# Combining knowledge-based engineering and case-based reasoning for design and manufacturing iteration

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**Abstract.** Design has a major impact on downstream manufacturing activities, therefore computer and knowledge-based design support in early product development are crucial for long-term success in the manufacturing industry. Work on knowledge-based design and manufacturing exists, though too little supports iteration systematically. The aim of this paper is to provide a systematic approach for computer-based design and manufacturing iteration. This paper presents a way to combine the strengths of case-based reasoning (CBR) and knowledge-based engineering (KBE) to enable true design and manufacturing iteration in a CAD-environment. A KBE module generates a geometry definition. A CBR module then retrieves recent manufacturing plans, adapts the most feasible plan and evaluates the manufacturability. If manufacturing is not feasible, redesign suggestions are automatically generated for the designer. When a manufacturing plan is accepted, KBE enables a swift "what-if" analysis of the geometry to enhance the plan further. This method contributes by combining the strengths of CBR and KBE in a CAD-environment. An example case study of sheet metal products at a Swedish automotive industry demonstrates the potential for industry implementation. Using the proposed method, the designer can optimize the geometry for manufacturing activities and thereby reduce development cost.

**Keywords:** Design support, design and manufacturing iteration, knowledge-based engineering, case-based reasoning.

## Introduction

The success of manufacturing companies depends on their ability to use computer-based design support and proper decision-making in the early stages of product development [1]. Iteration cycles between design and manufacturing are crucial to avoid costly design flaws, though, paradoxically, time to market needs to continuously decrease. Traditional computer-based design and manufacturing iteration using CAD/CAM often suffer from too many time demanding and repetitive steps. The functionality of CAD/CAM tools is continuously developing thanks to today's hi-tech computers, but the methods to use these tools have not developed at the same speed. Therefore, the research community has focused on new design support methods for several decades. Relevant research on design support for early design and manufacturing evaluation exists [2-4], but few have focused on design and manufacturing iteration. Therefore, this paper focuses on iteration by combining the swift "what-if" synthesis and analysis of KBE with the systematic and plan-based analysis of CBR. An approach to use KBE and CBR to conduct several different design and manufacturing iterations is proposed. A case study investigates the proposed approach in cooperation with a Swedish automotive manufacturer. As several iterations (automatic, plan-based, "what-if") take place, the possibilities of finding all opportunities to enhance the design for manufacturability exist.

## Literature Review

This section focuses on research for computer-based design support for design and manufacturing activities in early product development.

Work for holistic design support methods exists, e.g. [1], and it is up to researchers to define the method details by means of industry close research. Shehab and Abdalla present a design support system for machining cost assessment, where inexperienced users can generate a design and evaluate manufacturing cost [2]. This system supports automated iteration, since redesign is suggested if the cost is deemed too high. Sandberg et al. describe a system for design, manufacturing, performance and maintenance evaluation based on the KBE "what-if" analysis, i.e. a geometry change can directly be evaluated by means of parametric rules [3]. This work enables iterations to be performed in each discipline and manufacturing iteration is supported by an automated "what-if" analysis. Both [2; 3] lack plan-based manufacturing iteration. Sharma and Gao present a rule- and plan-based approach to support the early design stages of machined components coupled to a PDM-system [4]. Even though this approach may enable automated iteration (both plan-based and "what-if"), their paper does not focus on iteration.

Therefore, iteration focused approaches are still needed.

## Combining KBE and CBR

This section describes the proposed approach and neighbouring subjects to use KBE and CBR for design and manufacturing iteration. The fundamentals of KBE and CBR are outlined, followed by the presentation of the proposed approach. Lastly, the case study at a Swedish automotive manufacturer is explained.

### Short Introduction to KBE and CBR.

**KBE.** The Concentra Corporation founded the embryo of knowledge-based engineering in 1984, while releasing one of the first commercial CAD-systems with a closely integrated rule base module [5]. In KBE, an object-oriented approach is used to code rules that can automate repetitive CAD-tasks. This is for the designer to make visible manufacturability effects due to design in the CAD-environment and also reduce loss of knowledge due to staff turnover, as knowledge is acquired and formalised in the KBE system. One challenge is to make the code easy to maintain.

**CBR.** Case-based reasoning is based on ideas from manual development where recent solutions (cases) are often modified to fit new requirements. By implementing algorithms to retrieve recent cases and adapt the best to the new requirements [6], areas such as manufacturing planning have benefited from CBR research. One challenge is to integrate CBR techniques in the industry, as CBR-algorithms are often research lab centric stand-alone modules.

**Proposed Approach.** This section describes the proposed approach for design and manufacturing iteration. A flowchart of KBE, CBR and manual activities is depicted in Fig. 1. The flowchart consists of three phases: *KBE synthesis and routine analysis*, *CBR* and *KBE "what-if" analysis*.

**KBE Synthesis and Routine Analysis.** This phase starts with "Specify Input Requirements" and ends with assessment of "Routine Verification". The user initially gives input to the system, typically geometric properties (e.g. dimensions and tolerances) and manufacturing constraints (e.g. acceptable cost) through a graphical user interface (GUI). Based on these inputs a geometry is generated. If errors are found due to general design for manufacturing (DFM) guidelines, e.g. a hole is too close to a bend line to comply with given form tolerances, an error message is generated explaining which rules are violated and how to change the input to resolve the problem, *automated iteration*. The next step is "Routine Verification", where automated and semi-automated (contains automated and manual steps) manufacturing assessment are based on manual calculations or applications that, for example, take the geometry as input and assess its manufacturability. Routine verification can also be automated verification through applications based on methods in FEA, CFD or modal analysis that are controlled by the KBE system. If the user finds the results from the routine verification to be non-satisfactory, iteration is started and the user must do a redesign, *manual iteration*, otherwise the CBR phase is entered.

**CBR.** The CBR module takes the design definition parameters from the KBE module as input and retrieves the manufacturing plans for similar cases (designs). If no other plan is adequately similar, an arbitrary plan is retrieved. The arbitrary plan then needs to be manually modified to suit the new design features. The "Adapter" then chooses the most similar plan according to a similarity metric and adapts the plan. If the adapter fails to adapt, feedback is given to the retriever to help avoid retrieval of non-manufacturable plans, and the "Design Definition Change Proposal" algorithm is triggered, *automatic iteration*.

**KBE "what-if" analysis.** The final phase visualises the retrieved and adapted manufacturing plan as well as the geometry for the user who can do swift manufacturing "what-if" analysis by changing the last design features in the feature-history and directly see the resulting change in the plan. If the user finds the plan unsatisfactory, new fundamental design (the first features in the feature tree) inputs can be altered, *manual iteration*. If the plan is deemed satisfactory the user can decide if the plan is unique enough to be saved in the "Manufacturing Plan Case Base" and continue to the next design phase.

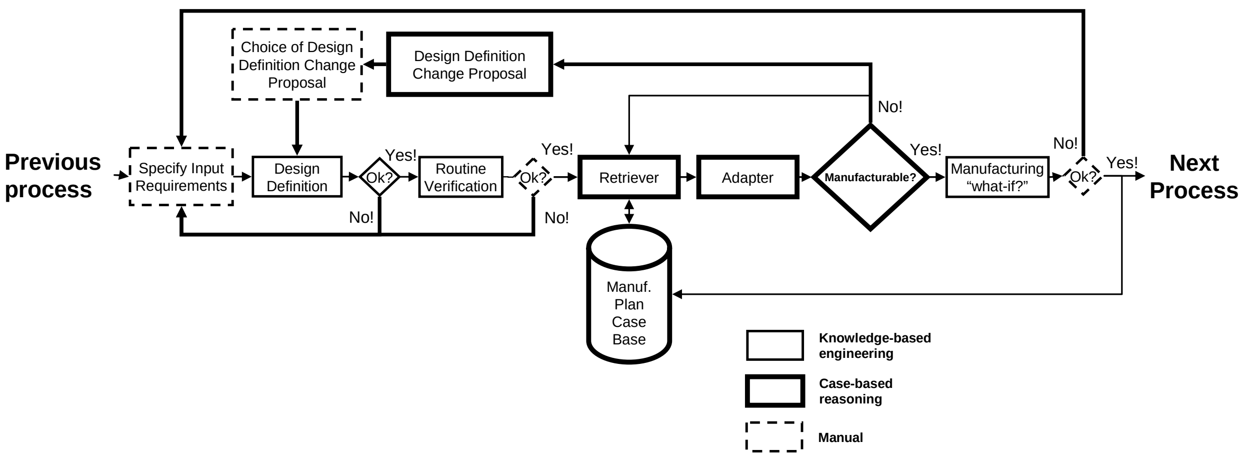


**Figure 1. Proposed approach process flowchart for KBE, CBR and manual activities. Arrows that describe start of iteration are in boldface.**

**Case Study.** A case study at a Swedish automobile manufacturer was preformed to initially investigate the potential of the proposed approach. Brackets are common components in an automotive structure; hence, bracket design was to be supported in the case study. Knowledge acquisition was performed through interviews with industry staff within design and manufacturing along with studying product specifications containing requirements for the brackets and the components to fasten to the bracket (e.g. the signal horn and circuit breakers). The acquired knowledge was then formalised to suit the KBE-module *UGS NX Knowledge Fusion* [7], and *Python* for the CBR algorithms [8]. A GUI was developed using the *UI styler* application in UGS NX; see Fig. 2. In Fig. 2, the user has received a partly adapted plan, since the "Total manufacturing cost" is higher than the "Maximum allowed manufacturing cost". The system suggests redesign proposals that the user can accept or start from scratch.

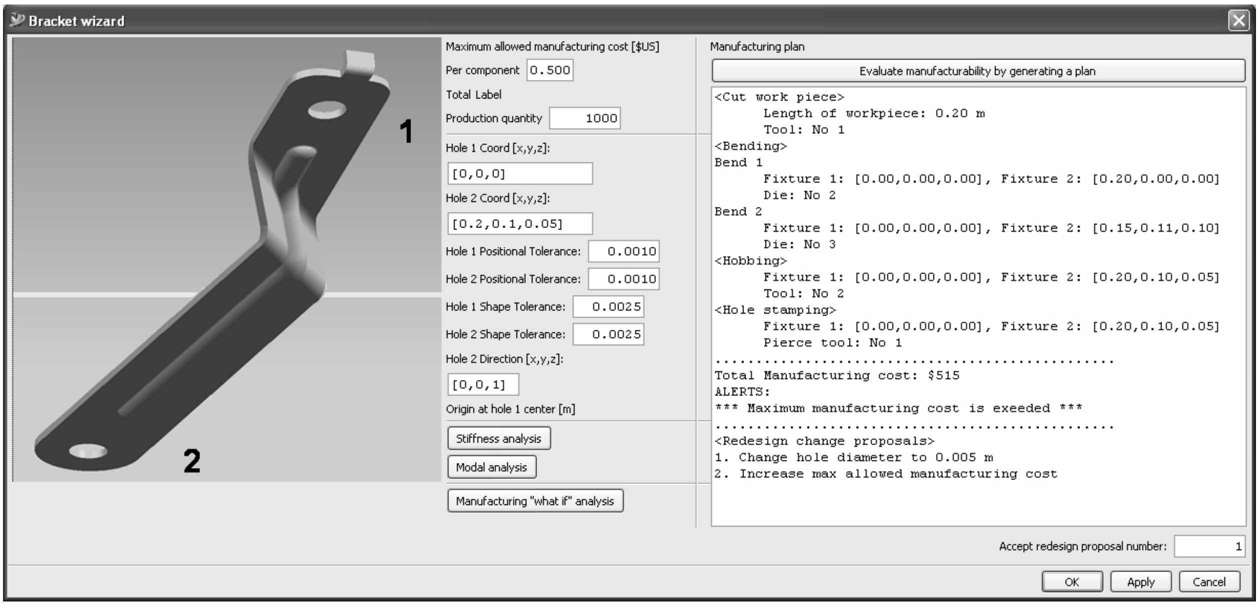


**Figure 2. GUI for case study example.**

## Discussion

This section discusses the capabilities of the proposed approach by addressing iteration, system maintenance, industry potential and generic issues.

**Iteration.** The proposed approach enables four iterations, viz. two manual iterations triggered by the "Routine Verification" and the "Manufacturing what-if" activity and two automatic iterations triggered by the "Design Definition" and the plan-based iteration triggered by the "Adapter". Since four iterations are possible, the probability of finding a design property that can be enhanced in a manufacturing point of view may increase, and costs can be saved. As these iterations are performed both automatically and manually in a four-step dialog with the user, the user may trust the system more rather than if all four iterations were conducted automatically in one step. The black-box feeling may then increase and the level of trust may be reduced. Although the focus is to move forward in the product development process, more iteration may save further costs if costly design flaws are found and avoided. It may also be possible to increase the number of iterations and reduce the development time. Further refining the iteration at the KBE "what-if" analysis would permit altering design changes more freely than just choosing between the suggested redesign proposals or starting from the beginning with new inputs (start of phase 1).

**System Maintenance.** It is important to separate the design support knowledge into *application logic* and *analysis logic* as described in [4], where the analysis logic needs to be updated more likely than the fundamental logic governing the generic information flow of the application. As all geometric features are defined in the KBE module, feature recognition for the CBR module is facilitated. Feature recognition for CBR can otherwise be time demanding to code.

**Industry Potential.** Because KBE-systems often are integrated with a CAD-system, industry implementation of the proposed approach is facilitated, as no new software needs to be introduced. KF was used in the case study, but the choice of KBE system may need to be adapted to other industry CAD-environments. If the CAD-system lacks a KBE-module, API or Macro programming can be used instead, even though this may increase the programming burden. Python is suggested for implementation of the CBR algorithms and because Python is freeware even for commercial products, cost issues of investing in software may not hinder industry implementation.

**Research Issues.** This approach is suitable for manufacturing industries that have timely and repetitive phases in their product developing process and develop products that require several years of experience to evaluate the manufacturability. There may otherwise not be time saved in automating the process. The proposed approach has been informally validated through the case study, though to be able to state that the proposed approach can improve product development in the industry, a comprehensive validation needs to be conducted. In such a comprehensive validation, a measure such as time or cost needs to be stated and used to compare the work process with and without the proposed approach.

## Conclusion

This paper presents an approach for computer-based support for design and manufacturing iteration in early design by combining KBE and CBR. A case study at a Swedish automotive manufacturer was performed to initially validate the proposed approach. The main contributions from the work are the following:

- Because several automated and manual iterations are available, the possibility of finding potentials for design enhancements to reduce the manufacturing cost may increase compared to doing fewer iterations.
- Since the iterations are divided into several steps in automatic and manual dialogs with the user, the user may trust the design support more than if all iterations are conducted in one step.
- As the proposed approach uses KBE, which often is integrated in CAD-environments, industry implementation may be facilitated.

A comprehensive validation where a measure is identified and used to clarify the impact of the proposed approach on the product development process needs to be done.

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