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PLM optimization with cooperation of PMS in production stage

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ABSTRACT

Purpose: To present a short overview of PLM and its directions including evolution, different phases of PLM and Closed-loop PLM. To describe a new approach in order to improve the closed-loop lifecycle by using production monitoring systems at an early stage of the lifecycle. Monitoring of products in their early life stages in production processes and to use this information for the improvement of the product development and implementation process.

Design/methodology/approach: Implementation of a production monitoring system plays an important role in our approach. Sensors that are part of a production monitoring system are sending valuable data from the production to the PLM database where it can be used for production development and analysis.

Findings: It is demonstrated that installation of the production monitoring system improved product lifecycle at the beginning of their lifecycle. Feedback from production monitoring systems helps to make better conclusions and quicker decisions in the development phase and gives real-time input to the analysis process.

Research limitations/implications: Production monitoring systems improve product lifecycle management in the early stages but do not support the product directly in the other life stages. Decisions can be made only based on this information.

Practical implications: Information gathered by production monitoring systems could help to modify the production development and implementation process . Also afterwards the information can be used to identify deviations and mistakes. All this is necessary to fill the gaps in product lifecycle.

Originality/value: The proposed installation of production monitoring systems improves new data income to the system that provides better decision making opportunities. Based on this real-time information, it is easier to make changes in the product development phases.

Keywords: Product Lifecycle Management (PLM); EOL; MOL; Closed-loop PLM; Production Monitoring Systems (PMS)

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Today's competitive manufacturing landscape requires that companies should be more flexible, innovative and responsive to their customers' needs. Customers can choose from a wide range of products and services. If small and medium-sized enterprises (SMEs) want to gain competitive advantages, they should replace their old traditional business models to new ones to facilitate collaboration with suppliers and customers [1,2,3]. It is necessary to update and improve their product development and production processes for maintaining their place in the market [4,5].

A common objective for industrial enterprises is to increase the overall production reliability. It is necessary to maximize output with current resources [6] and to satisfy customer expectations and at the same time gain profits and fulfil quality requirements at a good price [7]. Product Lifecycle Management (PLM) systems enable enterprises to satisfy the requirements. PLM is a huge bundle of complex IT tools and applications which support digital design and manufacturing practices in several ways [8]. It is a holistic business concept developed to manage a product and its lifecycle including items, documents and BOM`s. Also, it supports analysis results, test specifications, environmental component information, quality standards, engineering requirements, changing orders, manufacturing procedures, product performance information, component suppliers. Modern PLM system capabilities include workflow, program management, and project control features that standardize, automate and speed up product management operations [9].

New trends in PLM are closed-loop lifecycle management meaning that the whole lifecycle is controlled during its existence, from cradle to grave, i.e. the control is held from the beginning to the end of the lifecycle.

This paper has two main objectives. Firstly, it provides a short overview of PLM and its directions including evolution, different phases of PLM and Closed-loop PLM. Secondly, it introduces an approach how to improve closed-loop lifecycle by using sensors in early stage of its lifecycle. The aim is to monitor products in their early life stages in the production process and to use this information to improve the development and implementation in the production process. Based on the data gathered from the sensors placed on the processing machine, decisions can be made that support product development and retail information of the processes to the system. Information movement is managed between different stages of the lifecycle.

2. The evolution of PLM

Many large corporations, often the leaders in the engineering-manufacturing industry, found their efficiency severely downgraded by paper-based systems. Some attempted to develop their own data management solutions.

When engineering design entered a new era in the early 1980s software companies realized the potential market of efficient data management methodologies and began to develop the first generation commercial PDM (Product Data Management) systems. Developers were already involved in CAD (Computer Aided Design)/ CAM (Computer Aided Manufacturing) / CAE (Computer Aided Engineering) software market [10].

First PDM systems were used to control information, files, documents, work processes required for design, support and maintenance of products. Information included geometry, engineering drawings, project plans, part files, assembly diagrams, product specification, analysis results, correspondence, and bill of material (BOM) [10]. Further PDM was supplemented with new functionalities like change management, workflow management and project management that promised concurrent engineering and streamlined product development processes within the enterprise. First generation PDM systems were effective in the engineering domain but failed in non-engineering areas in enterprises like sales, marketing, supply chain management. Two biggest constraints in the early PDM systems were: systems limitation to the engineering information like geometry and BOM that came from the limited scope working with systems without engineering/technical background was not easy [11].

In the 1990s PDM vendors began offering web-based PDM systems the advantages of which were user-friendliness because web-based PDM systems required minimal training in comparison to other systems. Also, the cost of system implementation was reduced because inexpensive web browsers continued to expand to greater accessibility and applicability to companies personnel. Thanks to web browsers there was no need to install and maintain specialized software on each machine. It enabled effective linking to the supply chain. Web-based PDM systems allowed easy sharing of vital information with their suppliers and partners. Effective linking to geographically diverse organizations was ensured through web-based PDM systems. This helped geographically diverse teams to simultaneously work on the same project. Virtual organization made it possible to create temporary unions of companies that possess expertise in a specific field and are gathered for a particular project. Drawbacks included data transfer speed. At that time local area networks (LAN) and wide area networks (WAN) were not comparable. There was growing concern about security issues as the information flow between a company and its supply chain increased [11].

The web-enabled PDM front-end brought also more powerful and user friendly visualization tools to broaden the user base. Concurrent to PDM systems development, such enterprise applications as Enterprise Resource Planning (ERP), Customer Relationship Management (CRM) and Supply Chain Management (SCM) were introduced. They all focussed on one Product Lifecycle phase and are dependent on product information. But the first PDM was unable to provide EPR/CRM/SCM with such information because the systems were created to handle engineering data [10].

First, three kinds of implementation methods were used to integrate PDM systems to ERP/ MRP (Material Resource Planning). The most popular method was the product-oriented integration. This meant that the main database was ERP/MRP. PDM was responsible for sending the related information about the products, such as the configuration, usage quantity and time. Another method was project-oriented integration where PDM was the main database. The role of ERP/MRP was to support a PDM system with required information like existing product configuration. The final integration method was to treat both the PDM and the ERP/MRP database as equal. This was the most appropriate method suitable for product and project oriented environment. This meant that most of data had to be duplicated [12].

At the end of the 1990s the concept of PLM was devised. The aim was to move beyond engineering aspects of a product and to provide one tool across extended enterprise, from cradle to grave. PLM seeks to extend the reach of PDM from design and manufacturing to marketing, sales support, after-sales support and subcontracting. PLM tries to fill the gap between enterprise business processes and product development processes. PLM, at its core, is a process which supports capture, organization and reuse of knowledge throughout the product lifecycle [11].

3. Different directions of PLM

In the 1980s different PDM systems started to develop in different directions. PLM systems, advanced followers of PDM systems, developed almost in the same direction. The direction was mainly based on a developer`s background whether the developer was with engineering or economic background.

Product Lifecycle management has two directions. The first direction is ERP based PLM solution that is based on Enterprise Management, the predecessor of MRP and ERP, CRM and SCM. In this case PLM serves as a decision support tool [13]. Here all the information is coming from the ERP system and it is pumped to PLM to ease data management.

The most important modules that an ERP system supports are; sales, marketing and distribution, enterprise solution, production planning, quality management, materials management, cost control, project management financials, and plant maintenance [14].

The other direction is CAD based PLM solution. Here the whole of product information is managed through the entire lifecycle. In this case systems are integrated among CAD, CAM and PDM [13]. All the information comes to PLM from different computer aided systems and is stored in PDM. From the PDM system it is possible to send it forward to the ERP system. In this case computer-based methods are used to support the engineering decision making process [15].

4. Different phases of PLM

Product Lifecycle Management is divided into five phases. In each of those phases the product is in a different stage. In the imagining phase the product is on the idea level in people's minds. During the definition phase, an idea is turned into a detailed description. Realization phase ends with the products existence in its final form. This is a produced product that can be used by a customer. During the use/support phase products are being used by the customer. Supporting means that the product is supported by servicing. Finally, the product reaches a phase where it is no longer useful. It is retired by company and disposed by costumer [16].

The phase of Product Lifecycle Management is divided into three main categories (Table 1) [16]. Beginning of Life (BOL) contains information about the early stages of a product. Information about the product development and the idea is stored. In this phase it is made sure that the idea of the product is not lost or misunderstood. A product is defined and it is identified that the developed product meets its objectives. It also includes the prototyping phase. In the realization phase all the information necessary for mass production is generated and stalled. All this is done in the design and manufacturing company and information is stored to the PLM database, the ERP system or to some other data storage program.

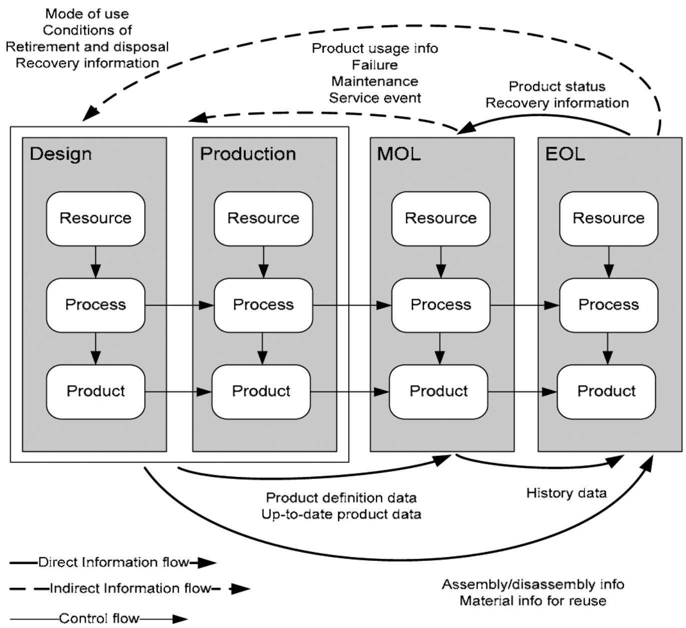

Fig. 1. Information flow between the different stages of PLM

Table 1.
PLM categories

Beginning of Life	Middle of Life	End of Life
Imagine Define Realise	Support Maintain Use	Retire Dispose

Middle of Life (MOL) contains information about the use of the product. All instructions and guides how to use the product are coming from BOL. Instructions and guides are written by the design or manufacturing company to users. It also contains information about maintenance, including instructions of who to address when the product is broken and who will provide the maintenance service. It provides extra support in the case of major changes, for instance if some laws have changed or something needs to be rearranged. End of Life (EOL) contains information about the time when a product is retired, i.e. the product is not needed any more by the customer. Information and action is included how to retire the product in this phase: dismantling information, how to demolish how to handle demolished parts, what will go to re-use, remanufacturing, recycling, energy recovery or landfill.

5. Closed-loop PLM

A Major problem today is how to close the loops in Product Lifecycle Management between different stages. The information flow between design and production is quite complete. Supported by different systems like CAD and CAM, PDM and knowledge management systems are effectively and efficiently used in industry and through their influence by their suppliers. Usually the first two steps are completed in the same company or the process is controlled by a certain company. Information flow from manufacturing to use and support (MOL) can be also be achieved because all the product information is available and defined in the company by that time. From Middle of Life to End of Life the information flow is more or less complete. Usually information flow breaks down after the delivery of the product to the customer. There is no feedback of product-related information such as product usage data, disposal conditions from MOL and EOL to BOL. Lifecycle activities of MOL and EOL phases have limited visibility of the product related information [17,18].

Closing the loops in PLM means that information is taken from different stages of the product. Compared with traditional PLM, the closed-loop PLM focuses on the complete lifecycle of a product with more emphasis on tracking and managing of information of the whole product lifecycle and possible feedback of information to each product lifecycle phase. This also means sending information from the current stage to the next stage (see Fig. 1) [18]. Information such as BOM, product definition data, updated product data is moving from the Beginning of Life to the Middle of Life. From the Middle of Life the same information moves forward to the End of Life adding information about the history of product usage. Information about the assembly and reuse moves directly from the Beginning of Life to the End of Life. Thorough control and distribution of information between different lifecycle agents and phases is the underlying goal for the PLM approach [19].

Information movement in the other direction is also very important, i.e. feedback that is coming from the following product stage to the previous one. Information about the mode of use, condition of retirement, disposal and recovery information comes from the End of Life to the Beginning of life. Data of product usage, maintenance, failure and service events move from the Middle of Life to the Beginning of Life.

Rapid development of the Internet and wireless mobile telecommunication technologies have changed the product lifecycle, making information visible over the whole product lifecycle. The core element of these technologies is the product embedded information device (PEID) technology. Thanks to this technology product lifecycle data can be tracked and traced in a real time way over the product lifecycle by embedding an information device to a product itself. PEID can gather, process and store data into itself. Data gathering from products through PLM agents and storing them to its own memory after suitable processing is completed. The gathering and storing can be a request-driven or an event-driven mechanism [18].

The whole product lifecycle is visible and controllable by tracking and tracing the product information activities and information with PEIDs. It allows all actors of the whole lifecycle to access, manage and control product-related information in particular after the product delivery to the customer and up to its final destiny, without temporal and spatial constraints. The information is returned to the designers and production engineers so that the information flow can be closed over the whole lifecycle. The closed-loop PLM can support the decision making of several operational problems over the whole product lifecycle by real-time gathering and analyzing of product lifecycle information providing new opportunities at strategic and operative levels [18].

Operations in the closed-loop PLM are based on interactions among the PLM agent, the PLM system and a product (Fig. 2). The PLM agent gathers the product lifecycle data from the PEID of each product using mobile devices, personal digital assistant (PDA) or a fixed reader and a built in antenna sending gathered information at each site like production lines, disposal plants, retailers to the PLM system. The PLM knowledge agent in the PLM system generates new information or tacit knowledge that cannot be automatically captured based on the gathered information. After storing the information to the PLM system it provides necessary information or knowledge through the information network to the requesting personnel or organization. The PLM agent can also update the information of PEIDs [18]. PEIDs are mostly based on the radio frequency identification (RFID). There are standards that can support either RFID based identification or sensor systems, however, there are gaps remaining for sensor data integration and for the data analysis and their integration in the product development and PLM solutions [20].

Another opportunity to get information is directly from the customers or service providers. Results show that between 50 and 95% of information and knowledge exchange is verbal [17]. A new approach is to integrate new development partners and service partners as well as customers within the early stage of product lifecycle. In the Customer Centric PLM project, PLM models and methods are extended in order to integrate customer feedback into the product development process [21]. Customers or maintenance providers provide feedback through certain programs and get information from BOL through other systems like the International Material Data system (IMDS) and the International Dismantling Information System (IDIS).

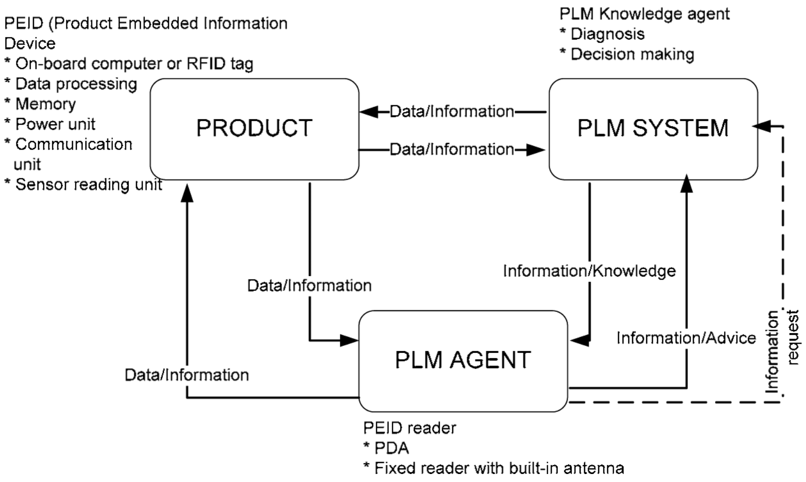

Fig. 2. Concept of closed-loop PLM

An important part of the PLM and closed-loop is the knowledge, i.e. a knowhow of using the data acquired in work activities and making various decisions. Knowledge management is an important subsystem of management in an enterprise where relevant data associated with technological expertise is stored [22,23].

6. PLM cooperation with PMS

The task of production monitoring systems (PMSs) is to collect and distribute real time data of events in the shop floor. At the same time, collected data should support the PLM system with historic knowledge regarding the state of machinery, correctness of assembly operations, etc. during the production of a certain product. Stored data may help to identify the problem in the production process if the product offers the desired result or to analyse the customer claim regarding the quality of the product.

Harmonisation of different systems is a highly challenging goal and the number of separated systems should be maximally decreased.

Today companies demand real-time communication that flows automatically between the information systems and departments of the company. But in most cases, PMS is designed as a separate module with the possibility to integrate it to ERP through the manufacturing execution system (MES) that is an intermediate level of information transfer between the business and plant floor control systems. The benefit of installing an efficient PMS is the immediate access to all required or production related information by the relevant personnel [24].

It is evident that the amount of information collected from control systems increases tremendously with the degree of increased automation on the shop floor. Manufacturing systems grow because of the need for more complex processes to meet the needs of increased product functionality [25]. It means that PMS has to be connected to more equipment and process more data at the same time. That is why automatic recording should be preferably used by connection of sensors to the machines. But due to the high deployment cost of automated manufacturing systems, machines are not integrated on most shop floors [26]. So, production industry still gathers most of the data in the shop floor through manual inputs.

Machinery monitoring that is the core function of a production monitoring system (PMS) is becoming the necessary part of the information systems used in the production companies that try to improve productivity and minimise losses. At the same time machinery monitoring comprises condition and utilisation monitoring systems. Condition monitoring is the process of monitoring the parameters of machinery condition. It eliminates unwanted wastages due to unplanned stoppages in order to increase maximum return on assets and lower the production costs. Mostly rotating elements (e.g. bearings, shafts) and tool condition are monitored. At the same time, utilisation and machine event monitoring shows which machines are running, downtime and performance. If a machine is not working, operators will know exactly why, so they can optimise processes and revise productivity. It gives detailed real-time and historical knowledge of what is/was happening on the shop floor with the machinery.

The idea of a real time PMS is not to give some information simultaneously as the event occurred, but provide the production team, as fast as possible, with the accurate and meaningful data. But there should be enough time to respond timely on these events. It will always take some time (seconds, minutes or even hours) to analyse monitored data and respond on it and the goal is to try to decrease this time [24].

It is not reasonable to store all collected data (every single measurement) in a database. If the measurements are taken at high frequency (e.g. vibration) by using wireless sensor network (WSN), it is recommended to process original data already in WSN node, before sending the analysed data to the database. In this manner, WSN node energy can be saved, radio frequency channel can be held free for a longer time and the database can be held more compact [27].

The most important requirements of any monitoring systems are that the system is economical, accurate and easy to set up on a production line. An effective production monitoring system should be at least comprised of the five elements: collection, display, analysis, prognostics and data storage.

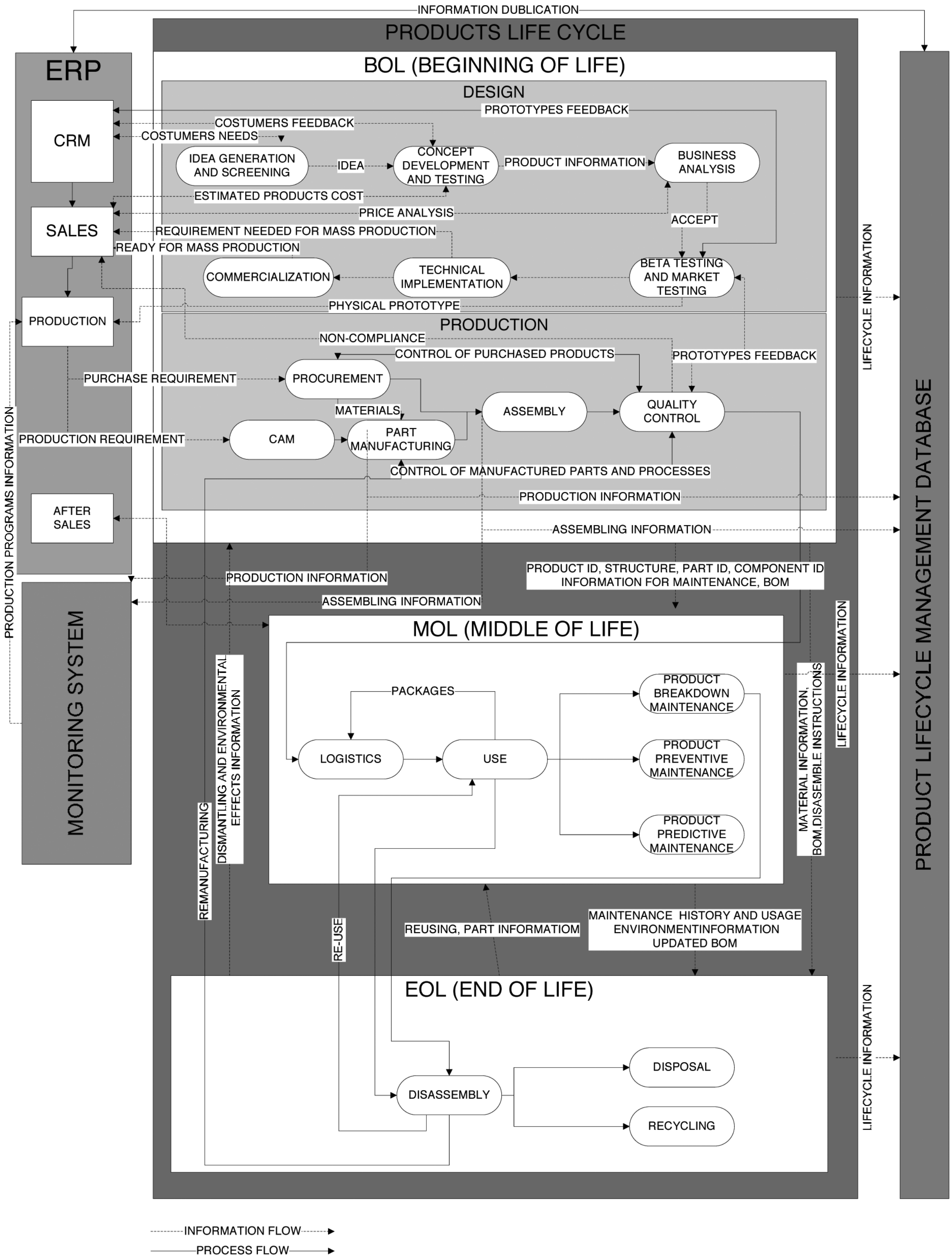

Fig. 3. Information movement in product lifecycle

Prognostics can be distinguished from an analysis module due to the focus on the prediction of future performance of the monitored component. It is a decision tool that quantifies how much time is left until the functionality is lost. The estimation of remaining useful life (RUL) of a faulty component is the core of prognostics. RUL forecast must deal with several sources of error such as modelling contradictions and system noise. Potential use of prognostics is in predictive maintenance. Prognostic performance assessment is of crucial importance for a successful prognostics system implementation.

7. Overview of the model

Product Lifecycle starts with the Beginning of Life (Fig. 3). There are several possibilities of how an idea of a new product is coming to a company. One of the situations is when companies lead for a new product comes from customer activities [28]. Then the sales division offers a solution for it. Another possibility is that the idea of a new product comes from a certain need of a customer. All this information is clarified with customers from the early stages of development through CRM. In this stage idea generation and screening information is sent to CRM, irrespective of whether it is sent forward to the customer or independent of the situation.

Idea generation and screening should be followed by the next stage of the development project. CAD models together with FEM analyses should be developed in the concept development and testing stage. In the offering phase some of this information is sent through CRM to the customer. All this usually needs confirmation from the clients that they accept current properties and the design of the products. If client demands and expectations are satisfied, an offer is made to sign a contract.

After the concept development and testing phase, main product information should be clear. Based on this information the sales department sets a preliminary selling price for the product that is put on offer. After confirmation beta testing and market testing are usually performed. In this phase, prototypes are prepared and shown to the client or a larger amount of prototypes is produced and sent to market testing where a group of people test the product for a short period of time. Customer feedback, such as prototype feedback, goes usually through CRM to the developers and to production.

Corrections are done after beta testing and market testing in the product and after that technical implementation can start. In this phase, requirements for mass production are set and if necessary, new devices are designed to simplify and lower the cost of production. If needed, new technologies are taken to use to simplify and lower the cost of production. All this information has to be sent to the sales department for corrections to be made in the pricing policy. Designers and manufacturing engineers prepare all necessary information for production, such as models and drawing information in ERP. In the final commercialisation the product is made ready for mass production.

The second stage in the Beginning of Life is production, which is also done in a manufacturing company. If it is not based on project production, the order for production comes from the sales department. ERP creates demands for material procurement and production requirement. Usually all this is done previously in the prototyping phase. CAM has to be done according to orders and parts manufactured according to BOM. Due to the implementation of the production monitoring system, sensors are installed onto the machines to store all the information needed. Stored information about component production and assembling is duplicated in the product lifecycle management database and monitoring system.

Quality control, an important part of production, is done after the components production separately for assembling. Non-compliances and mismatches are passed on to the production and sales department that they can alert customers that batch might not be ready on time. Information goes also to the design phase where it is forwarded to the development team.

Middle of Life phase starts with logistics, when the product is sent from the company to the customer. A logistics company transports the product to the place where it is used. From this stage only connection between the product and the PLM system is through PEIDs. The biggest problems that can occur are related to maintenance. Maintenance categories are: product breakdown maintenance, product preventive maintenance and product predictive maintenance. After product breakdown maintenance information is sent to the development section where this information is used to improve this product or product family in future. The same information also moves through after sales when they order new spare parts. Product preventive maintenance and product predictive maintenance are only sending information through spare parts movement to the production company. Information is also sent forward to the end of lifecycle where it is used in the decision making process what to do with the products afterwards.

The final phase of the product lifecycle is the End of Life. The products not usable or retired are going from the Middle of Life to the End of Life phase. This means that products are not needed by the customer and they are going to be disassembled. From disassembling products can go to re-use, remanufacturing, recycling, energy recovery or landfill. From there information goes to the earlier stages of the lifecycle. All this information and knowledge about the purpose of the products is coming from the previous stages of lifecycle. BOM information about the materials used and reuse information is coming from the beginning.

In summary, closed-loop lifecycle management using information from the production monitoring system was reviewed. Movement of information between different stages of the lifecycle was described.

8. Conclusions

PLM plays an important role in the modern production landscape. Evolution of PLM was briefly reviewed. Different phases of PLM like BOL, MOL and EOL, and closed-loop PLM were described in more detail. Solutions for using the production monitoring system at the beginning of product life phase are covered and the process enabling better decisions in the development phase is introduced. Also analysis and prognosis of the defects based on sensors information were discussed.

In the second part the information movement between different parts of product lifecycle management and between the production monitoring system is described.

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