can be summarised as follows:

- It has to be used directly at shop floor level.
- It has to propose possible solutions to problems that are identified during daily CIP activities linked to the OEE improvement.
- It has to allow recording information related to solutions applied to solved problems, to increase the knowledge base of the system with relevant cases.
- It should be intuitive and easy to use, since the target users are shop floor employees.
- It has to request very few data about the manufacturing problem to compensate the possible lack of time and knowledge of the user.
- It has to follow an MPS methodology to guide the user in the resolution of the problems identified during the CIP activity.
- It has to allow reusing knowledge stored in existing PFMEA documents of the company.
- It should allow simultaneous access by multiple users from different plants, supporting in this way the sharing of knowledge within the company.

Figure 1 shows a view of the Manufacturing Problem Solving (MPS) process followed by the developed knowledge management prototype system. The communication among user, agents and main applications is also illustrated.

The MPS process model defines the steps to be taken by the user to solve a problem. It follows basically the steps defined in the 8D method [10]. It specifies also the kind of interaction expected at each step between the user and the system. A Graphical User Interface (GUI) was developed to support the interaction with the user along the process [8, 9].

The MPS knowledge representation model comprises the following main concepts: Problem, Component, Function, Failure, Context, and Solution. The relations among these six concepts, their associated taxonomies, and their parameters were designed to fulfil several constraints: support a generic definition of a manufacturing process and its location, be compatible with the information structure of the PFMEA method, comprise concepts to describe different aspects of a manufacturing problem, and allow case similarity determination [8].

The proposed MPS system architecture model is based on SEASALT (Shared Experience using an Agent-based System Architecture LayouT) [14], which supports the deployment of the different agents across different manufacturing plants. Within each plant, agents can be deployed across the areas with different manufacturing processes. In this way, each topic agent, hosted in a specific manufacturing

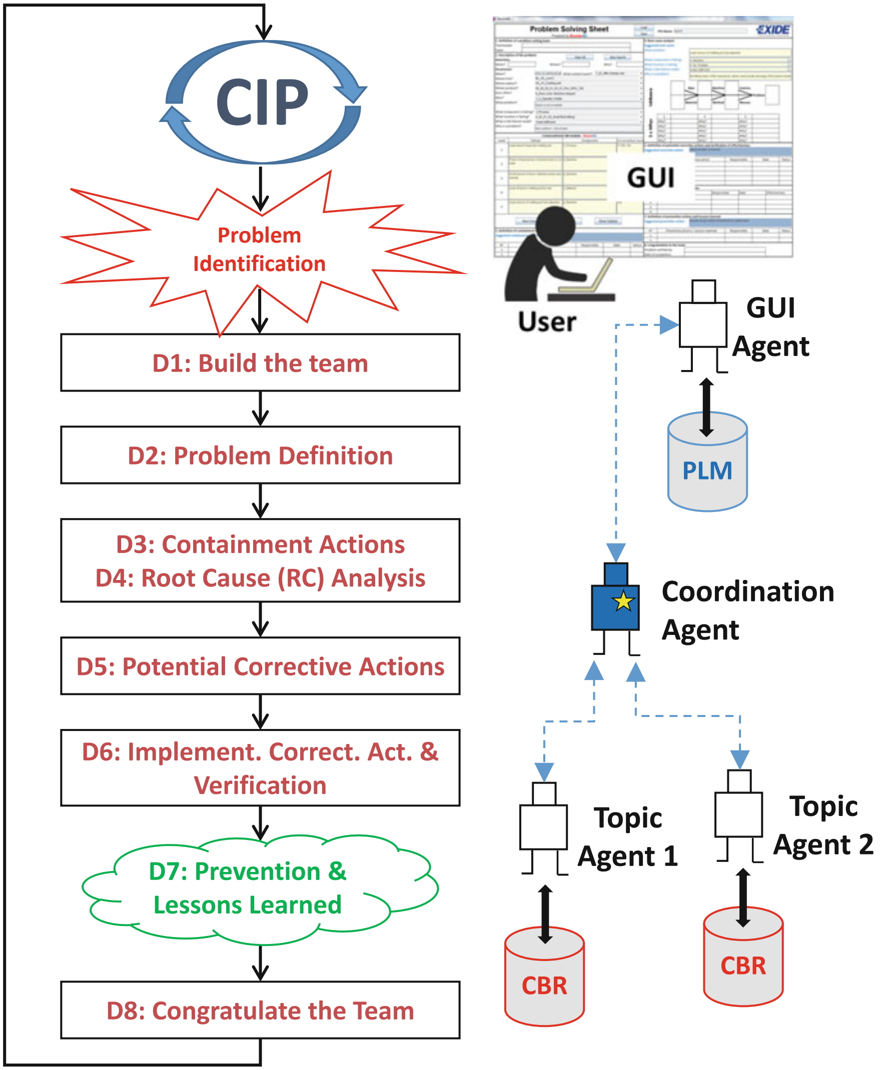


Fig. 1 Proposed manufacturing problem solving process and knowledge management prototype system

process of a specific manufacturing plant, is able to collect and to store knowledge related to its own area, becoming an expert of its process and plant. By means of a coordinator agent, a topic agent can communicate and exchange information with all the other topic agents hosted in different processes and/or plants through the company's intranet. Each topic agent has its own case base and uses CBR technology to find the most similar cases related to a user query. This information exchange supports the MPS process by providing the user with solutions for the most similar failures stored in any topic agent of the architecture [8, 9].

3 Implementation

The implementation of the proposed approach was conducted in a knowledge management prototype system. The method to develop the prototype system was divided into the following steps:

- Selection of a suitable IT infrastructure: development environment, Case-Based Reasoning tool and PLM system.
- Programming and customisation of the software tools to support the developed models.
- Testing, fine-tuning and validation of the prototype system.
- Population of the system with the information and cases from one manufacturing plant of Exide Technologies.
- Execution of case studies in two manufacturing plants of Exide Technologies to obtain results and extract conclusions.

The selected development environment includes Eclipse to program the prototype software, JADE (Java Agent DEvelopment framework) to monitor the behaviour and communication of the agents, and AML (Adaptive Markup Language) Studio to develop and test the communication between agents and the PLM system. The implemented communication model is a simplified version of SEASALT [15]. SEASALT is a multi-agent architecture from which three types of agents were selected: GUI agent, topic agent and coordination agent; they communicate with each other to provide solutions to the user [14].

The selection of the IT infrastructure was driven by a balance among openness, functionality, compatibility, and easy access to the applications. myCBR (www.mycbr-project.net) was the selected CBR software. Aras Innovator (www.aras.com) was the selected PLM system. Aras Innovator is developed on Microsoft technology, which makes it compatible with all the systems and software infrastructure available in the company. It also offers a communication tool based on an XML (eXtensible Markup Language) dialect language (AML) that allows extracting any type of data from the PLM database.

SEASALT, and its current instantiation, is based on JADE, therefore Java was selected as the programming language. The Luna release of Eclipse was selected as the development environment. Eclipse is an Integrated Development Environment (IDE) used in computer programming and is one of the most widely used Java IDE (www.eclipse.org). Luna was the default release at the time of installation.

JADE was used for the control of the communication and behaviour of the agents. This environment is linked to the SEASALT architecture. JADE (jade.tilab.com) is probably the most widespread agent-oriented middleware in use today. This framework facilitates the development of complete agent-based applications by means of a run-time environment, implementing the lifecycle support features required by agents, the core logic of agents themselves, and a rich suite of graphical tools.

The last development tool was AML Studio. This is part of the software installation package of Aras Innovator. It supports the connection with the server of Aras to interchange messages using the AML language. Clients submit AML documents to the Aras Innovator server via HTTP, and the server returns an AML document containing the requested information.

Based on the information model created for the PLM system [9], staff from production and engineering, located in the selected German plant of Exide, were interviewed to identify the characteristics of the wet filling reality that make different each product, machine, process, worker, or environment from each other. These differences are the key to distinguish problems from each other in the similarity calculation executed by the CBR system. The steps followed in the interviews were:

- Identification of key elements.
- Identification of their relationships.
- Identification of the relevant attributes.

All the elements, relationships and attributes were mapped into the created model and then incorporated into the PLM system by using the creation and modification functionalities available in Aras.

A similar customisation step was conducted with myCBR. For the defined two case studies, the different case bases in the prototype application were populated with a total of 226 cases. These cases were collected from the existing PFMEA documents, and from problems solved at the production lines. The latter were recorded during the implementation time of the developed prototype.

The user manages the system through the GUI. The GUI represents a Problem-Solving Sheet (PSS) divided into the corresponding areas of the 8D method. The user inputs the description of the problem through the GUI. The user must provide an answer to the questions ‘What?’ (a brief description of the problem), ‘When?’ (date and time), ‘How often?’ (frequency), ‘Where?’ (this question is divided into three different fields related to the line and station where the problem happens and the product that is being produced), ‘Who?’ (operator name), and ‘Why?’ (a brief description of why it is a problem). Based on the input from the user, a GUI Agent sends a query to the PLM system to receive the contextual information related to it. Then, a comprehensive query, comprising both the user’s input data plus the retrieved context data, is sent to the Coordination Agent. This agent needs to collect a set of possible solved cases from the available CBR systems. The Coordination Agent communicates with the different topic agents to request proposals for similar problems. The case base of each topic agent needs to be populated with an initial set of cases (i.e., already solved problems). To do so, the company’s PFMEAs were taken as the initial set of cases. The case base can be continuously extended with new solved problems. The decision to include a new solved case is taken by an expert. Based on the received responses, the Coordination Agent is configured to send only the ten most similar cases to the GUI Agent. The information is then shown to the user through the GUI. Figure 2 shows the communication model [9].

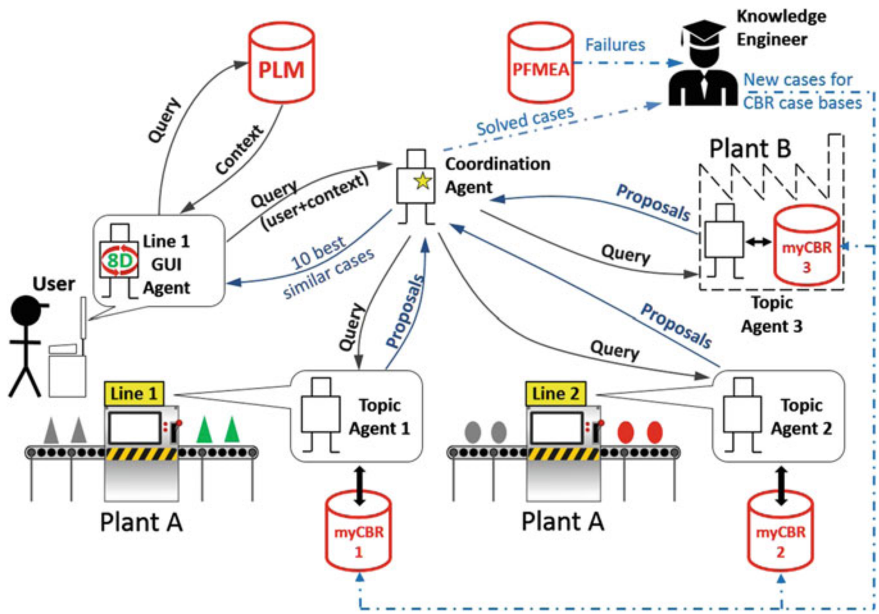
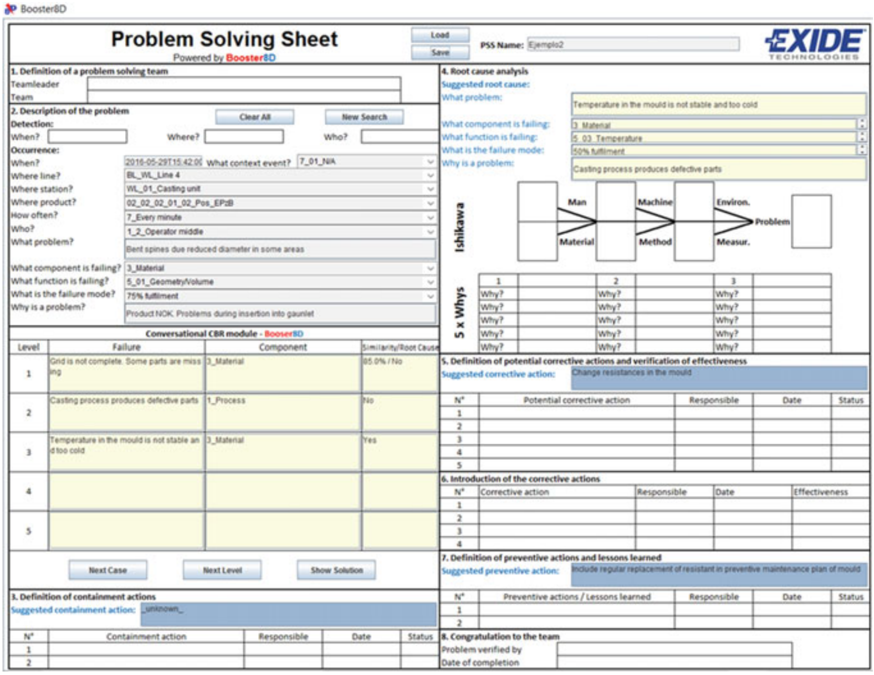


Fig. 2 Communication model of the prototype system [9]

4 Results

The prototype system was tested and validated in three main steps. For the first validation step, the Wet Filling production area in Plant A, located in Germany, was selected (Case A). Case A represents the lowest level of complexity for the system, since the cases were all collected in this process and plant. The Wet Filling production area in Plant B, located in Spain, was selected for the second validation step of the prototype system (Case B). Case B represents a higher level of complexity for the system, since it occurs in a different manufacturing context (plant) from where the knowledge was collected. The types of problems in both plants can be quite different (e.g., machines can be different, some materials are bought from local suppliers, and personnel have different levels of training and experience). Finally, for the third validation step, the Casting production area in Plant A, located in Germany, was selected (Case C). This Case C represents the highest level of complexity for the system, because the case base did not contain any kind of problem from this area and the PLM system was not set up with data about this area either. The objective was to evaluate the response of the system to a situation where a problem arises in a manufacturing process that is not included in the prototype system. In the three cases, the corresponding group leaders were trained and used the prototype system to solve ten problems that arose during their shifts. Queries, results, and real solutions were all recorded for a detailed analysis and evaluation afterwards [8]. Figure 3 shows an example of the developed GUI with input data and results proposed by the system.



Problem Solving Sheet
Powered by BoosterBD

PSS Name: Ejemplo2

1. Definition of a problem solving team
Teamleader
Team

2. Description of the problem
Detection:
When? Where? Who?
Occurrence:
When? 2016-05-29T15:42:0(What context event? 7_01_N/A
Where line? BL_WL_Line 4
Where station? WL_01_Casting unit
Where product? 02_02_02_01_02_Pos_EP±B
How often? 7_Every minute
Who? 1_2_Operator middle
What problem? Bent spines due reduced diameter in some areas
What component is failing? 3_Material
What function is failing? 5_01_Geometry/Volume
What is the failure mode? 75% fulfilment
Why is a problem? Product NOK. Problems during insertion into gaunlet

Conversational CBR module - BooserBD

Level	Failure	Component	Similarity/Root Cause
1	Grid is not complete. Some parts are missing	3_Material	85.0% / No
2	Casting process produces defective parts	1_Process	No
3	Temperature in the mould is not stable and too cold	3_Material	Yes
4			
5			

3. Definition of containment actions
Suggested containment action: _unknown_

N°	Containment action	Responsible	Date	Status
1				
2				

4. Root cause analysis
Suggested root cause:
What problem: Temperature in the mould is not stable and too cold
What component is failing: 3_Material
What function is failing: 5_03_Temperature
What is the failure mode: 50% fulfilment
Why is a problem: Casting process produces defective parts

1		2		3	
Why?		Why?		Why?	
Why?		Why?		Why?	
Why?		Why?		Why?	
Why?		Why?		Why?	
Why?		Why?		Why?	

5. Definition of potential corrective actions and verification of effectiveness
Suggested corrective action: Change resistances in the mould

N°	Potential corrective action	Responsible	Date	Status
1				
2				
3				
4				
5				

6. Introduction of the corrective actions

N°	Corrective action	Responsible	Date	Effectiveness
1				
2				
3				
4				

7. Definition of preventive actions and lessons learned
Suggested preventive action: Include regular replacement of resistant in preventive maintenance plan of mould

N°	Preventive actions / Lessons learned	Responsible	Date	Status
1				
2				

8. Congratulation to the team
Problem verified by
Date of completion

Fig. 3 Developed GUI with data

The execution of the cases using the developed prototype demonstrated the feasibility of the adopted approach. Depending on the case, the suitability percentages of the proposed solutions were different. The overall values were: 90% for problems in Case A, 80% for problems in Case B, and 20% for problems in Case C [8]. The suitability percentages reflect how close was the testing environment to the cases stored in the case-base. The overall conclusion was that the approach fulfils the aim of assisting shop floor manufacturing employees, such as operators or quality inspectors, in the execution of MPS processes, which are characterised by knowledge intensive activities heavily based on prior experiences. The main benefits of the conducted work can be summarised as follows:

- It allows capturing knowledge at shop floor level of any type of manufacturing process and in any location with Internet access. Problems from different manufacturing processes collected in different countries and companies were represented without issues in the developed prototype system. The clarity and simplicity of the created model was illustrated by the profile of the person who collected problems at the production lines for two weeks. The person did not have any previous industrial background, and after an introduction to the model for about 30 min, was able to collect information concerning many problems properly, and also in the right format to be directly inserted into the case base of the prototype system.

- It allows reusing the captured knowledge. The prototype was able to provide solutions to the presented issues with significant percentage of success in two different manufacturing plants located in two different countries, and in two different manufacturing processes [8].
- It provides blue-collar personnel with a low time-consuming problem-solving tool, which can be used even by personnel with very low knowledge about the manufacturing process in which they work. With a short training, it is possible to fill the user query fields in the GUI in around one minute. The requested information about the problem under analysis requires a low level of knowledge. It just requires knowing the product name that is under production, and the structure of stations and substations of the line. The rest of the context information is provided automatically by the PLM system.
- It supports knowledge sharing across different manufacturing processes and locations. The flexibility of the agent architecture of SEASALT allows use of the system by many different users at the same time and in multiple locations. This was successfully tested in two manufacturing plants located in Germany and Spain.

5 Next Steps

The developed system is a prototype, which means that work is still necessary to have it fully ready for its usage as a daily support CIP tool at the industrial level. There are quite a few lines that we consider to be worth investigating as future works. They can be summarised as follows:

- The development of the Knowledge Source and the Knowledge Formalization modules, which are part of the SEASALT architecture, to extract automatically knowledge from a PFMEA document. Currently, a PFMEA document is created on a semi-structured format and specific knowledge is introduced using natural language. This requires the intervention of humans to transform it into a structured format, to make it processable by a software application. In that direction, some research works propose the use of SysML to create a system model where artefacts contain FMEA information, and the use of a Prolog engine to query the created model to derive FMEA results [16].
- The use of semantic methods to collect information directly from free text describing a manufacturing problem.
- Adding a functionality to connect the proposed system with the Manufacturing Execution System (MES) used at the shop floor to integrate data from it. This connection should allow extracting automatically context event information like changeovers, starts of shifts, or change of operators at the line.
- An application test of the proposed approach integrating suppliers, manufacturers and customers, to achieve a collaborative CIP.

- The development of the adaptation container in myCBR to have automatic adaptation of the solutions proposed by the prototype system to the specific context of the user query.
- The display of visual media content in the GUI of the developed prototype would help to understand the problems and the proposed solutions. It would also help to remove the language barriers. As negative effect, it would demand more work to prepare the documentation.
- The systematic recording of manufacturing problems opens the door to the development of additional functionalities to process the stored data. For instance, a dashboard showing statistics data and predictive analytics about: failures, components, suppliers, machine components, etc. This leads to analysing the use of machine learning techniques to make predictions and assist in decision making tasks.
- Development of a multi-language dictionary with all technical terminology to support the parallel use of the system by different users in different countries. With such a dictionary the system could translate automatically issues captured in a native language A into a different native language B.

6 Lessons Learned

The lessons learned along the execution of this work can be grouped into two main sets. One set relates to the knowledge collection process and a second set relates to the usage of the prototype system.

Conclusions about the defined process to collect knowledge:

- During this first phase of the project several peculiar behaviours, which can hinder the collection of knowledge related to problems, were observed in the operators. For instance, when operators or technicians try to explain how they have solved a problem, very often they give a list of different things that they did or changed in the machines, but they do not know which of them had real impact in the solution of the problem. It was also often observed that, even when operators fill in the Problem-Solving Sheet (PSS), following the eight steps of the method, in reality, they have figured out a solution previously. Then, they follow the MPS method from the beginning, but just looking for the arguments that justify their initial assumptions and solutions. This hampers completely the application of a CIP.
- PFMEA was considered as the initial source of information for the system. Nevertheless, a PFMEA document needs to have a certain depth of detail to be useful. A very generic document that focuses only on processes and does not take the analysis down to other components (e.g. machine or human resources), will be of very little help. The same consideration can be applied to other documents, from which problems and solutions could be extracted. For example, 8D

documents with very poor problem descriptions or generic corrective actions do not add value.

- For the representation of a problem, it is recommended to start filling the information about “What problem” and “Why it is a problem”. This helps to settle down the reasoning about the problem. Then proceed to fill in the rest of the parameters.
- In a chain of problems, until a root cause is identified, it is possible to go from one step into the next one in a very detailed way (e.g. the machine tool is stopped > there is not enough coolant > valves do not operate properly > valves are dirty), or to jump quickly to the root cause (e.g. the machine tool is stopped, the coolant valves do not operate properly because they are dirty). The more defined steps, the easier it will be to reuse them in the future. More specific and detailed steps give the possibility to reuse any of the levels included in the case by a bigger variety of problems under analysis. A good practice, to ensure this during the representation of a case, is to observe which element is selected at the first level. It is recommended to select “Material” as the component of the first level, if the problem was identified as a quality issue in a product, and to select “Process” for any other case. In industry, problems are identified rather in products with poor quality (i.e. Material) or in processes performing wrongly (i.e. Process). Then, in the following lower levels of analysis, the rest of the types of components can be selected. In this way, it is avoided to jump directly into conclusions and facilitates generating at least two or three levels of problem analysis in each case.
- When the name of the user of the system is explicitly recorded in the digital PSS, there is a clear possible rejection, or even blockage, from the operators or work council to use the proposed system and to share knowledge. There is a belief that this kind of tools can be used by the company as a personnel performance control tool.
- The context event information comprises, among others, the options: “New operator” or “New shift”. These two options create a conflict of interest. The context event information could not be always properly filled, because for an operator selecting as relevant event “New operator” or “New shift” means recognising his/her own guilt.

Conclusions about the use of the prototype system:

- The application of this model to unstable or very new processes, where their technical parameters are either not well defined or with extremely large tolerances, is very difficult. The difficulty derives from the definition of the similarity rules when there is a significant overlap in parameter values. This situation could arise when a process is used to manufacture more than one type of a product.
- In the developed prototype, the PLM system Aras Innovator was populated through its application user interface, which is extremely time consuming and a possible source of errors. It is recommended to develop macros to upload data automatically from Excel or csv files.

- The prototype system was developed to prove the theoretical concepts of this work. The PLM system was only configured to support until the level of the workstation. Therefore, data about lower level components were not included. At the maintenance level, searches are performed at lower level, therefore, data should be available in the PLM system to calculate the cases' similarity properly. This shows that the implementation of a PLM system should be part of the highest-level company strategy.
- The proposed framework requires the pre-existence of computers at the shop floor level and a PLM system containing the PRR data of the company. This is a barrier to apply the proposed approach when that is not the case. Nevertheless, the current trend of digitalization in the industry [17] shows that the access to digital content from the shop floor will be more and more common in the near future.
- Another expected barrier is that the system requires incorporating, as much as possible, company existing data to create a significant set of cases. This implies incorporating data from existing documents (e.g. PFMEA, paper PSS, 8Ds, minutes of meetings) into the new data structure, and this process could consume many resources and much time at system set-up. For example, in the installation of a new CAD system in a company all old designs remain in the original format and they are only brought to the new format when they are involved either in a modification or used in a new project. However, in the presented system, if the PLM system of the company is not adapted to incorporate the defined data structure, and the data of existing documented manufacturing problems are not incorporated into the system, the system will not be able to provide the users with any solution proposal.

7 Advice

When considering the implementation of a similar system, there are a few recommendations that can be extracted from this case study. Some of them are common to any other industrial software system implementation, but perhaps it is worthwhile to emphasise them. The advice can be summarised as follows:

- Ensure proper support from management for the project. This will ensure both resources and enough time for the implementation.
- Start the project in a single manufacturing area that has enough relevance for the company. This will allow having impact after a successful implementation of the first prototype and will open the door for an easy spread of the project across other areas.
- The selected area for the first prototype should also have PFMEA documents with a good level of detail to populate the initial set of the case-base.
- This selected area should have enough performance troubles to give the system the possibility to show improvements quickly, but a too deteriorated area may put

too much pressure on the project, not letting enough time for showing positive results.

- For the context information, it is important to select a reduced set of parameters. They should be the ones that allow differentiating strongly one case from another. Too many context parameters create issues in the similarity calculation, because the weight of each one becomes quite irrelevant.
- Provide support and early access to the system to the personnel at the shop floor. Spend enough time with them working with the new system. Make minor adjustments to fulfil their suggestions, then they will feel relevant and part of the project, and they will become motivated to use it.
- For the development of the software, it is critical to engage the IT department. They should provide the support needed to incorporate modifications into the PLM system, otherwise it may end in a never-ending bureaucratic process. Also, a lack of proper programming expertise in the project may cause the consumption of too much implementation time and deviate the focus onto software issues that add no value.

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Significance of Cloud PLM in Industry 4.0

Shikha Singh and Subhas Chandra Misra

Abstract The Industry 4.0 revolution is already initiated and under adoption by various industries. This case study highlights the elements of Industry 4.0 and discusses the contribution and significance of cloud product lifecycle management into this revolution. The present status of adoption of Industry 4.0 and cloud PLM is discussed with suggestions for future studies for better understanding and implementations. Challenges to cloud PLM adoption are discussed through two case studies.

Keywords PLM · Cloud · Industry 4.0 · Manufacturing · Case study · Digitization

1 Introduction

"Industry 4.0" is the latest buzzword among the manufacturing industries all over the world. The industrial revolutions are changing with the evolutions and development in technology. Industry 4.0 is about the digitisation inside the factory and digital integration among the smart factories as well as with all the stakeholders [16]. Real-time collaboration, Internet of Things (IoT), cloud [21], automation [2], and data analytics are the enablers of Industry 4.0. Ferreira et al. [2] termed the Industry 4.0 "Digital industrial paradigm" and expressed the integration of people, process, and technology as the major constituents of Industry 4.0. Data analytics and digitisation are the topmost agenda in industries as these are the core elements of 'Industry 4.0'. Greater integration offers better data analytics opportunities to collaborate and identify the changing requirements of customers as well as new business opportunities.

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Although digitisation existed earlier through several distinct design tools such as CAD, CAM, etc., this industrial revolution stresses the real-time collaboration of all. Considering the need for a collaborative approach, PLM emerged to integrate all the enterprise systems [5]. PLM supports the integration of people, processes, and tools in order to reduce the overall product complexities in organisations [4, 15].

Cloud PLM is the advanced version of PLM systems which offers the digital collaboration of all the stakeholders and products through the internet. The on-premise PLM systems were limited to the factory's boundary. But the concept of Industry 4.0 has broken those boundaries and motivated to collaborate and integrate globally. While depicting their PLM experience in aerospace firms, viz. Airbus and Boeing, Mas et al. [5] have discussed the need and future of PLM as Software as a service (SaaS) model based cloud PLM. Silva et al. [9] have elaborated the relation and differences among PLM, digital manufacturing, and virtual assembling to show how digital manufacturing and virtual assembling are co-related with PLM.

Such arguments clearly indicate the important role of cloud PLM which will act as a significant IT system in manufacturing organisations. However, presently it is under the planning phase for adoption by many manufacturing organisations.

Considering the cloud PLM as an enabler of Industry 4.0 [18], it is the time to understand and adopt the cloud PLM systems. Based on the research experience of PLM in an aircraft manufacturing firm and an automotive firm, the authors have described the open challenges which manufacturing industry is facing with cloud PLM adoption.

2 Cloud PLM Adoption

Initially, PLM systems were available as on-premise tools only. After the emergence of cloud technology, PLM systems are available in two deployment modes, i.e., on-premise and cloud [19]. On-premise systems are the traditional PLM systems [12] available in the last decade, while the cloud deployment models were developed more recently. But many manufacturing firms are now evaluating the cloud deployment models to migrate [1] for better collaboration and quick reachability. Due to the better offerings of connectivity and integration, cloud PLM is a significant contributor to digitisation and Industry 4.0 revolutions [8]. The different roles which PLM plays in a manufacturing organisation are shown in Fig. 1.

PLM systems are integrating the 'Internet of Things' to manage the smart products embedded with 'Radio Frequency Identity Devices' (RFID) and 'Product embedded information device' (PEID) [17].

The ecological, social and economic demand for sustainability is a serious concern. Customers, legislations, and government laws are also affecting product requirements. In such an ecology-prevalent scenario, PLM offers to manage products from their idea and development to their disposal. In order to achieve and maintain eco-friendliness in product designs, the process of disposal of the product and its components must be decided at the design phase. The product development has

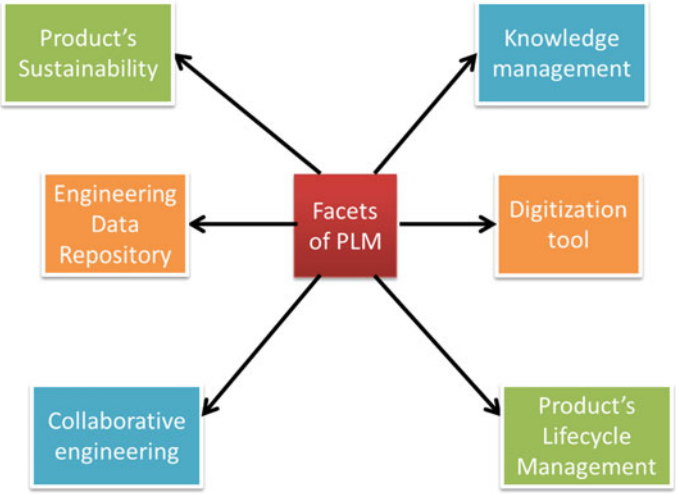

Fig. 1 Different facets of PLM in manufacturing industry

become complicated due to the complexities of decisions for choosing the eco-friendly raw material, user-friendly designs, ecological manufacturing processes, handy maintenance, and disposal. Such product development issues demand a need to collaborate. Gmelin and Seuring [3] have studied the role of PLM in managing data, process, and project, to facilitate the complex design and development of sustainable products in six automotive companies.

A Report by Tanna et al. [16] on the fourth industrial revolution in India illustrates that digitisation is the current need yet only 27% of the companies declare their firm to be a digital company. Hence, the means to facilitate digitisation must be evaluated, implemented, and institutionalised properly to meet the competitive needs of Industry 4.0. Roblek et al. [7] have investigated the outcomes of Industry 4.0 and anticipated the emergence of the knowledge management revolution with IoT. Xin and Ojanen [20] studied the impact of digitisation to manage the different lifecycle stages of products and discussed how time to market could be reduced in the beginning phases, followed by cost reduction in the middle phases and quality improvements in the later stages of product lifecycles.

Due to several reported failures of PLM implementation, the barriers to PLM utilisation were explored in an aircraft manufacturing firm by Singh and Misra [10]. Considering the rapidly increasing product-related data in manufacturing organisations, Singh and Misra [11] suggested the necessary need of PLM to manage the product lifecycle of complex products and explored the success factors for PLM systems implementation through a case of an automotive firm. Meier et al. [6] have discussed the last 20 years of PLM by considering the participation of the blogger community also in case of PLM implementation. They studied the six cases based on the need of collaboration and integration of all enterprise systems in a common plat-

Table 1 Comparison of findings in two case studies

Cloud PLM adoption challenges	Findings of a case study in an aircraft manufacturing firm [14]		Findings of a case study in an automotive firm [12]	
	Prominence values (based on DEMATEL technique)	Ranks	Prominence values (based on DEMATEL technique)	Ranks
Decision of Migration process	7.9086	*1*	14.359	*1*
Integration and interoperability	6.5052	2	11.784	7
Data security	6.3664	*3*	13.482	*3*
Trust on solution provider and users	6.1697	4	13.771	2
Authorisation control	5.2858	6	12.248	5
Performance	4.7449	7	11.967	6
Customisation	6.034	5	12.271	4

form. Several other researchers have examined different aspects of PLM systems and their implementation. Most manufacturing organisations have already implemented on-premise PLM systems [13].

Based on personal research experience, the authors have witnessed the implemented on-premise PLM systems in the two case companies. It has been observed that the cloud concept is considered as a new one in organisations. The on-premise PLM systems are already implemented in the firms; now the decision is to be made about migration from on-premise PLM systems to cloud PLM. Such decisions need rigorous technical scrutiny of existing on-premise PLM systems in order to study the adaptability/integration of existing on-premise systems to cloud. Based on the case study in an automotive firm [12] and an aircraft manufacturing firm [14], the prominence data has been reproduced to compare the findings of these two case studies as shown in Table 1.

Singh and Misra [12–14] have identified the cloud adoption challenges after reviewing the literature and performing case studies in two large Indian manufacturing organisations. The identified challenges are listed in Table 1. The PLM experts in the case companies feel that the decision of selecting the migration process to move to the cloud from the on-premise system is a crucial challenge. In order to utilise the financial investment and effort made during the establishment of on-premise systems, these have to be integrated with the cloud PLM systems. Moreover, these large manufacturing organisations are bothered about the performance of cloud PLM systems as it may vary with the internet speed. Trust in the external cloud solution provider is another concern as customisation and authorisation will be limited, or not at all permitted.

Considering the above concerns, and other concerns about data security, private cloud deployment is suggested for such large manufacturing organisations. But the interoperability of other on-premise enterprise systems must be technically proven to enable Industry 4.0.

Concerning the challenges listed in Table 1, it has been revealed that all these challenges were found relevant in both the firms. The inputs on the impact of the challenges on each other were collected from the PLM experts in both the case companies independently. Decision Making Trial and Evaluation Laboratory (DEMATEL) technique was used to analyse the inter-relationships of these challenges in order to find the core challenges to be addressed first. The prominence values represent the relative importance of a challenge among all. Hence, based on the prominence values, ranks are given to the challenges. The two challenges of 'decision of Migration process' and 'data security' were given the same rank in both the firms. The 'Trust' and 'integration and interoperability' challenges were also found significant in both the firms.

The collaboration of technology, i.e., the interoperability among the enterprise systems, is a backbone of Industry 4.0. Although interoperability is a necessity which helps take the advantages of new technology as well as of previously existing systems, most organisations haven't yet integrated their enterprise systems [2]. The lack of interoperability exists in both the case companies. Among several technology adoption challenges in the mechatronics industry, Ferreira et al. [2] highlighted integration and interoperability as a severe challenge which can be addressed through Industry 4.0 implementation.

3 Conclusion

The two case studies were highlighted and compared to check the future transformations to the cloud. Defining the migration process for cloud adoption, while maintaining the previously existing system, is considered as a challenge by the PLM experts of both the firms. Although the investments are already made for on-premise PLM systems, they still need further technological development in order to improve functionality, interoperability, and cost [2]. Hybridisation of PLM systems with the cloud ultimately enhances the ease of use and usability of PLM systems. Considering the planning stage of cloud PLM generally, the cloud adoption issues must be addressed in different contexts through different case studies in leading organisations. Such studies provide a better understanding and preparation for the future. The generalisation of cloud PLM challenges is still an open issue.

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Examples of PDM Implementation

John Stark

Abstract These case studies are from four companies in different industry sectors. One company is in the electronics industry, one is from the automotive sector, one is an engineering industry company, and the fourth is from the aerospace industry. The case studies show that although the four companies are in very different circumstances, there is significant similarity between them. They are all caught between rapidly evolving technology, demanding customers and aggressive competition.

Keywords Product Data Management · PDM

1 Introduction

These case studies, from four companies in different industry sectors, were originally published in 2004 [1]. They show that while much has changed in the intervening years, much has stayed the same. More than ten years later, many of the lessons learned are still relevant.

2 An Electronics Industry Company

2.1 Background

Company A is a medium-sized electronics manufacturer operating in over 20 countries. Revenues exceed $1 billion of which about half comes from its domestic market. Most of the product development operations are concentrated in 3 countries. Among the challenges facing this company are the globalisation of its markets, global competition, and rapidly advancing technology. There is fierce competition in the electronics

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markets and a fast rate of change. Prices for some products drop by 1% each week as more competitive products appear on the market. Many electronics companies derive more than half of their revenues from products less than three years old.

The lifetime of many new electronic products, from conception to obsolescence, is already less than two years. New generations of products such as PCs and printers appear every 3–6 months. As product lifetimes fall further, the effect of being 3 months late with a product will be disastrous. Most of the customers will already have bought the competitor's product. Those who have not, will be waiting for the next generation of product. Similarly, producing a product that does not meet customer requirements will lead to disaster. There will no longer be time for trial-and-error, the product will have to be right the first time.

Company A read somewhere that Philips Semiconductors, for example, produces certain products that are outdated after only six months and require as long as three months for development.

Company A knows that Hewlett-Packard, which used to take 54 months for a major new computer printer project, reduced this to 22 months for its first DeskJet, and then to 10 months for the DeskJet 500C. Intel reduced its development cycle for motherboards from 12 to 6 months, then to 3 months.

Leading manufacturers can now produce 10 new versions of a product each year. They can also rapidly reduce product cost, taking 30–50% out of the cost of a product over a two-year period. Some major manufacturers outsource more than 60% of manufacturing.

Globalisation has created other types of problems as well. For example, Company A had problems because it produced different quality products in different countries. Its suppliers performed erratically. It also had problems making sure that the various companies and divisions of multinational customers were given the right discounts when they ordered across national boundaries. The multinationals want to get the same product and service from Company A wherever they are operating. They also expect Company A to respond to local market conditions, which implies that Company A may have to engineer special products anywhere in the world—quite a challenge when all the developers are located in just three countries.

2.2 *Objectives*

Faced with this environment, Company A's prime objectives are to increase its ability to develop new products and services much quicker, and to find new ways to make and deliver them to the customer faster than competitors. Time, not cost, is becoming the key parameter. High quality is no longer an option—it's essential.

2.3 The Response to Change

Company A has made tremendous efforts to change. It has all the latest CAD, CAE and CAT systems. It spent a lot on ERP systems and on getting JIT working. It invested a lot in new manufacturing facilities. One year it did TQM and another year it did SPC.

In spite of all the investment, there has not been enough improvement in performance for Company A to remain competitive. The main problem is that its products are consistently late to market, and some 40% of projects to develop new products fail.

Looking back at some of its recent initiatives, the company found that when changes were made, they were uncoordinated, project-oriented, non-interrelated, and non-sustaining. For example, one VP would push the idea of strategic IS, while another tried to do TQM and SCM, and someone else did fuzzy logic. One VP wanted to build a "lights-out" factory in Silicon Valley. His successor wanted all production and assembly done in the Philippines.

Initiatives were not brought together. Improvement activities conflicted. And, often, by the time initiatives got down the hierarchy to working engineers they had already been watered down, and since the next initiative was known to be on its way, no-one could be motivated to change their behaviour.

2.4 Current Situation

A lot of effort and money has gone into attempts to change, but the end result has met no-one's expectations, and some people are very unhappy with the results. Top management has come to the conclusion that product development is an unmanageable black box, a Black Hole with a never-ending appetite for dollars. Management thought it had got to the stage of being able to estimate likely underestimates of new product development costs and cycles until they saw some of the software that was developed to go in the products. 90% of the time this was more than 3 months late. It was always full of errors, and 40% of the effort went into fixing the bugs.

Top management believes that developers don't actually understand the business environment and don't want to communicate with anyone else in the company. They seem to be incapable of teamwork.

Product development managers know they waste a lot of time. They know that sometimes they put too much effort on the wrong project and don't get the expected payback for their investment. However, they believe the real problems in the company are caused by top management. Top management responsibilities change frequently. Top managers know they'll change job before initiatives and projects are finished, so they try to get easy short-term success, and leave the long-term hard issues to the next guy. They start something with a bang, and a few months later it disappears without even a whimper.

Product development managers feel that top management is dominated by the bean counters. They believe the financial controller runs the business, putting together plans and budgets in his spreadsheet. They say he does this very well—but there is no link to the customers or the products. And other top managers are so busy looking at the figures he produces they don't have time for customers and products.

Product development managers claim top managers use the wrong measurement systems to judge performance. The main indicator for product development performance is product development headcount. They complain they're rarely involved in decision making.

Product developers claim they are assigned to far too many projects. One was assigned to 15 projects at the same time. So many that he wasn't even sure which projects he was working on. Product developers claim that managers don't define in enough detail what is expected of them in a particular project. Different managers have different expectations, but these are not clearly explained. After many reorganisations there are numerous uncoordinated systems and inconsistent sets of documentation. Product engineers claim it's not surprising that projects fail when it's unclear what the targets are, who should do what, or how it should be done.

2.5 What Comes Next?

It's clear that there are a lot of problems in Company A, and they are not only in product development. That said, product developers shouldn't be looking to blame their poor performance on others. There are many organisations which have problems at the company level but still have excellent product development performance. There are many things they can get on with, and do, without top management involvement.

Apparently, there's no vision of what product development should look like in the future, and there's no medium-term strategy or plan. All of these could be proposed by product development managers without the assistance of top management. Product development managers don't have to limit themselves to producing the short-term budgets and plans required by top management (In practice, it looks as if top management would be delighted to see product development managers trying to get organised.).

There's a similar problem with metrics. There's no reason why product development managers shouldn't propose their own metrics to help improve performance. Why not start with some metrics that address the product development cycle—such as cycle time, cost and number of changes? Why not find out how product development performance compares to that of other organisations?

2.6 Introducing PDM

As it had all other computer systems, the Design Engineering Department decided to invest in PDM. One of the Engineering Directors was given the responsibility of selecting and introducing the system. He held a meeting with some of his colleagues and they came up with the following list of reasons for introducing PDM:

- support Concurrent Engineering
- provide a vault for Engineering data
- manage Engineering BOMs
- manage CAD files
- classify parts
- support ISO 9000 implementation

When the Engineering VP presented a proposal about the introduction of PDM to top management, he showed the above list. He was asked why the list only contained reasons related to the Engineering Department, and it was suggested he should get some outside help and try to define a PDM project that would support the company's business objectives.

The Engineering VP realised that if the project was going to have to support company-wide objectives, it had better be led by a cross-functional team. He didn't want to work with people from other functions, so got one of his Directors to lead the project and put together a multi-functional team. To start with, this included someone from Marketing, someone from the factory, and someone from Service. Later, it was decided to extend it to include all major functions, sites and product groups.

The team worked with a consultant who suggested that rather than trying to invent a project among themselves, they should interview a lot of people in the company to find out what they wanted. The team liked this idea, and decided that they should even interview top management to identify what the company's business objectives were.

Top management told the team that the company had to change because the world was changing fast and it just couldn't keep doing business the same way as before. They said there would need to be product development teams on three continents, and that products developed in one place would need to be manufactured at other sites.

The approach taken by the team was appreciated by many people in the company, both among top management and in functions other than Engineering. The Engineering VP thought it was strange that a project about product data should suffer so much interference from people outside Engineering, but he didn't complain as he was congratulated on his new style.

The team identified a fourfold vision for PDM. PDM would be an enabling component of the company's strategies to move towards a new organisational structure, to stop re-inventing the wheel, and to support business objectives to reduce time-to-market. It would enable Concurrent Engineering across multiple, geographically-dispersed organisations. It would support this with accessible and accurate information, and real-time, change-controlled information exchange. It would provide a way to have all the right information at the right time, in the right form, and in the right place, all the way through the product lifecycle. Sales and Service users would have lifecycle visibility to see what's coming and what's gone before.

The Engineering VP was loudly applauded when he presented the results of the team's work to top management.

3 An Automotive Industry Company

3.1 Background

Company B is an automotive manufacturer with plants in several countries and world-wide sales. Over half of its sales are made in its domestic market. Most of the engineering organisation is located near the main site.

In the early 1970s, Company B's technical and marketing activities set the standard for many of its competitors. It was a dominant player in its domestic market and had significant sales in overseas markets. Times have changed. Company B has been faced by issues such as global competition, Total Quality, environmental pressures, and rapidly advancing technology. Trouble seems to come from all sides. Competitors from Newly Industrialised Countries appear from nowhere to compete against its models. Customers expect cars to run tens of thousands of miles without a costly service. In customer surveys, competitors always have much better quality. Environmental groups and product liability attorneys are a continual menace, and prevent new developments that would enable a fair fight with the competition.

The real problem though is the competition. If only they would go away it would be possible to produce cars the way they always were, but somehow things have changed. Company B heard that, somehow, a team of only 85 people designed Chrysler's Dodge Viper in 36 months instead of the traditional 60 months. Then the Chrysler Neon took only 31 months to bring to market. By 2003, many car manufacturers had reduced the time to develop a new vehicle to 24 months. In some cases only 15 months was needed, and 12 months was the new target.

Company B read somewhere that GM's Corsa had 30% fewer parts than its predecessor and cost 25% less to assemble. 30% of Honda's 1992 Civic came from the previous model compared with traditional reuse of less than 10%. Simultaneous use of a digital mockup in each partner's vehicle environment, together with scientific computation and rapid prototyping capabilities, reduced development time of a new 1.4-L common rail diesel engine, marketed by PSA Peugeot Citroen and the Ford Motor Company, to 32 months.

Due to a shortage of cash, Company B had to delay mid-life facelifts on some models by two years—leaving competitors 2 years to grab the market with their new models. This was the beginning of a downward spiral. By holding back the facelift, less cash would be generated and be available for urgently needed actions—which would also be delayed, further delaying cash inflows.

Many competitors appear to have mastered the apparently contradictory challenge of being both a low-cost producer and a provider of high value-added. How this is done is something top management at Company B can't find out. Apparently some of these companies even use existing manufacturing capacity for new models. They seemed to have mastered techniques for rapid development and introduction of new products and technologies with short life cycles and minimal lead times. As a result they are capable of efficient make-to-order and low volume development and production, and can apparently manufacture anywhere in the world. It's a frightening prospect.

3.2 Objectives

Faced with this environment, Company B's prime objective is to generate enough cash to be able to fund development of new products so they get to market when customers want them, not two years later. Then, it has to improve product development performance. In particular, it needs to reduce the time and cost of bringing new models to market.

3.3 The Response to Change

In the past, Company B reacted quickly to changes. It brought in the best consultants and changed its corporate organisation several times. The CEO was moved aside. It invested heavily in robots and computers. It closed plants and squeezed its suppliers. It followed the path taken by its main competitors and ordered the introduction of techniques used with success in the Japanese automotive industry. It made tremendous efforts to improve Engineering performance and regain its position as a world-leader. It developed its own CAD system so that it could make the best designs, built its own robots to ensure the best quality, and implemented all the new acronym technologies. It claimed to have the best CAD in the world. Company B and its suppliers were using nearly 50 different CAD systems.

There was publicity about major changes and progress, but much of it was to impress the customers. Very little real progress was made. Even if a particular project succeeded, the lessons that should have been learned from it were forgotten, and not institutionalised. The end result has been some very heavy financial losses and a continual decline in market share. Massive investments in automation have failed to produce the desired effect. As more and more computer systems were used in the development process, the cycle time actually became longer rather than shorter. Continual translation of data between CAD systems led to design errors. Increasing customisation of models made it more difficult to verify all the design parameters, and the only way that quality could be maintained was by employing more and more inspectors at the end of the line. Many of the computer systems were incompatible, and it seemed that the more advanced the functions they offered, the more unlikely they were to fit in with the other systems.

Recently, Company B took a long, hard look at the way it was running the new product development process. It found there had never really been a strategy for New Product Development. Of course there had been a corporate strategy, and highly-paid consultants had been brought in to dream about a Vision of the company ten years forward, but no-one had developed a product development strategy. Instead each product manager had acted independently. If someone thought of a good idea they just went ahead and did it—without anyone considering the effects it might have elsewhere in the business.

How was it that top management had not noticed what was happening? Company B concluded that the corporate focus just wasn't on Engineering. Much of the top management attention was elsewhere, for example, on getting trade barriers erected and maintained, and diversifying into other industry sectors.

3.4 Current Situation

Very few of today's corporate managers understand the requirements for new product development. They are happy to leave the Engineering function to itself, and let it do what it likes—provided it doesn't want to spend lots of money. The main criticism that top management has of Engineering is that products represent the engineers' dreams, not the customers' requirements. Time and again, new designs are for rugged pick-up trucks, high-powered sports cars and futuristic luxury models—yet most customers just want a low-cost reliable car to get to and from work, the mall, and the football stadium.

Top management is frustrated, and talks more and more about out-outsourcing Engineering. Top management can't understand why the engineers always start their designs with a blank sheet of paper—can't they re-use existing parts, or use purchased parts? Why do they always try to do it all themselves? Can't they go out and see what customers really want? Can't they listen to the marketing specialists and use the specifications that come from the market? Can't they make themselves clear when they communicate with the plants? Can't Engineering understand the difference between lowest initial cost and lowest lifetime cost? Can't Engineering see that competitors' designs are fresher, have more variety, and are technically more sophisticated? Isn't it obvious that it's better to take 2 years on a development rather than 7 years? Can't Engineering understand that if a mid-life replacement is late, customers won't just wait for it to arrive, they'll go and buy a competitor's product?

Engineering management recognises it has some problems, but knows it has a lot of solutions. Approval to develop, over the next five years, its proposed New Product Realisation Process will guarantee quality improvement by an order of magnitude.

If top management would only provide the funding for its 10-year CIE (Computer Integrated Engineering) project, it will be able to slash lead times.

Engineering management sees the main problems with performance as being related to top management attitudes and behaviour. Top management seems to have no real understanding of the underlying engineering processes, and seems to run the business on the basis of a simplistic, top-down, cost-centre view. In this picture the business runs itself, and top management makes fine tuning through annual "flavour of the year" adjustments. One year it's Total Quality Management, then it's Customer Focus, and then Logistics Management, or Cycle Time Reduction. The title is always written with capitals, but even this doesn't make people think it's important—everybody knows that next year it will have disappeared.

Another criticism from Engineering is that every time things look bad, top management "downsizes" across the board. Downsizing by 10% means reducing headcount by 10%, so a certain number of people, regardless of their skills, knowledge, or their role in the engineering process have to go. Middle management decides who should go and who should stay, so middle management stays, while design and manufacturing engineers go.

3.5 What Comes Next?

The company's lengthy decline implies that corporate management is unlikely to provide much help to the Engineering organisation in the near future, so it's really up to Engineering to save its own skin. There's unlikely to be much money around for improvement initiatives, so the 10-year CIE project should be shelved—mega-projects like this usually fail anyway. Probably the most cost-effective approach will be to introduce the New Product Realisation Process—since this underlies everything done in Engineering. A good starting point for the process will be to look at the development processes of other companies. Building on the basis of what they do, the new process should be defined in less than a year.

3.6 Introducing PDM

The first attempt at PDM was made in the mid-1980's by a Technical Systems Manager who implemented it for:

- management of CAD files
- scanning of paper drawings
- parts classification
- archiving

A lot of CAD designers used the system, but the practical results of this PDM implementation were hard to see. Later, the need for a PDM system was re-identified when the corporation realised that the lack of an IS strategy was hampering growth. It was realised that, as a result of a departmental approach to IS whereby people could buy whatever system they wanted, there were dozens of platforms and operating systems and 34 different types of PC in use across the company.

The corporation's response came soon after, with the introduction of an overall Vision and a set of Annual Pro-Activity Objectives. These mirrored the philosophies of the world-wide automotive industry, and included techniques such as Just In Time, continuous improvement, right first time design, reduced product development lead times, reduced material costs, Kanban, empowered employees, and measures to further enhance Total Quality. The plan showed the major steps needed to meet world-class objectives. PDM was identified as a key tool for achieving many of the corporation's strategic objectives. A list of PDM areas of focus, and the corresponding objectives, showed:

- digital model definition and virtual engineering for fast product development
- a single PDM system replacing multiple legacy systems to manage all the product data
- collaboration tools to support development on several sites
- image management to improve access to thousands of drawings for thousands of people
- change control

One area of focus is change control. With paper systems, engineering change control was a horror story. There was always a huge backlog of change notes. No-one knew the exact status. Now, PDM will give visibility of the entire change control process.

Another focus is safety. In the precise, demanding business of designing and manufacturing safety-critical passenger transport vehicles, the implementation of PDM came to be seen as a major step in reinforcing the corporation's Total Quality culture.

4 An Engineering Industry Company

4.1 Background

Company C is a major multinational conglomerate. Its divisions operate in discrete manufacturing sectors as well as plant and process engineering. The divisions have operating units, plants and customers in countries all round the world. About one-third of sales are made in the domestic market and two-thirds elsewhere. The engineering organisations are attached to the divisions, and are located throughout the world.

Company C operates in many countries and has found currency instability to be a major problem. Many of the projects it develops take several years to implement and involve people from many countries. It only takes a few percentage points change each year in the value of major currencies for all the expected profit to be lost.

In developing countries, complex political and environmental considerations often outweigh the usual business and technical aspects. In the developed world, customers are increasingly looking for customised solutions that offer more functionality and are more reliable, yet are cheaper and resource-saving. A greater variety of solutions has to be produced, and Company C has to respond quicker to market needs. It's an increasingly difficult environment.

4.2 Objectives

Faced with this difficult environment, Company C's primary objective is to increase the quality of today's products and the productivity of today's processes, while simultaneously preparing for more adaptable products and more flexible processes in the future.

By increasing quality, the customer's cost of ownership will be reduced, customer relationships improved and profits increased. Increasing productivity will reduce the cost of components and products. The shorter development cycles resulting from increased adaptability will lead to more products getting to market faster. Without increased flexibility, Company C will not be able to produce a wider range of products in the small batches that will be needed. Together, the improvements in quality and productivity will lead the company to a position as a highly competitive low-cost producer. The improvements in adaptability and flexibility will bring products to market faster, and increase market share. With reduced costs and increased sales, profitability will rise significantly. The volume of customer requests for quotation is increasing. Response time to requests for quotation needs to be reduced.

4.3 The Response to Change

To meet these objectives, Company C has already been very active. There have been many corporate re-organisations in response to the changing business environment. Many initiatives have been started to improve engineering and manufacturing performance. Almost every year, top management has introduced an important new Program. Recent examples include Integrated Logistics, Total Quality, Cycle Time Reduction, Supplier Focus, Global Benchmarking, Concurrent Engineering, and University Partnering.

The company is a world leader in CAD, especially solid modelling, and has developed some very effective interfaces to stress analysis programs. It has connected its sites with a world-wide electronic mail system. It has a highly regarded make-to-order ERP system, and its Flexible Manufacturing System (FMS) is regularly featured in press reports and Business School case studies. Six Sigma techniques have been introduced in most of its plants, and cycle time reduction teams have been set up to bring lead times down.

In spite of all these improvement programs, Company C is not satisfied. Revenues have stagnated, and profits come mainly from financial transactions and not industrial activities. There are still many problems with basic technology, and these have not been alleviated by the availability of the electronic mail system to communicate error reports rapidly. Recently, new product introductions over a whole range of product areas have been delayed for all sorts of reasons. Product quality is erratic despite the vast investments in engineering and manufacturing technology. Lead times seem to remain the same in spite of all the new investment. Overall, the costs associated with engineering and development rise rather than fall.

Recently, Company C has being trying to work out where it went wrong. Looking back, it found that the corporate focus hasn't been on long-term issues like Engineering and New Product Development. Much of top management's attention was on getting the quarterly results right. The 1980s and 1990s were years of expansion, and it was easier for top management to improve the results by restructuring and buying up companies in faraway parts of the world, rather than by improving the core business.

Many of the improvement programs developed a life of their own, and instead of helping to reduce costs, only increased them. For example, the benchmarking program was meant to follow the trend of many other companies that started benchmarking their engineering performance against that of other companies. However, most of the effort and investment went into the benchmarking exercise itself, and not enough went into interpreting the results and finding ways to enable performance improvement.

From its benchmarking program, Company C learned that increasing the speed of new product introduction usually requires stripping out unnecessary levels of middle management and bureaucratic control, taking a new look at the whole development-to-finished goods process, and promoting multi-function teams. Instead of letting Engineering do its job alone, then handing over to Manufacturing, which does its job alone and then handing over to Sales, Company C wanted to bring individuals from Marketing, Design Engineering, Manufacturing Engineering, Production, Sales and Logistics into a product team with total authority for product functionality, build and cost. However this Concurrent Engineering concept soon ran into problems because many people either didn't want to work with people from other departments, or didn't know how to. On the first Concurrent Engineering projects, when there was a lot of management attention, the results were promising. Once management focus moved to the next improvement initiative, performance dropped back to previous levels.

4.4 Current Situation

In spite of all the effort that top management is putting into the improvement process, the engineering managers around the world feel that the real problem is that no clear direction is being set. There are countless exhortations to work harder, to schedule better and to "do your best". One top manager even spread the message that people weren't expected to work the 40 h in their job contract, but to do 60 h a week. This went down badly with teams trying to introduce Just-In-Time and reduce cycle times. They preached that wasted effort is the cause of most problems in business processes, and that if it could be removed, things would get done faster yet with less effort. They counselled that rather than working longer hours, people should work smarter. The 60 h week was seen as confirmation that top management had lost control. It was yet another unrealistic target that would distort their efforts to improve the process. Unrealistic targets were often proposed by top management or the sales force, and this gave the impression that development was always late, when it was actually on time compared to its own targets.

An on-going problem is that far too many projects are handled at the same time by a few people, and a lot of time is lost as the effort is switched from one project to another. One year, top management came up with the idea of using a scheduling system on a PC to enable engineers to do more work. Engineering management had explained that scheduling wasn't the problem, but were forced to implement this idea from above. In the meantime, top management still holds projects up by forcing everyone to wait for management decisions that are only made at monthly management meetings.

Engineering management is aware that new product development performance could be better, but they aren't quite sure what to do about it. They know for example that most of the time, 80% of a new product already exists in other products, but don't know how to access the information or how to reuse it.

Top management is tired by the Engineering organisation's unquenchable desire for high-risk, high development cost projects. The culture of the Engineering organisation doesn't seem to tie in with the rest of the company. The engineers are individualistic and don't even seem to understand the benefits of working in teams. They rarely talk to their colleagues in manufacturing. Top management has tried for a long time to communicate with the engineers, but has given up since the engineers never seem to say anything in management meetings. At times, top management has seriously discussed outsourcing the entire new product development process, and focusing on financing, production and marketing.

4.5 What Comes Next?

In many conglomerates and multinational companies, the responsibility for Engineering is divided among the managers of individual divisions and companies. The reason for this is to let them best serve their internal customers in these divisions and companies. A side effect can be the weakening of the corporate focus on Engineering. This seems to be the case with Company C. There is nobody representing the interests of Engineering at the corporate level. As a result, Engineering managers around the world are continually buffeted by new corporate initiatives that have unforeseen effects on Engineering. They feel no clear direction is being set.

4.6 Introducing PDM

When the question of PDM came up, the COO assigned its implementation to the corporate IS organisation. He said that it should be implemented by a professional IS organisation, not amateurs.

The IS organisation carried out a review and proposed implementing PDM to achieve the following seven benefits:

- a common IS infrastructure
- standard platforms, OS, DBMS, GUI, network
- enterprise vaulting
- information factory
- information accessibility
- workflow management
- information logistics

When the Engineering organisation heard about this they said “We don’t want that. No way. It just shows again that IS doesn’t understand our business—it’s lost in its bits and bytes. We want PDM to manage our product data and structures. We tried workflow once and it doesn’t work in our environment. And we know that training our people will bring many more benefits than just buying more systems”.

There was head-to-head confrontation for several months until the COO decided to get an outside expert to review the situation.

A team was set up representing people from all areas of the company. The team worked with the expert to understand where the opportunities were. They interviewed a lot of people in the company, from the president down, to find out what was needed. It soon became clear that, among the barriers to success were unintegrated systems, departmental mindsets, lack of customer participation, projects running across country boundaries, and lack of feedback from the field.

The team produced a short report in which they showed that in their vision, PDM would be the information backbone for the corporation’s main business of international projects that typically ran for several years. It would replace several legacy systems. It would be a central repository for data. Computer systems from different departments would be integrated to the backbone. People from different parts of the organisation would share information through the PDM system. Everyone would have easy access to up-to-date information. For example, field problem reports would be fed into the system and would be immediately available to developers of new products. Project managers would have access to up-to-date financial and technical status information. Even customers and suppliers would have access to the system. PDM would help reduce time-to-market, reduce costs, support compliance with ISO 9000, reduce waste in the process and reduce customer response time.

The report was circulated among the top management team. One day, the COO asked what the Corporate IS VP thought of it. He was pleased to hear that Corporate IS approved, saw it as a confirmation of their ‘7 benefit’ approach and was just about to start the implementation. The following day, he asked the Engineering VP what he thought of the report. The Engineering VP said it was exactly what Engineering had been asking for since the beginning, would save them a lot of time and money, and would help them overcome a lot of the criticisms that Engineering received from other departments.

5 An Aerospace Industry Company

5.1 Background

Company D is a medium-sized corporation with interests in several segments of the aerospace market. Sometimes it plays a prime contractor role, sometimes it provides assemblies for other manufacturers.

In its civil markets, Company D is faced by issues such as global competition and the recent recession which has had a devastating effect with airlines cancelling orders and holding on to their old planes. In military markets, the main problem has been the end of the Cold War, and the resulting changes in defence spending. Across all markets, the electronics component of products is growing rapidly. The general slow-down in business has led to downsizing and corporate re-organisation.

5.2 Objectives

The prime short-term objective is to ensure survival over the next few years. These are expected to be very difficult. Longer-term objectives are to increase the capability to develop new products and services—possibly by increased joint venturing with companies on other continents, and to find new ways to make and deliver products and services to the customer faster than competitors. In the short term, cost reduction is all-important, but in the longer term, time, not cost, will be the key competitive parameter.

5.3 The Response to Change

Company D has made tremendous efforts to change. It has been through extensive corporate restructuring activities and has divested some operations. It has started joint ventures and new relationships with new partners. It has tried many new strategies, and is torn between the benefits of focused factory, low-cost, niche, agile, and high-velocity manufacturing. As one of the leading companies in its various markets, it is generally one of the first to develop and use new techniques. It has all the latest CAD, CAE, CAM, aerodynamic and structural analysis systems. It has invested a lot in new plants, introducing new techniques wherever possible. It has invested heavily in TQM, CIM and time-based management. It was heavily involved in CALS activities, was one of the first companies to get involved in GATEC (Government Acquisition Through Electronic Commerce) and CITIS (Contractor Integrated Technical Information Service). It was also a leader in IETMs (Interactive Electronic Technical Manuals).

In spite of all the investment, there has not been much change in performance. Although performance has improved a little, the results are nowhere near as good as expected. Competitors are known to be making much faster progress. Company D heard that Boeing worked really closely with its customers when developing the 777. Also, when it put together the body, wing and tail sections of the 777 for the first time, they actually fit—which says a lot for the use of CAD. On a 737 redesign it used 3D techniques to cut design time for one activity in half. Someone heard of the development cycle of a major 767 derivative being cut from 40 to 30 months. At the P&WC subsidiary of United Technologies Corporation, development time for a new engine was slashed from five years to less than three. The Boeing F/A-18E/F used 42% less parts than earlier models from the same family, yet was 25% larger.

Company D has been evaluating its efforts, which have not been so successful, and trying to work out where it went wrong. Looking back it now recognises that the company focus was too far from Engineering. When business conditions were good, top management attention was elsewhere, for example, on Mergers and Acquisitions. Without focus and pressure from top management, Engineering, like other functions, felt no pressure to significantly improve performance. It over-engineered many of the products. Then came the end of the Cold War and the recession, and top management has been so worried about not getting enough work, and wondering which operations to sell off and which to buy from other companies in a similar position, there's been no time to think about productivity improvement.

Without an overall focus, many of the improvement programs that were started have developed a life of their own, and instead of helping to reduce costs, have only increased them. For example, a lot of money was spent on customising the CAD system. This should have been left to the system vendor. Eventually the company decided to change to a system from another vendor, so most of the customising effort was wasted. A lot of money was spent on developing an in-house Product Data Management system. Again this appears to be something that should have been left to the vendor community. The company's mission is to develop aerospace products and services, not to develop software to support product development.

The company has found it very difficult to improve performance within its departmental organisation. Performance improvements are implemented on a departmental basis. Each department is responsible for its own performance, so it does what it can to improve itself. The result is generally invisible. Even if Marketing could identify which potential customers were going to buy which products on a given day, it wouldn't make much difference. By the time that Engineering has deformed the product specifications, and Manufacturing has made whatever adjustments it deems necessary, and Finance has pushed the price up, the potential customer will already have bought the competitor's product. Even if Engineering buys the most modern

CAD technology, it's not going to make much difference. Designing products that customers don't want with a modern CAD system isn't any better than designing products that customers don't want with an old CAD system. More unwanted designs will be produced, creating even more pressure on Manufacturing, and distorting the production plans. Manufacturing's new ERP system would probably be able to handle all the new designs, if only someone knew how it worked with Engineering's new CAD system.

During piecemeal implementation, the departments don't work together. Each does its own thing. The resulting sub-optimisation has little overall effect. Activities involving more than one department are not considered for improvement as it would be impossible to get everyone to agree, so activities like engineering change which involve 16 departments, more than 50 documents, and a 9-month cycle time are not considered for improvement.

5.4 Current Situation

Top management is concerned that Engineering still seems unable to keep to plan. No sooner is a plan in place than Engineering wants to change it. The different engineering departments seem unable to work together, reports from different departments are often inconsistent, and even when they address the same subject, different departments come up with different answers. There appears to be continual inter-departmental strife, with departments not working together to solve problems. Each has to solve problems from its own viewpoint. They don't share important data (e.g., on customer requirements and competitors) between departments, and don't share reasons for engineering choices with manufacturing engineers.

The engineering function has become very expensive to run, and a major customer for capital investment. In view of its cost, top management is pursuing options to spin it off as a separate company, or to sell it to a competitor. Any increase in its efficiency will have a positive effect on its chances of survival. However, much of the engineering process seems uncontrollable, and engineering management finds it difficult to get productivity up.

Top management has also been looking at setting up an organisation along the lines of Lockheed Martin's Skunk Works or Boeing Phantom Works.

Engineering managers recognise they have frequently missed important deadlines and that some of the big projects have taken too long, for example the one that came in 9 years late. They realise that marketing, engineering and manufacturing processes are changing fast under the influence of new techniques and technologies. They know that management processes and organisational structures must change correspondingly. They read about other companies using new approaches to reduce product development time, to reduce batch sizes, to increase quality, and to improve overall productivity of the workforce. When they look at the way their own company is behaving, they see nothing likely to help the company gain or maintain a competitive advantage. They feel they're missing out—but don't know what to do about it.

In spite of top management effort in restructuring, re-engineering and other improvement initiatives, engineering managers feel the real problems are at top management level. There say there are too many people who were once working in government bureaucracies, too many corporate staffers, too many levels of middle managers. They recount countless horror stories highlighting top management's failure to understand the specifics of the business. Although theirs is essentially a long-term business, they say that management is primarily short-term profits-oriented, and unable to define or stick with a long-term view. Because they can't trust top management, they say they always add 15% to cost estimates, so that when management makes across-the-board cuts they will be able to absorb the cuts and continue with their programs.

5.5 What Comes Next?

Although the company may be on the way to solving some of its major organisational problems, the engineering departments mustn't sit back and hope for the best. They should start meeting and working together. The first step would be to agree a Vision of the Engineering environment—not an easy task for people who have problems working together, but it will get them talking and working towards a common objective.

In order to start putting things on the right path for the next decade, top management recently instigated and carried out an extensive review of business and manufacturing processes with the aim of protecting current product positioning and revenue streams, and developing new markets.

It was found that the single biggest cost driver was configuration management and control. The review also showed up many areas where improvements could contribute significantly to lowering costs, improving quality and reducing cycle times. Enterprise-wide reengineering was identified as the key improvement activity, along with the introduction of a new ERP system and a sales configurator.

5.6 Introducing PDM

As a result of the review it was decided that PDM was a strategic technology for the corporation's future, and should be implemented with the objectives of:

- supporting digital design
- managing configurations
- supporting reengineering
- providing an enterprise-wide information vault

- enabling global product development collaboration
- improving customer service world-wide
- speeding up change management
- facilitating regulatory compliance

It is planned that the system will manage the common repository of product data for the full spectrum of business processes, including pre- and post-sales support. The ultimate objective of the reengineering initiative is to double revenues over the next few years, and the corporation's first step towards this goal is to be able to respond more quickly to its customers.

To this end, new information systems will be developed to leverage the PDM system's capabilities. One of these will enable all sales, marketing, and support personnel to access, in less than sixty seconds, any product literature, such as drawings, data sheets and specifications, produced by the company, or any of its predecessors, at any time in their long history.

Another new-generation application will use the PDM system's change management functionality to identify parts needed for repairs, price them, and locate them, wherever they may be in the world, in less than sixty seconds.

A new phase/gate system will be introduced to improve project management and execution.

The CEO claims that the enterprise-wide reengineering initiative has the highest level of corporate priority. He expects it to have a massive impact on reducing costs, cycle times and defects, while increasing customer satisfaction and corporate profitability.

The Engineering VP is a leading supporter of the improvement initiative—which he characterises as reengineering, process-based, oriented to cross-functional teaming, and intended to change the whole logistics of product information—resulting in pulling product information rather than pushing it.

He envisions a future development and maintenance environment in which there will be instantaneous flow and availability of accurate and complete engineering information, from initial customer contact through to product delivery and superb lifetime support.

He expects that PDM will enable the reengineering activity to meet its targets of a 20% reduction in production costs, a 50% reduction in time-to-market, and 100% customer satisfaction. He also expects that it will greatly increase the productivity of Product Engineering, and ensure its future within the corporation.

6 Summary

Although the four companies are in very different circumstances, there is a lot of similarity between them. Companies like these feel they are reaching the crunch. They are caught between rapidly evolving technology, demanding customers and aggressive competitors.

Technology issues they have to face include the effect of the increasing amount of electronics in products, the possibilities offered by widespread communication networks, and the rapidly decreasing cost of computer power. Taken with customer demands and pressure from competitors, these imply more frequent design and volume changes, smaller volumes, and much more responsive management. Other issues leading to change include the rapidly changing world business environment, increasing globalisation and global competition, new technologies, deregulation, privatisation, environmental requirements, and consumer resistance to price increases.

All of these forces point towards reduced product development costs, reduced product costs, reduced product development cycle times, improved quality and improved asset utilisation.

Although managers often feel that their company is unique because the product they make is different from other companies' products, the four examples show that there are many similarities between companies, and when it comes to improving performance there are many commonalities.

Although there may be, as the examples indicate, many problems along the way, the existence of successful, world-class companies shows that it is possible to make progress. There are many technologies and techniques available. It is not the fault of the technologies that sometimes they don't appear to work, because in other circumstances they do work. Those who have succeeded in making techniques and technologies work have discovered that the best results occur when information systems are used to support a more effective process.

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Reference

1. Stark J (2004) Product lifecycle management: 21st century paradigm for product realisation. Springer, London. ISBN 978-1-85233-810-7

Case Study: GAC

John Stark

Abstract This case study describes the situation at GAC, a Tier 2 manufacturer of assemblies and components for the automotive sector. Product development timelines at GAC were too long, and it was faced with project overrun penalties. Executives launched many improvement initiatives in their own parts of the company. However, in spite of the many initiatives, problems with products continued and showed no sign of abating. As a result, the CEO called for a company-wide product development audit to identify problem areas, strengths and weaknesses. The audit would be one of the inputs for the development of action plans.

Keywords PLM · Product lifecycle management · PLM status review · PLM audit

1 Introduction

This case study, was originally published in 2007 [1]. It shows that while much has changed in the intervening years, much has stayed the same. More than ten years later, many of the lessons learned are still relevant.

2 Background

Global Auto Components (GAC) is a leading Tier 2 manufacturer of assemblies and components for the automotive sector. Its customers include OEMs and independent specialists, and it also supplies the replacement market. In 2005, world-wide sales were about $3 billion, the company operated in about 50 countries, the workforce numbered about 10,000, there were nearly 1000 people in R&D, and R&D spend was about 5% of sales.

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In 2003 GAC found product development timelines were too long. GAC was faced with project overrun penalties and failed to respond to important proposals. It missed the window of opportunity on new products because it could not get into the market before the competition.

Forward planning was difficult with uncertainties in sales estimates, competitors in low-cost countries producing copies, and cost pressures and changes coming from OEMs. It was expected that, in the future, there would be a need for a greater proportion of software and electronics, but these were areas in which GAC had little experience. Increasingly there was overlap between projects, and customers were mixing components together more and more, and a need was seen for a more systems engineering approach to projects in future. This was also an area in which GAC had little experience.

Top executives were highly stressed, launched many improvement initiatives in their own parts of the organisation, and blamed each other's functional areas for the problems. Marketing called for more Customer Focus, R&D managers introduced new technologies, and business planners examined opportunities for further global expansion. Acquisition, restructuring and cost-reduction projects were running in different countries and for different product families.

In spite of the many improvement initiatives, problems with products continued and showed no sign of abating. As a result, the CEO decided to call in consultants to conduct a company-wide product development audit, to identify problem areas, strengths and weaknesses, and to develop resulting action plans.

3 Findings

To understand fully what was happening, the consultants conducted interviews with a range of people from each function, and the following selection of comments was included (anonymously) in the audit report to give the CEO and other readers a feeling for the actual situation.

3.1 Feedback from Top Management

> "We don't have a clear overview of where we are with our product development projects."
>
> "R&D doesn't understand that we have to do business, not just play at making new toys."
>
> "We agree a budget to develop a product, R&D develops it, then they ask for another budget so they can redevelop it and remove their mistakes."
>
> "Culturally, this company was historically focused on individual products, not on the overall portfolio of products."
>
> "We need to get Sales, R&D and the plants to plan together for new products."

"We have sales figures for our 65,000 components. I want to see how those sales figures will be affected by new products we're bringing to market. We've spent millions on new products that bring less revenue than the products they replace. We destroy our own value."

"The Board needs a clear overview of project status at every monthly meeting."

3.2 Feedback from Marketing

"With a huge global market, we have countless opportunities, and many ideas for innovative new products and services, but R&D is unable to deliver."

"R&D reinvents everything. We need a VP of R&D who enforces standardisation and reuse of existing components."

"Customers are asking us to work with their processes, applications and documents. That's great. It gives us insight into their plans. That gives us a head start. The problem is that our processes and systems are not set up to take advantage of this information."

"The Production VP tries to block new product projects because bringing in a new product reduces plant productivity."

3.3 Feedback from Product Development Project Managers

"They keep changing the priorities of our projects, so as soon as we start making progress with one project, we have to switch to another one they say is more important. A few weeks later they say another project is even more important, so then we have to switch to that one. It's inefficient use of resources and frustrating."

"I used to work for one of our competitors. A friend there told me they now have all their product development project information on the Web so everyone knows what's going on. They have a standard cockpit chart for each project."

"I don't have a tool to manage my projects effectively."

"There are no guidelines for Risk Management."

3.4 Feedback from Corporate Planning

"We haven't grown our resources to meet the growth in company size. Since I've been here, the company has grown 500% but the product portfolio group is still the same size. If we had more people we could get more data about our products in the field and use it to help plan projects for replacement parts."

"Data checking takes about 70% of my time."

"In our planning process we don't have a way to value the potential reuse of a new component in future products."

“Different project managers provide different data about their projects. That makes it difficult to compare projects and to roll up data.”

“Our current ERP system doesn’t take account of the manufacturing location. When it was built we only had one location, now we have five, and the costs for each are different.”

“Often a project for a new product implies removal of an old product from the market, but there isn’t a process to do this, so the old product stays on the market. Some customers continue to buy the old product, which reduces sales of the new product.”

“We don’t do audits of projects after they finish. It would be good to look back at a project five years after it finishes to see what we can learn from how it ran, and how the product has performed in the market.”

“With all the cost pressures these days we don’t have people looking to see what we will need in 10 or 15 years.”

“Ten percent of our products bring 90% of our revenues. I’d like to find a way to avoid projects that lead to products that don’t make money.”

“The data we have about products for OEMs is about 10 times better than products for the after market. That makes it difficult to apply the same value analysis techniques.”

“There are too many projects in the company, many are never completely finished.”

3.5 Feedback from R&D

“Marketing people don’t realise how much effort is required even for a minor upgrade for their favourite customer. And they don’t understand all the work they make when they keep on asking for changes after we’ve started the projects. Why don’t they do their homework before starting the project? And besides, we have almost no time to do real work. Anyone above a trainee engineer spends most of their time in meetings and producing paper. I waste hours each week on tasks that are duplicate work and rework.”

“We have trouble working with the guys in Europe on global projects. They have a different project management system and work with different milestones. And they think differently.”

“I don’t think anyone here has been trained on MS Project. I use it my way. It’s a real headache to work with people who use it differently.”

“The change projects aren’t prioritised, so we just do them in the order they come in.”

“Purchasing looks for cost savings with new suppliers, but doesn’t realise that the cost of qualifying a new supplier is more than the cost savings they offer.”

“The Sales organisation needs to get its act together. Recently we developed a great new product but the Sales people forgot to put it in the catalogue so it was never sold.”

“A good product development process, built into software with cockpit charts, guidelines and template documents, would be very helpful.”

“Marketing does portfolio management in the ERP system. I don’t know how it works. We don’t have access. We manage our products in Excel.”

“Each year, a new corporate plan is announced and the actions in it usually impact our R&D projects in several ways – both intended and unintended. I guess someone up there is doing their best for the company, but they don’t seem to realise what the real situation is down here.”

3.6 Feedback from Operations

> "R&D's tests for new products keep interfering with our plant, costing us downtime for revenue-generating production."
>
> "We have capacity problems when R&D dumps a big batch of changes to existing products on us."
>
> "I get so many emails about changes to components and products that I don't what to do with them. There are so many that I don't know which ones are important."

3.7 Feedback from Communications and Documentation

> "No-one tells us anything. We don't know what's going on. We just do whatever someone asks us to do, and let the other work wait."

3.8 Feedback from Special Projects

> "We're outside the main company organisation and get involved say if a customer in Indonesia or Argentina wants a small batch of products based on an old design from one of our plants somewhere in the world. We have about 200 people worldwide. We don't do new products. We just make changes to existing products. Our sales figures are rolled up in the corporate ERP system, but on the technical side the situation is different in different countries. We all manage our own data and documentation. Our customers usually want a lot of documentation. The people in corporate documentation don't have time for us, so we do it ourselves. There's no overall management of our projects."

The above "Voice of the Employee" comments gave top executives a qualitative feeling for the issues the company was facing. This was reinforced by data presented on two slides:

- Seven different project management systems in use across the company
- Three different definitions of the product development process
- Five different applications for Portfolio Management
- Ten different formats for project management data
- Five different ways of measuring the length of a project
- Four different ways of quantifying manpower resources
- Many different layouts for documents such as the Project Start template
- No formal documented Portfolio Management process in the company
- No formal documented Pipeline Management process in the company
- No global capacity planning management
- No overall inventory of development projects
- No overall inventory of development skills
- At least 50 different report formats for product development projects
- Five major ongoing corporate improvement projects

- About 20 ongoing departmental improvement projects
- No differentiation between small and large projects, or between projects for large and small customers
- No guidelines for Portfolio Management
- R&D handling over 4000 projects world-wide, an average of more than four per person.

4 Action

The CEO decided that a corporate, cross-functional improvement project was needed to address the problems.

A five-year plan for an initiative called CHAIFA (Commonise, Harmonise, Align, Integrate, Fill, Add) was prepared. The objective was to have a common approach wherever possible across the company. Achieving commonality had the highest priority. Among the aims of CHAIFA:

- A common project management approach across the company.
- All development projects would be included in a common portfolio, which would be managed with a common enterprise-wide process supported by a common enterprise-wide information system with a single database.
- In the first 12 months of CHAIFA, the number of projects was to be reduced to 3000. It was to be further reduced to 2000 in the following 12 months.

Targets for the first year of CHAIFA included:

- Make an inventory of all product development projects
- Reduce the number of projects by 25%
- Make an inventory of the skills of all product developers
- Define the common processes
- Identify IS applications to support a common global approach
- Create a training plan for R&D.

5 Results

The CEO was pleased with the results of the company-wide product development audit. The audit had identified and described problem areas, strengths and weaknesses, and provided a basis for these to be discussed in a positive environment in which the focus was on improvement. It had led to company-wide agreement on a subject that had been a source of headaches for years. The audit results had led to an action plan that was widely supported.

In the first 12 months, an inventory of R&D projects was created, and the number of projects reduced to less than 3000.

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Reference

1. Stark J (2007) Global product: strategy. In: Product lifecycle management and the billion customer question. Springer, London. ISBN 978-1-84628-914-9