Integrating Energy-Saving Process Chains and Product Data Models

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Abstract
The evaluation of energy efficiency in the product life cycle should include the energy used for manufacturing. An early consideration of manufacturing processes during product development can help to optimize the product design in order to achieve an energy-efficient production. Existing approaches and product data management systems lack the integration of energy data for production processes and do not cope with the manufacturing of complex products. Therefore, an integration of energy-saving process chain models with the product structure is proposed in this article. Based on such process chain models, estimations of time, energy and cost for manufacturing parts can be calculated.

Keywords:
Product Data Management; Process Chain; Energy Efficiency

1 INTRODUCTION

Using resource energy efficiently has become an economic and ecological requirement for the manufacturing industry [1]. Efforts concentrate on the efficient usage of energy in production processes and on energy reuse. Depending on the specific product, manufacturing accounts for a considerable amount of the energy used during the product life cycle. On the one hand, an early consideration of manufacturing processes in product development can help to optimize the product design for an energy-efficient production and, thus, can save energy in the product life cycle. On the other hand, manufacturing processes can be planned and optimized while the product is designed. To achieve the data exchange between product development and manufacturing planning, product life cycle data of both fields have to be collected and linked together. This energy data link is an important part of energy-oriented product life cycle management (PLM), which focuses on collecting, storing, and distributing energy data during the product life cycle.

There exist several solutions that implement parts of PLM for sharing product or environmental data between, e.g., product development and manufacturing. To evaluate the environmental impacts of a product, methods like life cycle assessment (LCA) are utilized. Recent efforts make LCA easily available in product development by integrating LCA data with the product data management (PDM). As a consequence, the material composition of a product that is designed can be analyzed instantly. PDM systems also provide interfaces to the manufacturing phase, e.g. by exporting product data models to computer aided manufacturing (CAM). In this way, a CAD model becomes the input for the software control of a machine tool. Nevertheless, these interfaces between product development and manufacturing or LCA lack the integration of energy related process data. However, this energy data plays an important role when evaluating sustainable manufacturing, as stated in [2], and should be included.

Developing a new product and planning its manufacturing are collaborative activities for which IT systems organize information and communication flows. Integral IT systems for product development are PDM systems [3]. PDM systems contain a central repository for product data models and activities which are used to create and manipulate product data. A key functionality of PDM systems is to set up and store product configurations that can be used in manufacturing planning. Based on the design specification from product development, the production engineers plan all manufacturing steps and resources for manufacturing the product. The whole production includes manufacturing processes, logistic processes, and assembly processes. Software support exists for all the different aspects of manufacturing planning, but usually does not consider energy aspects. This article focuses on the aspect of modeling energy-saving process chains and the corresponding processes to manufacture the parts.

Energy-saving process chains consist of mathematical models of process steps with pre- and post-conditions as well as specific machine data to calculate time, energy and costs. Constraints for manufacturing processes can be combined with part data (geometry, materials, stresses, strains, etc.) to evaluate whether a part can be manufactured within the process limits. The process chains specify the technological processes, material and energy flows that are necessary to manufacture the parts.

This article shows an approach to model process chains and to integrate the process chains and the product structure for product development. The process chains are modeled such that energy can be saved in the manufacturing process. Additionally, process chain models can be used for energetic optimizations and energy reuse. An integration of these energy-saving process chains with product structures can provide the means to estimate time, energy and cost for manufacturing parts while they are designed. This energy data link between parts and process chain models can also provide helpful feedback to manufacturing planning by identifying manufacturing processes with a high energy usage and the corresponding parts.

In the following two sections the product data models for product development and process chains for manufacturing process planning are described. Use cases for an energy data link and the gains of the approach are summarized. An IT implementation for

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the data model and the necessary interfaces of an energy data link is proposed. Section 6 compares the approach with related work. The final section concludes the article and gives an outlook.

2 PRODUCT DATA MANAGEMENT

This section starts with an introduction on how current PDM systems prepare product data models for manufacturing planning. After discussing drawbacks of existing solutions, the integration of the product data models and process chains is proposed to enable an energy-oriented manufacturing process planning.

2.1 Product structure in PDM systems

In a typical PDM system, a product is described by a tree structure, which contains the product as a root node, assemblies or other sub products as inner nodes, and parts as leaf nodes. Along the product development process more and more details are added to the product structure by inserting additional nodes and attaching documents to existing nodes. Still during development, less important details such as screws are left out. For the manufacturing of the product, a complete specification of the product has to be created, including the parts to be manufactured and the buy parts. This specification is managed in PDM systems through the product structure.

The product structure managed by the PDM system corresponds to the structure of the detailed geometry in a CAD model. CAD systems allow the input of additional information for a CAD model to specify parameters, such as tolerance or material, and pre-defined geometry elements (features), e.g., for drill holes. The CAD model and its features already describe the part manufacturing and can be used for CAM to create and manipulate numerical control (NC) programs. As central repository, the PDM system stores parts with associated CAD models and NC programs.

The product structure can contain alternatives or substitutions for individual parts. From this information, product configurations and variants can be inferred and can be managed through the PDM system in the form of a bill of materials (BOM). The manufacturing engineer uses the BOM for planning the manufacturing resources. This includes adding standard parts, or determining the sequence of manufacturing and assembly processes to build the final product.

These existing approaches for integrating product development with manufacturing represent a sequential workflow of actions. Manufacturing planning takes place in the late product development phases. The information flow is usually from product development to manufacturing, but not vice versa. Thus, information about the energy used to manufacture parts is not available to product development. However, a variation of the part design may introduce an energy saving potential into the process chain. Therefore, a data link between the structure of a product and the process chains can provide support for such an approach. This link allows the data exchange in both directions: part data are required for manufacturing process planning, and manufacturing restrictions set limits for the product design. The benefits of the integrated approach for product development are discussed in the next section.

2.2 Integration of product structure and process chains

The integration is based on a data link between the product development view and the manufacturing view on the product structure as shown in Figure 1. Leaf nodes in the product structure (parts) are associated with appropriate process chain models that describe their manufacturing. The data link between parts and process chains can be utilized in the following ways.

The product development view shows the links between the product structure and different CAD models, drawings and other documents

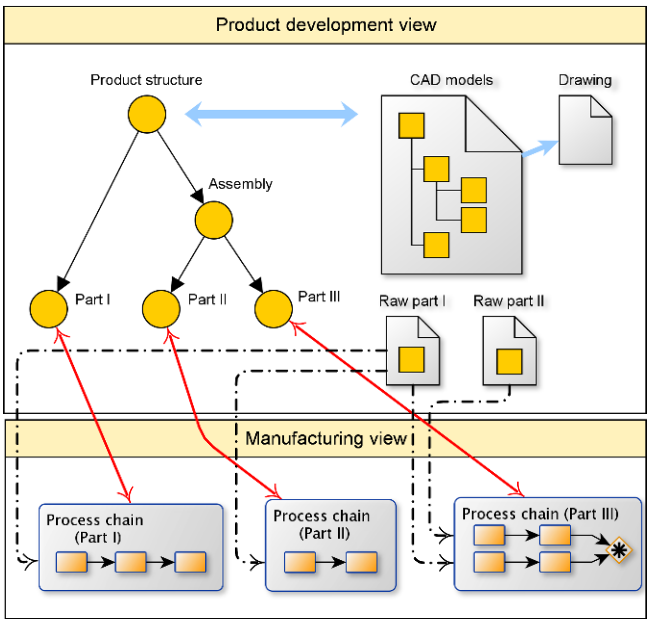

Figure 1: Illustration of the data links between product structure, CAD documents (top), and process chains (bottom).

in the PDM system (see Figure 1, top view). A part can be associated to a process chain by creating a link to a model in the manufacturing repository of process chains (see Section 5). If a CAD model and a corresponding process chain for a part exist, energy usage information for manufacturing the part can be invoked from the appropriate IT system, the process chain modeler. In case it is a buy part and no process chain exists, energy usage for manufacturing this part can be estimated either from information of the supplier or from an energy equivalent calculated from the price of the part. Another approach is to calculate the carbon footprint of a part which can be done as described in [4].

The manufacturing view lists the process chains and associated parts to be manufactured. Additionally, manufacturing engineers attach raw parts to the process chains. To achieve this, CAD models of raw parts from a part library of the PDM system or a supplier database are linked with the process chains. In the process chain modeler, the process chains and associated CAD models of the part as well as raw parts are utilized to calculate energy usage of manufacturing.

The value of the integration of product development and manufacturing planning can be summarized by sharing product life cycle data between these two phases. Product designs can be improved by selecting parts with respect to their manufacturing impact and by making manufacturing knowledge available for new product development.

3 MANUFACTURING PLANNING

This section first describes an approach for designing process chains for the manufacturing of parts. An overview of data and data models necessary for planning process chains in detail is given. Then, the description is extended to the assembly of parts resulting in assemblies and in the final product.

3.1 Defining and detailing process chains

A manufacturing engineer has to plan the manufacturing steps for a product based on the design specification resulting from the product development. For the planning of the manufacturing several approaches and methodologies can be used. The first step is to define the order of the processes in a process chain. In practice,