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PROCESS PLANNING BY INTEGRATED DESIGN AND EVALUATION OF TECHNOLOGY CHAINS USING A STANDARD ERP-SYSTEM

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ABSTRACT

The configuration, evaluation and selection of technology chains are some of the most critical tasks, regarding the determination of optimal product and production costs. Nonetheless, these process planning tasks are often still performed in a sequential way and are only unsatisfactorily considered within the process of product development. This paper presents a methodology to overcome these shortcomings, using an integrated configuration and evaluation of technology chains. Its implementation with a standard ERP (Enterprise Resource Planning) System is shown. Basically, the proposed methodology consists of three components. The first one is a product-technology-matrix that specifies the correlations between a company's products and its available or projected technologies. The second component is a modular generic technology chain model that enables a classification of technologies. A combined quantitative and qualitative evaluation model to calculate and compare different technology chains completes the proposed methodology. These three elements facilitate an appropriate knowledge management concerning products, technologies and their relations. Additionally, a fast configuration of alternative technology chains and a selection of the most adequate ones for newly designed products are addressed, reducing the time of planning processes by almost one quarter. The implementation of the methodology using a standard ERP system is illustrated by two representative use cases.

1 INITIAL SITUATION AND OBJECTIVES

Product and production costs are decisively influenced by the configuration, evaluation and selection of technology chains. Therefore, it is indispensable to closely integrate product development procedures with production process planning procedures [1, 2]. Numerous efforts like axiomatic design [3], design for manufacturing and assembly [4] or cost-effective development and design [5] were made to integrate these functions. Especially the definition of adequate technology chains forms a sort of linkage between product design and process planning. Within the early phases of product development and process planning, the product design can still be influenced by suggestions for a production oriented optimization. Consequently, the definition of technology chains plays a key role regarding the divergence of cost determination and cost occurrence [5]. In this paper, we define a technology as a general production technique like, for instance, grinding, turning or coating. Therefore, the planning of technology chains represents the early phase in process planning.

A recent survey of trends in technology management [6] within German production companies shows the importance of performing a systematic technology management. It is depicted that a proper management of technologies increases productivity, efficiency or the rate of innovation. Therefore and based on observations made in industry, the importance of systematic technology handling will increase. An almost sequential proceeding within product development and process planning is still dominating, even though multidisciplinary teams can often be found. The results within product development and process planning are often dependent on the individual experiences of the involved persons.

This paper depicts a holistic methodology aiming at four main objectives. First of all, the methodology should support a highly iterative proceeding between product development and process planning. Secondly, an elaboration of 'competing' alternative technology chains based on rough information about the product should become possible. Thirdly, it is very important that the methodology allows for a proactive consideration and integration of new technologies within process planning as a base for technological leadership. Fourthly, it is aimed to provide possibilities for a systematic detailing and a constant evaluation of technologies. This shall

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help to realize a continuous planning process and a selection of an optimal chain among alternative technology chains.

2 CONCEPTION OF THE METHODOLOGY

A methodology - especially for companies in the area of serial production - is proposed, which combines integrated process planning approaches, specific configuration methods, evaluation methods and cost accounting aspects. The core of the methodology consists of a product and technology correlation, a modular generic technology chain model and an evaluation model. The model interaction and the methodology application are specified by a procedure description (see section 6). In combination with a database of existing work plans (fig. 1), these four elements allow a systematic deduction of specific production technology chains.

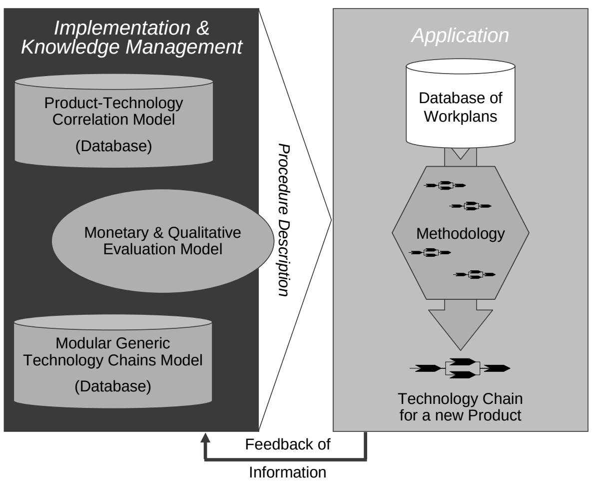

Figure 1. Major elements of the methodology

While initializing the methodology it is essential to build up the correlation model, the modular generic technology chain model and the evaluation model as a sort of knowledge base (database). During the application of the methodology, the partial models and databases are used to generate technology chains for new products. The procedure description ensures reproducibility in the field of initialization, application and administration. The data has to be continuously updated for guaranteeing actuality of the planning knowledge. The mentioned elements for the methodology are described in the following sections. Afterwards, an exemplary implementation using a standard ERP software solution is described.

3 PRODUCT-TECHNOLOGY CORRELATION MODEL

The product-technology correlation model implicitly forms a sort of knowledge management system and database, regarding products and technologies. The model comprises all of a company's production technologies currently being used or developed, as well as all of a company's products with their main features. Additionally, all reasonable relations between a product feature and the production technologies are represented by the model. When applying the developed methodology, a company has to analyze its products. The activity of structuring products concentrates on part and component level to be able to assign products and technologies in a feasible way. The structuring of products and technologies is carried out according to the method of Quality Function Deployment (QFD) [7, 8]. Product classes are generated to cluster the specific products. A class includes products which have an equal or comparable functional purpose, are subject to equal or similar operational restrictions, have corresponding geometries and/or have an active principle oriented similarity. Usually, the classes are comparable to those of a company's production program and thus can be identified easily. Subsequent to this classification, each product class (e.g. a disc brake or a turbine blade) has to be analyzed regarding its functions (e.g. take-up of forces). Following, the product elements (features) to realize the functions have to be identified [9]. If a more detailed structuring of product elements is necessary, they can be divided into product sub-elements. The result is the definition of a company specific product structure (fig. 2).

The structure of a product class with its functions, elements and sub-elements, is a kind of "master", including the maximum specification of a part of the respective product class. That means that the "master" of a product class is equal to a maximal possible part, consisting of all possible functional components and all possible product elements. Thus the "master" of a product class may be a part that will never be produced. So far, the structuring of a product class represents a knowledge base regarding all its included products. A maximum specification of a product of this class and all alternatives are documented. The individual characteristics of specific products are a subset of the product class structure.

The next step for an implementation of the methodology is the structuring of main technologies (fig. 2). A main technology is defined as a basic production technology which transforms a product to the next higher level of added value. A main technology may require several preparatory production steps as well as subsequent production steps. All of the company's specific technologies have to be separated in technology groups. The result of this activity is a hierarchical and company individual technology tree structure. Using standardized templates [10] helps to avoid redundancies within this structure. If new technologies are introduced, it is of vital importance, to update the product structure. Otherwise, the new technology would not be considered as a real alternative during the selection and evaluation of technology chains for a new product.

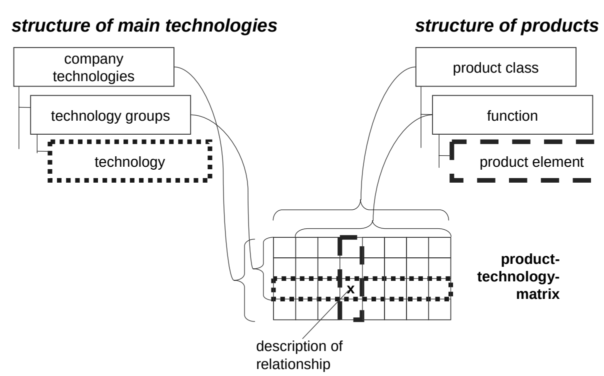

Figure 2. Matrix representation of product and technology structure

Subsequent to the structuring of products and technologies, information has to be linked to the technologies for decision support within technology selection. Additional information such as work plan data, alternative resources, technology limitations or cost functions has to be provided. This data has to comprise especially limitations of production technologies (e.g. limited level of quality, only applicable to certain geometries). That assists the planner to choose the appropriate technologies for a particular product. In the next initializing step, the relations between the product structure and the technology structure have to be defined. The required production technologies for the realization of specific product elements or the achievement of the next step of added value have to be connected to the correlating product elements. This is performed by the product-technology-matrix visualized in fig. 2. It is essential to represent all existing technological alternatives for the manufacturing of a product feature within this matrix. Using this matrix, which represents a bidirectional knowledge management tool, the product designer is able to immediately evaluate design decisions with regard to the process planning. Otherwise, the process planner can display the company specific production potential towards the design department. By combining product development with planning information, integration effects can implicitly be realized. The relation between the product elements and the different technologies has to be classified by a defined numerical code. This code needs to cover three aspects (fig. 3): The character of the relation (a), alternatives for the production of an element (b) and impacts of technologies on more than one product element (c).

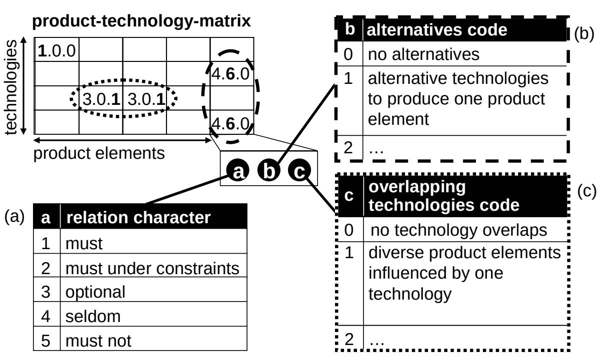

Figure 3. Nomenclature for product process relations

New technologies can be added easily, by inserting a new entry to the technology tree, which is equal to adding a new line to the product-technology-matrix. Afterwards, the new technology needs to be linked to all product elements or product functions that can be processed by it. In the same way, the methodology can be expanded to new product classes: First, the product tree needs to be enhanced. Afterwards, all of the added product elements and product functions have to be connected to suitable technologies to produce the particular element or function.

A holistic knowledge management system (database) regarding the characteristics of technologies/products and the classification of the respective relations can be developed within this matrix documentation. The product-technology-matrix represents a kind of knowledge warehouse to identify all relevant technological alternatives within the planning process for a new specific product.

4 MODULAR GENERIC TECHNOLOGY CHAIN MODEL

Each main technology is dependent on defined predecessor ('preparation') and successor technologies ('post processing') [11]. A so-called standard technology module for the main technology can be defined for each technology listed in the structure of fig. 2. A defined standard technology module comprises all relevant technologies to prepare a part for a main technology process (e.g. cleaning) and to post process the part after the main technology process (e.g. testing) (fig. 4).

Similarly to the relations between product elements and main technologies (fig. 3), there are interdependencies between the main technologies and the predecessor/successor technologies. The standard technology module represents a maximum characteristic. The relations between the module elements and their relevance within the production process have to be described. For each predecessor and successor technology it has to be defined whether it has a 'must', 'must under constraints' or an 'optional' relation to the main technology. In case of a must relation, the technology is a necessary precondition for the main technology. If the relation is set to 'must under constraints' or 'optional', functional or technological requirements that are required for the use of the technology have to be documented.

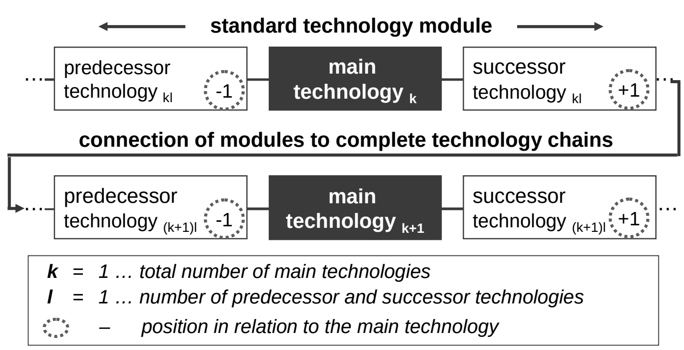

Figure 4. Modular generic technology chain model

The modular generic technology chain model is a kind of technology building set (documented within a technology-technology-matrix). The standard technology modules support a continuous proceeding from the definition of necessary product elements to the identification of possible main technologies up to the configuration of technology chains. A first draft of a complete technology chain (to be equated with a rough work plan) is the sequenced accumulation of selected main technologies with their standard technology modules. Therefore, it represents the skeletal structure for a following detailed process planning.

5 MONETARY AND QUALITATIVE EVALUATION MODEL

The product-technology-matrix and the standard technology modules in combination with the description of the highly iterative procedures, enable the generation of all possible alternative technology chains regarding the production of a part. Especially the documented product elements within the matrix and technology alternatives for their production result in a combinatorial number of alternative technology chains. This accumulation of alternative technology chains has to be evaluated in order to find out the best alternative. A great variety of methods and prototype software tools exists in the field of evaluating technology chains in the early process planning phases [12]. Within this methodology, a combined similarity and generic approach is selected. The technologies within the structure are stored with an individual identifier in the database of the product-technology-matrix and the standard technology modules. Using this resource independent ID, technologies are linked with existing work plan data like average process times, set-up times, hourly rates or parametric cost functions. The ID structure allows addressing product class specific technologies and product element specific data. Hence, it is possible to evaluate production costs in very early development and planning phases.

According to the maturity level of information, history based - and insofar analogy based - time and cost data can be updated by time and cost functions gained by regression analysis. These functions are technology specifically stored within the product-technology-matrix and allow a cost-reflective cost calculation similar to Activity Based Costing [13]. With defined input information (e.g. geometric data), times can be individually calculated and aggregated to costs multiplying it by hourly rates. Average hourly rates can be substituted by machine and worker specific rates as a further step to information maturity. Due to the option to update unspecific by specific information, according to the information maturity of the planning phase, the principle of a “maturing” cost calculation can be fulfilled. Due to the fact that technologies pass through different development phases, technologies and technology chains include risks regarding their feasibility. The predicted costs, the cost calculation accuracy depending on the calculation method and the technological risk are combined within cost-risk-graphs, to generate a holistic conclusion for each alternative technology chain. By this “maturing” production cost calculation and graphical representation of the results, a standardized decision making regarding the best alternative technology chain is possible. If the alternative technology chains differ in the field of further qualitative aspects like flexibility and/or non-recurring costs like fixture design or planning activities, the decision process can be completed by a value benefit analysis and/or a capitalized value calculation.

6 PROCEDURE DESCRIPTION

As shown in fig. 1, the methodology comprises two phases. In the implementation phase, the product-technology matrix with its respective correlations between product elements and technologies has to be generated. This preparatory task has to be performed prior to the application phase. Ideally the implementation of the methodology is carried out by integrated teams, consisting of members of the product development and of the process planning department. The business process methodology with its business process building blocks is suggestive for the description of integrated activities [14]. Therefore, all activities are described in detail and are complemented by information, like necessary input information, resulting output information, responsibilities and used methods/tools. A procedural-organizational combination of the described methodology elements and the holistic proceeding are provided in this specific nomenclature. Recapitulating, the procedure description of the methodology can be divided in five highly iterative main steps (fig. 5).

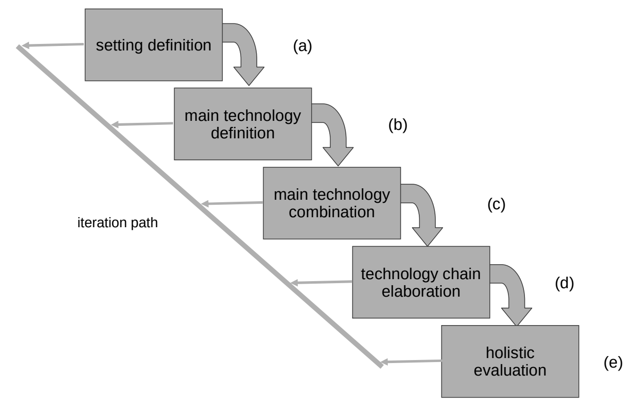

Figure 5. Conceptual illustration of the procedure

The first step (a) is the identification of the relevant product class and the selection of the necessary product elements based on the specification information (product-technology-matrix). Within a test implementation (see section 7) this step is conducted by selecting the desired product elements from a list representing the product tree. The next step is to assign possible alternatives of main technology chains to the selected product elements (b). This task is performed automatically by dint of the correlations between production technologies and product elements, stored in the product-technology-matrix. Afterwards, all possible combinations of main technology chains and the sequencing of the main technologies within the chains are created by the system automatically (see modified screenshot in fig. 6).

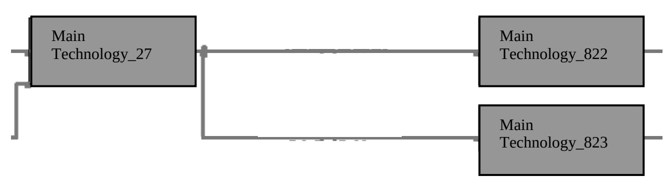

Figure 6. Part of automatically generated combination of main technology chains

7 METHODOLOGY IMPLEMENTATION AND EXAMPLES OF USE

The proposed methodology has been tested in two examples of the truck manufacturing industry [15] and the aviation industry respectively. Within the first example of use, the technology structure, the technology modules and cost functions were elaborated. In the second use case, the further elements of the methodology (fig. 1) have been developed and realized. A prototypical implementation with commercial software products has been carried out in both of the examples. The database used contained product structures, product technologies and their according technology modules as well as the relations between the product and technology structure. Using the underlying database, an exemplary production planning on the basis of raw input information like sketches or the number of cooling air holes was conducted. For this purpose, main technologies were selected using the relations between the product structure and the technology structure. These main technologies were detailed to complete technology chains by using the technology modules. The expected costs of the product were estimated according to the technology data base with its average process times, hourly rates or particular cost functions, thus enabling a well-founded evaluation and selection of different technology chains. A comparison of the calculated costs and those of the real world working plans showed a difference of less than 5 %. The experiences gathered within the development and application of the prototypes provided a basis for the requirements specification to implement the methodology within a commercial software solution. This requirements specification helped to identify eight possible software providers and their software solutions and assessing them according to previously defined criteria. As a result of the software assessment process, two modules of a standard ERP System were chosen to implement the methodology and to demonstrate its capability on an exemplary product class. By this procedure, the benefits of introducing the proposed methodology have been shown as well as the efforts for the adaptation of the software solution's standard functionalities. First results show the general possibility to model the above mentioned product and technology structures as well as their relations and dependencies within the first module of the software solution. In addition, the generation of technology chains has been realized in a quick and effective manner. The technology chains correspond to the previous existing working plans and need to be transformed to the second module for a qualitative and quantitative evaluation. There, costs and technological risks are calculated and analyzed. For cases where no specific decision can be taken between different alternatives, an enlarged cost-benefit analysis has to be implemented. This task has to be performed manually and is not considered within the described software solution.

8 SUMMARY

Within this paper, a methodology for an integrated design and evaluation of technology chains is presented. The methodology provides a modular generic technology chain model to create company specific technology modules. These technology modules are correlated to product elements via a product-technology-matrix. By this matrix, all possible alternatives of technology chains for the production of a part may be generated. In order to evaluate the different alternatives and select the most feasible one, the methodology comprises a combined qualitative and quantitative calculation model.

The methodology has been applied prototypically within two use cases of the heavy vehicle industry and aviation industry respectively. Within the use cases, the methodology was implemented with standard modules of a commercial ERP system. The experiences made in the use cases show qualitative improvements as well as a reduction of the time and thus the costs needed for the planning process. By using standardized technology chains and a standardized procedure for production planning throughout several departments, the process of production planning has become more transparent and comprehensible. Thus the dependence of the result of the planning process to the experience of the planner can be reduced. This can help to train new employees more efficiently. Additionally, the straightforward creation of different technology chains helps to consider alternatives which would not have been taken into account with the conventional procedure. Therefore, technology chains that are more cost effective will be selected, lowering the overall production costs. Furthermore, by using a consistent calculation scheme, the calculated costs for novel products become more independent of manual estimation and experience. Finally, using standardized technology chains in combination with the developed software solution, the time needed for the hole planning process can be reduced by almost one quarter. On the other hand, the use cases have shown that the efforts for the implementation of the methodology and the administration of the necessary data are not negligible. An economic realization is therefore only reasonable for companies with a high number of planning tasks. This is for instance the case for contract manufacturers that have often to submit offers with calculated costs. Within one use case, costs and benefits for the use and the implementation of the methodology were estimated. This cost and benefit calculation indicated that the efforts necessary will amortize within about 2 - 3 years.

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