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Computer aided manufacturability analysis: Closing the knowledge gap between the designer and the manufacturer

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ABSTRACT

Manufacturing today is marked by increased competition and dispersed global organization, thus necessitating enhanced collaboration among designers and manufacturers. Nevertheless, while Design for Manufacturability (DFM) has been the subject of in-depth research over the past decades, the supporting software solutions have not as yet matured. In this paper we present a holistic approach and supporting software tool, termed the *Computer Aided Manufacturability Analysis* (*CAMA*) tool, for capitalizing on available manufacturability knowledge. This is achieved by closing the knowledge loop between the design and manufacturing environments. CAMA captures the knowledge in a structured manner and incorporates this knowledge within the product design tools (CAD systems), thus enabling improved product timeliness and profitability. CAMA represents proof of concept and constitutes a demonstrative prototype of an adaptive and open DFX tool. It is based on industrial surveys of the Knowledge, Information and Data (KID) flows in CAD, CAPP and CAM processes within the manufacturing outsourcing environment. CAMA differs from other approaches in that it is an open system that enables continuous and intuitive capture, modification and implementation of updated manufacturability KID.

1. Introduction

In response to technology progress, fierce market competition and changing business environment, modern industry must continually improve product functionality and quality to gain market advantage [1]. To this end, various Design for X (DFX) methodologies have been developed over the years to address the "hottest" design problems or bottlenecks in marketing.

Each Design for X label incorporates a broad collection of specific design guidelines. Each design guideline addresses aspects either caused by or affecting product characteristics. The guidelines themselves usually propose an approach and corresponding methods for generating and applying technical knowledge to control, improve, or even invent specific product characteristics. Such guidelines represent an explicit form of knowledge that contains information about "knowing-how-to."

The current scientific edge, therefore, resides in incorporating this know-how, as well as additional customer needs, manufacturing experience and other product life-cycle aspects into the design of new products. In particular, taking the above factors into consideration in the early design stages is expected to significantly increase product profitability. Despite the expected benefits, only a few mature tools are available to support designers in defining product functionality and structure that incorporate additional DFX considerations [2].

This paper describes a software analysis tool that addresses this critical issue: the *Computer Aided Manufacturing Analysis* system (CAMA). This feature-based analysis system is capable of capturing diverse DFX "know how" in a structured manner. Moreover, it enables the evaluation of a product's CAD model for conformity to a selected DFX, in particular DFM in the early design stages, thus significantly improving product timeliness and profitability.

1.1. CAMA motivation

1.1.1. Closing the knowledge gap between design and manufacturing

Process planning and product design are concurrent processes requiring collaboration among all parties. To achieve such collaboration, technology and business processes must be improved through a more systematic and structured approach [3].

CAMA stems from the Design for Manufacturing (DFM) methodology. The need for CAMA was indicated by the results of a survey of SME manufacturers, leading PLM solution providers and designers, carried out as part of this research. The results of the survey highlighted the knowledge and cooperation gap between designers and manufacturers, and the lack of appropriate software tools to support this cooperation [4].

Solution providers such as UGS, PTC and Dassault have recognized the need to improve collaboration among the design, process planning and manufacturing environments. To this end, they are currently working in three directions:

(a) Providing well-defined compound features recognized by the CAPP system, to be used as building blocks in product design, along with a recommended process plan [5];
(b) Implementing standards for transferring engineering KID between the different CAD/CAPP/CAM/PLM systems (i.e.,

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tolerances, thermal treatment, coating), for example by incorporating this additional KID into the STEP standard [6];
(c) Including CAPP capabilities in CAM systems, thus closing the gap between process planning and manufacturing.

Nevertheless, solution providers have yet to capitalize on the expected benefits of increased collaboration between designers (CAD) and process planners (CAPP) in the early design stages. Bridging this collaboration and knowledge gap is expected to reduce product development lead time and improve product quality and performance, thus providing a more timely and profitable solution for industry.

CAMA closes the knowledge gap between the designer and manufacturer by incorporating manufacturing considerations in the early design phase. CAMA is an adaptive system that enables continual capture of manufacturing knowledge. The system also facilitates structured incorporation of this KID within the designer's environment.

1.1.2. Addressing multiple design methodologies

Past initiatives aimed solely at improving product cost, quality, or time-to-market are no longer sufficient for gaining market advantage [7]. The focus today is on innovation: products differentiated from those of competitors that are also affordable, reliable, and early to market.

Though CAMA originated to support the DFM design methodology, the tool has since evolved to incorporate additional DFX methods, including Design for Assembly (DFA) and Design for Disassembly (DFD). Multiple analyses are possible, either in parallel or consecutively. Designers seeking to develop, manufacture, market and sell innovative, economical and environmentally conscious products must consider all these aspects. Most designers, however, do not have the cognitive capacity to incorporate considerations and guidelines from all these paradigms. The aim of CAMA is, therefore, to enable designers to focus on product functionality and innovativeness, while the software analyzes the CAD model and points out where the model does not conform to the requirements of the selected design method.

1.2. The CAMA environment

As today's organizations become increasingly distributed, the gap between knowledge-based industry and resource-based industry is growing. Hence, care must be taken to capture and store core competencies and to close the growing KID gap between functionalities. This need is even more urgent when manufacturing and assembly are outsourced, often generating a conflict of economic interests.

The interface between design and process planning functionalities can usually be summarized by three KID flows (Fig. 1).

The first flow is a formal flow of engineering data from the designer to the process planner. This flow is usually supported by a configuration control mechanism.

The second flow involves interactions about changes or corrections required based on manufacturability issues, which are then either accepted or rejected by the designer. This flow varies as the product matures. In the early phases of product design, prototyping and release (the focus of our research), communication is usually limited, informal and not well documented due to differences in status between process planners and designers, as well as time constraints or conflicts of interest. These interfaces often become evident in an organization only when a new set of design and engineering data is formally released. Thus, no organizational learning occurs at this stage. Indeed, one of the main Achilles' heels of small and medium enterprises (SMEs) manufacturers and process planners is that errors tend to recur [4]. As a product matures, this communication becomes more formal and takes the form of Engineering Change Orders (ECOs).

The third KID flow is a post-analysis report from the manufacturer to the design department (usually Quality Assurance). This report, usually available only to market-dominant companies, incorporates all the difficulties encountered in process planning and manufacturing. These analysis reports are used mainly to ensure that the correct procedures for completing missing data or formally releasing a new product version have been carried out.

These feedback forms do not usually include the informal interactions that took place between the parties. In particular, substantial changes required in the product due to such interactions are not recorded and remain "off the record". Furthermore, there is no structured mechanism to capture and analyze this feedback or to provide it to designers; therefore, the learning effect is not achieved.

1.3. CAMA aims

CAMA aims at decreasing the number of iterations/multiple KID flows between designers and process planners, thus reducing efforts on the part of these two expensive and core resources. In particular, the aim is to decrease the number of KID flows in the informal interface (Flows 1 and 2) *until a final product is manufactured* (Fig. 2).

An additional aim of CAMA is to capture, store and reuse the knowledge created at this stage of the product life cycle. These aims will be achieved by:

- Creating a structured mechanism for capturing interactions between the designer and the process planner or manufacturer.
- Creating a structured mechanism for capturing the post-analysis.
- Creating a capability for analyzing these structured databases.
- Incorporating an intelligent component into the designer's environment. On demand, this component can evaluate product

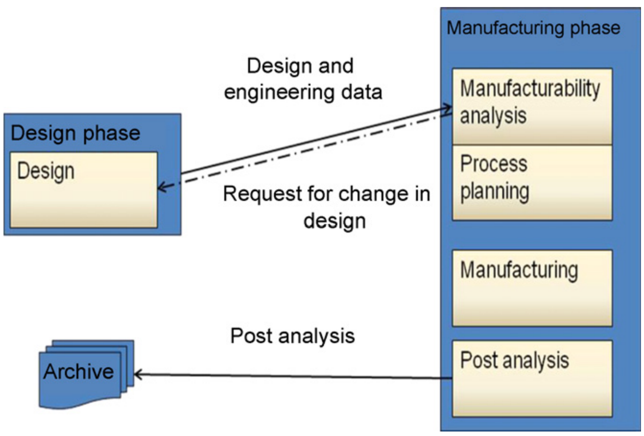

Fig. 1. KID flow between design and manufacturing phases.

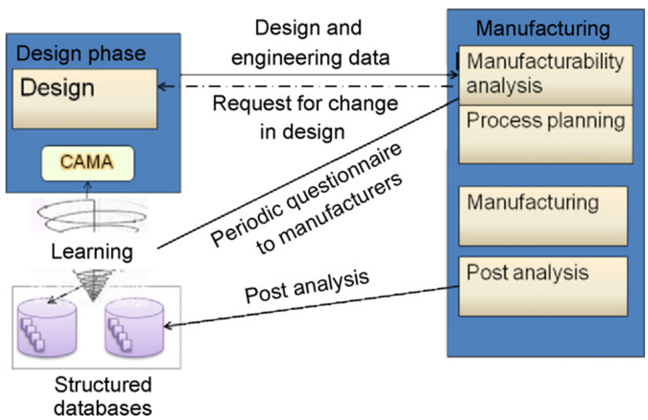

Fig. 2. Closing the KID loop.