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AUTOMATING REDESIGN OF SHEET-METAL PARTS IN AUTOMOTIVE INDUSTRY USING KBE AND CBR

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ABSTRACT

Automating redesign is an approach for engineering designers to prevent design related manufacturability problems in early product development and thus reduce costly design iterations. A vast amount of work exists, with most research findings seemingly staying within the research community rather than finding its way into use in industrial settings where research issues have often evolved from the concerned applied research. The aim of this paper is to present an approach with industrial implementation potential regarding automating redesign of sheet-metal components in early product development to avoid manufacturing problems due to design flaws and non-optimal designs. Geometry, generated by a knowledge-based engineering (KBE) system, gives input to the case-based reasoning (CBR) governed manufacturing planning. If geometry is found non-manufacturable or enhancement of already manufacturable geometry is possible, the CBR system will suggest redesign actions to resolve the problem. CBR extends the capabilities of the rule-based KBE-system by enabling plan-based evaluation. The approach has the potential for industrial implementation, since KBE is often closely coupled to an industrial CAD-system, hence enabling technology is at the industry. Also, combining KBE and CBR reduces the coding effort compared to coding the whole design support with CBR, as feature recognition is simplified by means of KBE. A case study of development of sheet-metal manufactured parts at a Swedish automotive industry partner presents the method in use. As it is shown that redesign can be automated for sheet-metal parts there is a potential for reducing costly design and manufacturing iterations.

1 INTRODUCTION

The act of making all manufacturing knowledge needed by the engineering designer in early product development available is crucial to make the right design decisions and iterative changes (Barton et al., 2001). By starting with design for manufacturing (Boothroyd et al., 2001) and concurrent engineering (Prasad, 1997), the importance of re-using experience by making knowledge available to the engineering designer in a computer-based product development environment is nowadays in focus (Finger et al., 1998; Gu and Asiedu, 1998; Stokes, 2001). Obviously, the more manufacturing problems related to design flaws or non-optimal designs that can be avoided, the better. For this issue, design automation is one enabler, (Rosenfeld, 1995; Soman et al., 2003) .

This paper focuses on industry potential research for automated design and manufacturing iteration of sheet-metal parts. Because all designs are subject to formal and informal redesign (Das et al., 1996), this iteration is crucial to be supported in a computer-based product model. A vast number of approaches for computer-based design and manufacturing iteration exist, though industrial close approaches for sheet-metal parts published in academia are deficient. Various other approaches for automated design and redesign have been presented for sheet-metal parts (Ramana and Rao, 2005; Soman et al., 2003; Xie et al., 2001), as well as some relevant research for machining (Das et al., 1996; Zhou and Gaines, 2003). Although many have approached the research issue of automated design and sheet-metal manufacturing iteration, research findings seem to stay within the research community. The potential for technology based firms to develop processes and products in collaboration with non-profit organizations (universities and institutes) is identified as beneficial (Bonaccorsi and Piccaluga, 1994), though not as common practice (Prabhu, 1999). Therefore, the need for an approach with industrial potential is evident.

Knowledge-based engineering (KBE) has proven useful in building computer aided design (CAD) models where both product and process information are available to the designer (Rosenfeld, 1995; Sandberg et al., 2005; Shehab and Abdalla, 2001). Today's KBE systems are often closely integrated to commercial CAD-systems, and a clear industry implementation potential exists. Although KBE is ideal for both conducting topological geometry modifications beyond parametric CAD and directly assessing product cost and manufacturability in, e.g., a commercial CAD-system, it is less ideal for generating manufacturing plans because the knowledge base is often built upon geometry coupled rules instead of computationally effective algorithms and is therefore hard to maintain when the search tree grows. During recent decades, automated planning has developed into an important field of artificial intelligence (Ghallab et al., 2005), of which case-based reasoning (CBR) is an important niche (Britanik and Marefat, 2004; Hanks and Weld, 1992). Although beneficial in limiting computational effort by zooming into a recent product's tree node (of the total search space) and adapting to suit the new product, CBR is less beneficial for making small modifications to the plan and directly assessing the cost.

The aim of this paper is to present a method with industry potential for automating redesign suggestions in early product development to avoid sheet-metal manufacturing problems due to design flaws and non-optimal designs. An approach combining knowledge-based engineering (KBE) and case-based reasoning (CBR) is thus proposed as a way of enabling automated redesign for sheet-metal parts. Because most methods often have benefits and drawbacks, combinations are usually preferable. CBR has been combined with rule-based reasoning (Chi and Kiang, 1991; Marling et al., 1999) and has shown to be successful, since the CBR module can retrieve and adapt a recent case and the rule-based reasoner can modify the details. CAD and case-based reasoning have been previously combined for mechanical engineering design, but only for the planning of finished designs. Product development is an iterative process where many disciplines cooperate in 'synthesize-evaluate' activities. Therefore, being able to change the design, evaluate, change the design again and evaluate and so on, rather than doing the first evaluation on the finished design is beneficial. Hence, a gap exists of how CBR can cope with poor, or not optimized, input being feed to the planner.

The contributions of the proposed approach are manifold. The potential for industrial use is evident as KBE-systems are often integrated with commercial CAD-software, and feature recognition is made easier as all available geometry is coded in the KBE-system, thereby reducing the coding effort.

Section 2 summarizes the relevant related work and section 3 presents the development of the proposed method for automated redesign and the method itself. Section 4 describes the automotive industry example and section 5 discusses the potential of the method and the remaining challenges. The last section summarizes the key conclusions.

2 LITERATURE REVIEW

This section reviews literature in design support systems by starting from a holistic view of product life-cycle analysis. Recent work within automated redesign is discussed and the areas of KBE and CBR, used in the approach presented in this paper are introduced. Design automation for sheet-metal parts is specifically discussed. Finally, concluding remarks are given to clarify the research gap.

2.1 Product life-cycle modeling

Early phases of product development have been in focus for a long time, since it accounts for a major part of the product cost (Barton et al., 2001). This cost is, however, seldom seen by the designer until later in the product development process, e.g. during manufacturing planning. Therefore, holistic methods of how to make available all needed information in a design support system and reduce cost by conducting overlapping activities have been proposed (Prasad, 1997). A main part of the cost is often related to manufacturing (Boothroyd et al., 2001), and though the product-life cycle also includes, for example, maintenance and recycling, much life-cycle analysis research tends to concentrate on manufacturing functions (Gu and Asiedu, 1998). Building intelligent product models have been in focus for several decades, with one of the most popular approaches nowadays to implement knowledge into commercial CAD-systems (Finger et al., 1998). The work cited in this section presents holistic methods for how to enable product life-cycle analysis. Researchers must now specify the details of the methods to reduce the gap between theory and practice.

2.2 Design automation

Recent work on automated design for sheet-metal parts is available (Ramana and Rao, 2005; Soman et al., 2003; Xie et al., 2001). Xie et al (2001) present an internet-based system for intelligent design and manufacturing that has not been developed in collaboration with a partner industry and seems to have too many software components to make implementation practical. Soman et al. (2003) use genetic algorithms and shape grammars to support automated sheet-metal design. Experiments on a real world component are shown, but the work seems to have been conducted without an industry partner. Ramana and Rao (2005) develop and present an extensive work regarding a rule- and plan-based approach for sheet-metal parts in mass production, including verification, quantification and optimization of manufacturing. The system takes a STEP file as input, considered beneficial for industry implementation as the majority of CAD-systems can handle STEP files. Similar to the other two recent works, this work seems to lack industry partners.

Although this paper focuses on sheet-metal manufacturing, some relevant machining work should be mentioned (Das et al., 1996; Lee and Saitou, 2002; Zhou and Gaines, 2003). Das et al. (1996) aim to minimize the setup time for prismatic parts by making use of volumetric features that directly correspond to machining operations. By combining modified and unmodified features, redesign suggestions are generated for the designer to manually choose from. This work is limited to handling already machinable features and setup cost is the only included manufacturability aspect. Lee and Saitou (2002) transform the initial design into constraint networks to handle the connection of manufacturing tolerances, and genetic algorithms are used to find redesign suggestions. This work is outlined to support the family of prismatic parts, but is still limited to only handling already machinable features. Zhou and Gaines (2003) present a tool-centric approach, i.e. assessing if available tools can manufacture the geometry, for identifying and repairing of non-machinable parts. Although the work discussed above seems feasible for the automated redesign suggestion for machined parts, any discussions of the implications on industry practice is omitted due to the seeming absence of industry from these projects.

KBE is an approach growing in popularity for modeling product and process experience coupled to a geometry engine in the CAD-environment (Rosenfeld, 1995). Using KBE is like having one default case to perform "what-if" analysis on. There is some work done in KBE for design and manufacturing iteration, where Shehab and Abdalla (2001) propose a system for inexperienced users to evaluate the cost of machining for a design. Sandberg et al. (2005) explain a method to evaluate machinability for jet engine components. Both of these works lack planning ability, which can be realized with CBR.

CBR is a niche of artificial intelligence that aims to swiftly generate a new solution based on recent solutions (Pal and Shiu, 2004). Hanks and Weld (1992) present a systematic algorithm for adaptation in cased-based planning. The authors claim it to be domain-independent, though it is only exemplified on Blocks World problems (BlocksWorld), and can only take correct input (e.g. manufacturable parts). Marefat and Britanik present CBPOP which uses multiple cases to form the new case (2004). As with the former work, this is only tested on Blocks World problems rather than real world problems. Many results from artificial intelligence research seem to remain in research laboratories and, according to Cser et al., one explanation is the isolation from the CAD/CAM environment in the factory (1991). It is further stated that a standardized product model, unification of knowledge acquisition, storage and processing, and compatibility with commercial CAD/CAM systems can help the usability of artificial intelligence techniques in industry. Few CBR approaches enable the iteration of design and manufacturing evaluation, though a majority of recent work does plan manufacturing for finished designs.

KBE systems have industry potential, but lack the ability for comprehensive manufacturing planning. It is claimed that there is a significant ability to use rule-based reasoning to generate new cases for later use by a CBR module (Marling et al., 1999). Also, retrieving an old case and performing "what-if" analysis is beneficial.

2.3 Concluding remark

To reduce the gap between holistic methods for product life-cycle modeling and industry detailed methods are needed. Recent design automation research in for example sheet-metal and machining evaluation of designs is available but few researchers have collaborated with the industry. As much work is focused on manufacturability evaluation of finished designs there is also a lack of work that supports automated redesign. Therefore this paper embarks the gap of automated redesign of sheet-metal parts with industry potential.

3 PROPOSED APPROACH

This section describes the method of combining KBE and CBR to enable automated design and manufacturing iteration of sheet-metal parts with industry implementation potential. The problem search space is discussed, followed by the motivation of approach, an overview of the information flow between the user, the KBE system and the CBR system, and finally the corresponding algorithms.

3.1 Search space

The question to answer in this work is: How to find combinations of geometry and sheet-metal manufacturing configuration with a feasible manufacturing cost by means of a computer-based design support? The generic property of this question makes the search space infinite, as geometry dimensions often are continuous. Therefore, the variables describing the geometry and sheet-metal properties must be made discrete. The initial state is the default geometry generated by the KBE system and the goal state is a geometry and sheet-metal manufacturing plan that satisfies the target cost. The scope of this research includes the following variables: *Hole parameters, sheet-metal geometry dimensions, material, bending parameters, embossing parameters, hole making parameters* and *plan sequence parameters.* Concerning sheet-metal manufacturing without automated redesign, it is possible to hierarchically visualize the planning levels; see Figure 1 for a hierarchy that is connected to the example case study presented in the next section. The arrows in Figure 1 indicate order of operations.

Picturing the search space including automated redesign is not a straightforward process, as it is possible to change almost any of the variables at each state. Thus, it is important to specify the constraints between each state variable to omit non-feasible states. One way to do this is to create a constraint network; see Figure 2 for a constraint network created in the case study.

3.2 Motivation of approach

Because this research collaborates with industry in an applied research, it is important to make the results useable while still containing the research approach. KBE is often available as a CAD software module or can be reasonably easy to join with an existing CAD environment, since KBE-systems are built to handle geometry (Rosenfeld, 1995).

Some planning approaches are available, e.g. partial ordered planning (POP) and hierarchical task network planning. CBPOP is a domain-independent POP for systematic retrieving, suitable for reuse for finished geometries without giving geometry change proposal (Britanik and Marefat, 2004). Hierarchical task network planning is useful when the planning search space is hierarchical, as is often the case with manufacturing planning, shown in Figure 1. However, when automated redesign is needed the search space is less hierarchical.

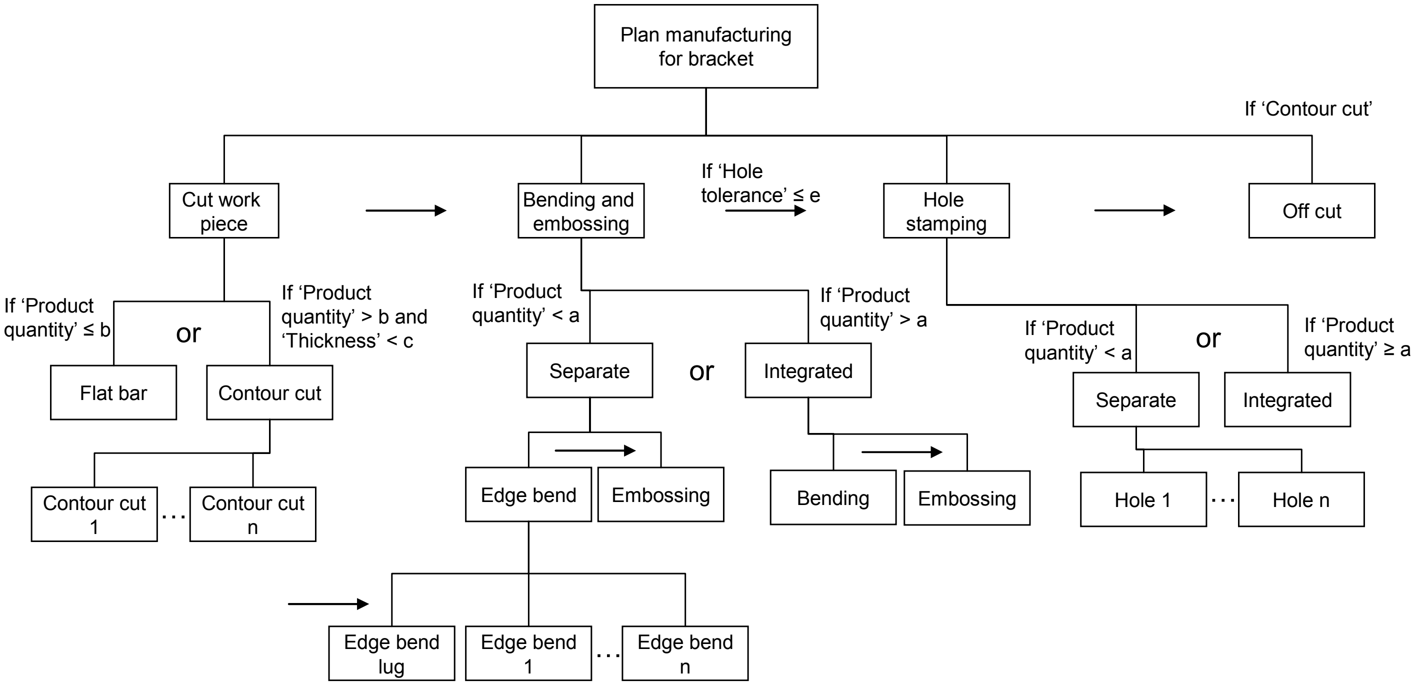


Figure 1. Hierarchical planning for sheet-metal manufacturing.

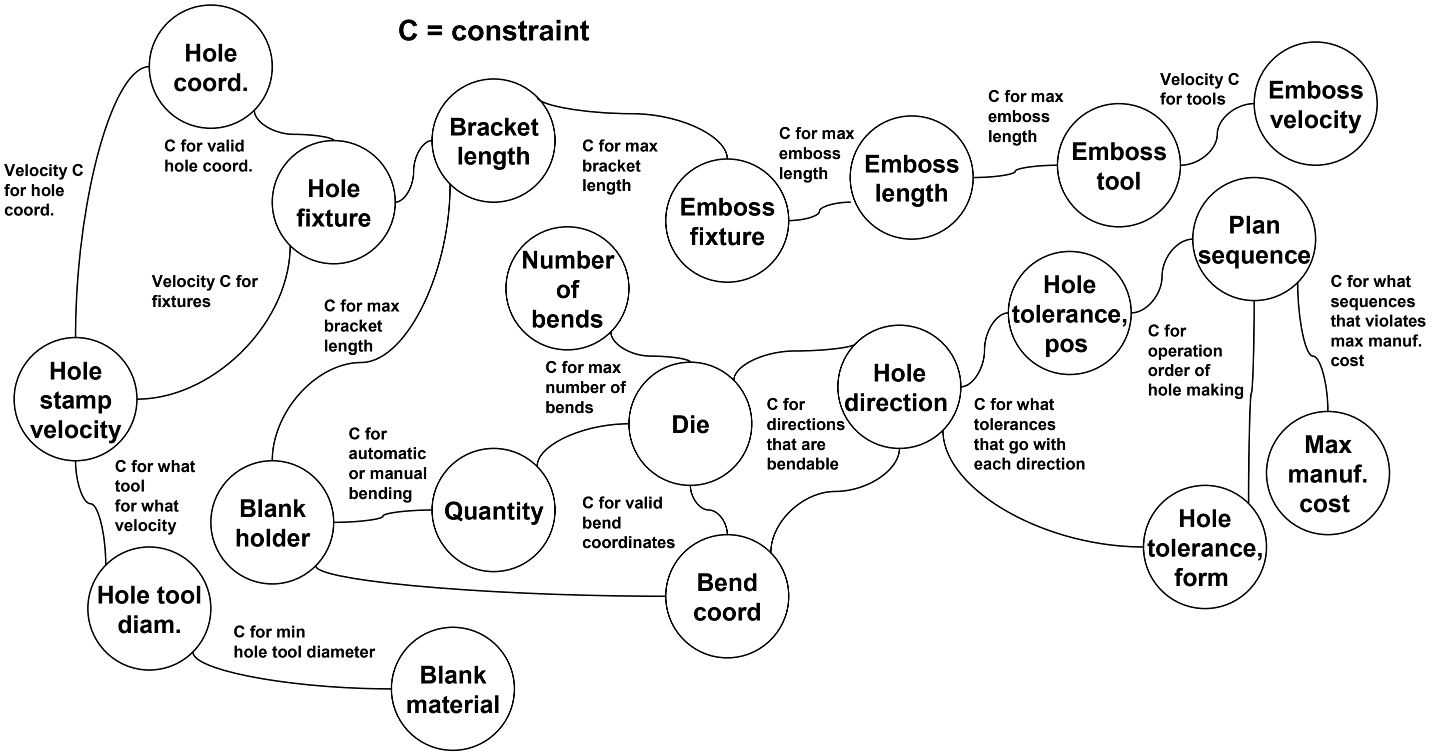


Figure 2. Constraint network.

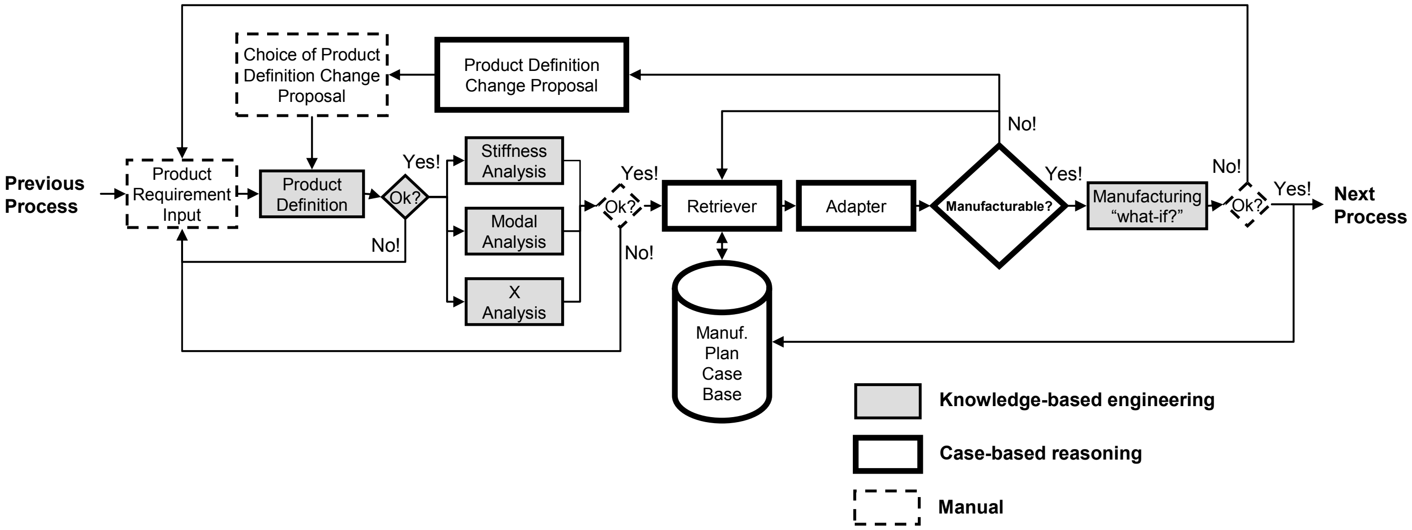


Figure 3. Information flow between user, KBE and CBR.

The development of the method was an iteration of studying recent work, generating research ideas and implementing the case study example.

3.3 Information flowchart

An information flow chart between user, KBE-system, and the CBR module for design and manufacturing iteration of sheet-metal parts is presented in Figure 3. The information flow is divided into three parts – *KBE generation and analysis*, *CBR* and *KBE "what if" analysis*.

The first part starts with the user providing requirements to the system, such as some feature coordinates and manufacturing requirements, by using a specially designed graphical user interface. A geometry is then generated based on the input. If the input results in non-feasible geometry, e.g. due to feature collision or manufacturability problems, an error message informs the user to alter the geometry. The geometry can then be subject to routine analysis, i.e. that is performed often and is therefore suitable for automation in terms of, for example, modal and stiffness analysis. The last part of *KBE generation and analysis* is when the user assesses the analysis results and decides whether to keep the geometry or give new requirements inputs to the system.

The first part of *CBR* is an algorithm for *retrieving*, which takes the KBE geometry code as input and retrieves a number of similar manufacturing plans by working through abstraction levels. Adapted from Pitta (2005) the abstraction levels are defined as:

- Level 1 – Feature availability
- Level 2 – Feature type
- Level 3 – Geometry dimensions
- Level 4 – Geometry tolerances
- Level 5 – Process details

The plans for which the retriever reaches the least abstract levels (the higher level number the less abstract) will be retrieved. If no plan exists even for Level 1, an arbitrary plan is retrieved. The adapter then uses an algorithm for *adapting*, for example (Hanks and Weld, 1992), chooses the most similar plan using a similarity metric and tries to adapt this plan to the geometry using manufacturing process knowledge. The similarity metric is used to find the best plan if more than one reaches the same abstraction level. If the adapter fails to adapt, the geometry is considered non-manufacturable and two events are triggered. The first event is when the retriever gets feedback on the problem of adapting the recent plan to reduce retrieval of non-feasible plans in the future. In the second event, the product definition change proposal (PDCP) algorithm is triggered and the PDCP algorithm pseudo code is described in Figure 4. *General geometry change proposal* in row 8 in Figure 4 constitutes general design for manufacturability guidelines, such as using feasible tolerances (Bralla, 1999).

```
1.  function PDCP(abstraction_level, geometry_dimensions,
    geometry_tolerances, manufacturing_problem)
2.  if abstraction_level =  1
3.    then print "The rule base for adaption need to be updated for this
    geometry type"
4.  else for i in manufacturing_problem
5.      if manufacturing_problem exist in database
6.        then for j in geometry_dimensions
7.          do geometry change proposal(j, manufacturing_problem(j))
8.      else print general geometry change proposal
```

Figure 4. The PDCP algorithm pseudo code.

The product definition change propositions are presented for the user who can manually choose among the propositions.

If the adapter manages to adapt the manufacturing plan, then the last part, *KBE "what if" analysis,* is entered. The manufacturing plan is presented for the user who can assess the plan, try to improve the manufacturability by changing some details in the geometry and the plan, and directly see the how the manufacturing cost changes. When satisfied, the user decides if the manufacturing plan is different enough to be saved in the case-base and moves on to the next product development process. When a plan is saved to the case base its parameters are abstracted to reduce the effort of the retrieving algorithm to find recent plans.

3.4 Algorithm requirements

This section describes requirements that apply to the algorithms of this approach: *PDCP*, *retrieving* and *adapting*. Hanks and Weld (1992) point out three important requirements an algorithm should have to be effective: *systematic*, *complete* and *sound*. When searching for a solution the systematic requirement states that each node in the search space will be visited only once. Completeness states that if a solution exists the planner will find it, and soundness guarantees the correctness of this solution.

4 INDUSTRY EXAMPLE

This section presents a case study example at a Swedish automotive manufacturer. The product is outlined and the knowledge acquisition and formalization parts are then presented. The specially designed graphical user interface is shown next and finally an example scenario is given.

4.1 Product

The design of brackets found in automotive products was chosen as the industry example because this product exists in a variety of ways in automobiles. Bracket geometry may be fairly simple to design, but most brackets of the industry partner are manufactured from a flat bar that makes the design of the bends time demanding and motivates support by KBE. The bracket example shown in Figure 6 is intended for the fastening of the vehicular horn. A number of requirements are of interest here: bracket attachment to horn, fundamental frequency, harmonic frequency content, vibration, production quantity and maximum allowed manufacturing cost.

4.2 Knowledge acquisition

Interviews, CAD-models and manufacturability handbooks were used for knowledge acquisition. Senior designers and manufacturing engineers were interviewed and are considered representative of the process. Standardized methods such as MOKA (Stokes, 2001) are available, where special forms are used to collect the knowledge and visualize the connections between all rules. This method is more useful in larger projects.

4.3 Formalization

Knowledge Fusion (KF), a module integrated in UGS NX3, (UGS), was used as the KBE system. KF uses the LISP (list processing)-based language Intent! for the coding of the rules. Some geometry objects were not supported by the predefined classes in KF why the NX function user-defined features were applied. The class hierarchy is shown in Figure 5.

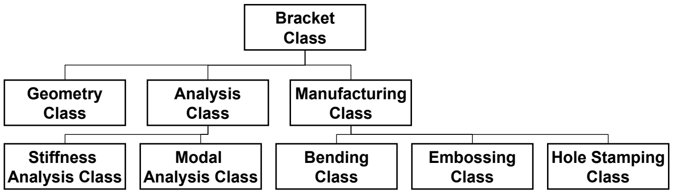
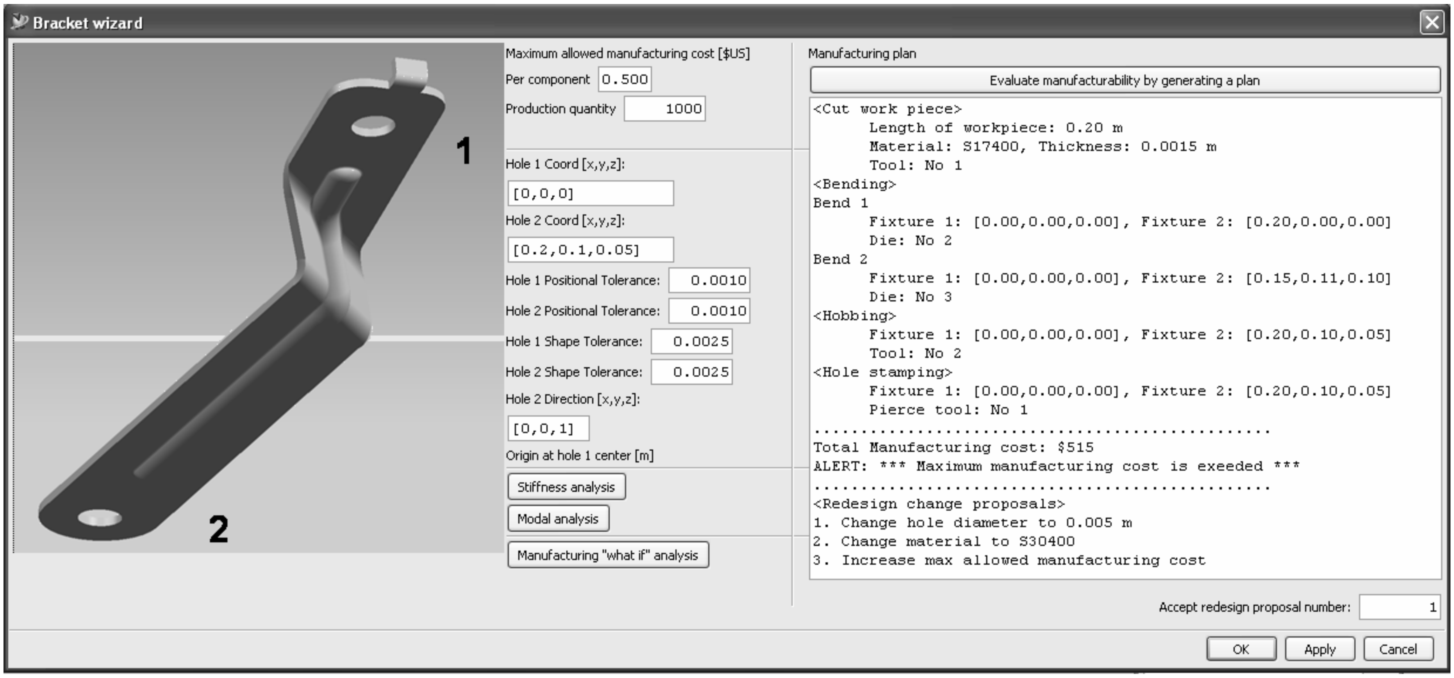


Figure 5. The bracket wizard class hierarchy.

Python (Python), was used to program the CBR algorithms plus the additional PDCP algorithm.

4.4 Graphical User Interface

A graphical user interface was developed using the UI styler module in UGS NX. Based on a direction, two hole coordinates and position and shape tolerances, a bracket geometry is generated by the KBE-system, as shown in Figure 6. Maximum manufacturing cost and production quantity are parameters for the manufacturing evaluation by the CBR module.



Maximum allowed manufacturing cost [$US]
Per component: 0.500
Production quantity: 1000
Hole 1 Coord [x,y,z]: [0,0,0]
Hole 2 Coord [x,y,z]: [0.2,0.1,0.05]
Hole 1 Positional Tolerance: 0.0010
Hole 2 Positional Tolerance: 0.0010
Hole 1 Shape Tolerance: 0.0025
Hole 2 Shape Tolerance: 0.0025
Hole 2 Direction [x,y,z]: [0,0,1]
Origin at hole 1 center [m]

```
<Cut work piece>
      Length of workpiece: 0.20 m
      Material: S17400, Thickness: 0.0015 m
      Tool: No 1
<Bending>
Bend 1
      Fixture 1: [0.00,0.00,0.00], Fixture 2: [0.20,0.00,0.00]
      Die: No 2
Bend 2
      Fixture 1: [0.00,0.00,0.00], Fixture 2: [0.15,0.11,0.10]
      Die: No 3
<Hobbing>
      Fixture 1: [0.00,0.00,0.00], Fixture 2: [0.20,0.10,0.05]
      Tool: No 2
<Hole stamping>
      Fixture 1: [0.00,0.00,0.00], Fixture 2: [0.20,0.10,0.05]
      Pierce tool: No 1
.................................................
Total Manufacturing cost: $515
ALERT: *** Maximum manufacturing cost is exeeded ***
.................................................
<Redesign change proposals>
1. Change hole diameter to 0.005 m
2. Change material to S30400
3. Increase max allowed manufacturing cost
```

Accept redesign proposal number: 1

Figure 6. Graphical user interface for bracket wizard.

4.5 Example scenario

Hole positions, hole direction, geometric tolerances and maximum acceptable manufacturing cost are specified by the user, with KF generating a geometry (with hole diameter D1) assuring that general design for manufacturability recommendations are followed, e.g. minimum distance between the hole and bend and since the part will be made from a flat bar that is bent, KF assures a bendable geometry. Modal and stiffness analyses are found satisfactory. Retriever fetches the most similar plan. During adaptation it is found that the hole is too small to be pierced. Drilling is then chosen, but is more expensive and the maximum manufacturing cost is exceeded. PDCP algorithm suggests among others an increase of hole diameter (to D2) to allow for the less expensive piercing and user chooses diameter D2. Modal and stiffness analyses are still satisfactory and the retriever fetches most similar plan. It is possible to adapt the plan and is therefore acceptable. The plan is shown for user who can try "what-ifs" by changing the manufacturing plan (fixture positions, piercing details, etc.) and the manufacturing cost is presented. The complete manufacturing plan is stored in the case-base if the plan is different enough than earlier plans.

5 DISCUSSION

In this paper an approach for computer-based design support with industry potential for the design and manufacturing iteration of sheet-metal parts is presented. This section discusses this approach from four aspects: the industry potential is argued, the systematic issue of the algorithms is discussed, the issue of integrating KBE and CBR is presented, and the research methodology is discussed.

5.1 Industry potential

One drawback for the research community is that its interaction with industry often relies on students as the knowledge transfer mechanism instead of researchers collaborating directly with the stakeholders on a more frequent basis. It is, however, important to always seek a long-term relationship that can provide industry issues more of a research essence. By implementing research ideas in computer environments similar to industry, in this case UGS NX, implementation is made straightforward compared to a specially developed software. The freeware software Python also reduces expensive software investments during implementation. This approach also facilitates the use of CBR-related work, since a KBE-system is used as an entrance to the industry computer environment. There is, however, a need for an industry position to manage these knowledge intensive design support systems, where a person with broad skills in mechanical, manufacturing and computer engineering is required.

The industry implementation of the proposed approach still needs time to be realized fully. Still, it is better to aim towards an industry potential and have preliminary results than have comprehensive results lacking industrial potential. One way to measure industry potential is by counting the number of software systems used by both the researcher and industry. In this case the CAD-system UGS NX, where the KBE system KF is a module, is used by both. Other factors also decide whether a research result has industry potential or not, e.g. how willing the industry staff is to changing their working process to adopt the results. This factor can be estimated by conducting an interview investigation or by allowing groups of engineers from design and manufacturing test the case study demonstrator. Industry design engineers have tested the case study demonstrator with positive feedback, though to clearly state that this approach can reduce costs for industry the tests have to be more extensive. To show a major impact of research results the case study demonstrator has to be extended to embody more product development knowledge by, for instance, coupling the KBE system to other systems for e.g. finite element analysis and computer aided manufacturing systems.

5.2 Algorithms

It is more a matter of specifying the algorithm requirements than trying to make new contributions to CBR algorithms. The PDCP algorithm is most important here and needs to be tested to determine whether it is systematic, complete and sound enough to help design and manufacturing iteration.

5.3 Issues with integrating KBE and CBR

One benefit of combining KBE and CBR is that feature recognition is made easier because KBE attributes can be read by the CBR module compared with feeding the CBR system a non-documented geometry definition, an arbitrary geometry file like constructive solid geometry, boundary-representation, STEP or IGES. The programming skills requirements of the design support developer are reduced as KBE reduces the often intricate act of feature recognition. Recognizable features are, however, limited to the geometry of the KBE model.

Both KBE and CBR are used to evaluate manufacturability through holistic and "what-if analysis" (KBE), and by extensive evaluation (CBR). Rather than evaluating the design in one fashion it is believed that by using three different approaches, a broader spectrum of manufacturing issues can be evaluated. Therefore, this work also shows how CBR can be used earlier in product development, since designs being fed into the planner are not finished designs, but rather designs that are subject to several iterations.

5.4 Research methodology

In the area of design support for mechanical engineering design, much applied research exists where a software system is developed and the authors often try to lift the results up to a more systematic and generic level. In computer science, the work tends to be systematic and stringent, though these works are seldom done in collaboration with an industry partner. Today, computational power makes it possible to model anything; instead, it is more of an issue of how to best manage the information to optimize the usefulness of the model. Computer science can therefore be useful to tackle such issues. Hence, a multi disciplinary approach combining mechanical and computer engineering is beneficial for this research issue.

6 CONCLUSION

Automating redesign is an approach for engineering designers to prevent design related manufacturability problems in early product development and thus reduce costly design iterations. This paper presents an approach for computer-based design support of design and manufacturing iteration of sheet-metal parts where KBE and CBR are combined. Geometry is generated and holistically analyzed by the KBE system on which CBR is used to extensively evaluate the manufacturability by generating a manufacturing plan. If the CBR system finds that the design is non-manufacturable or can be enhanced for more robust manufacturing, redesign proposals are automatically generated for the user to choose from. When the CBR system manages to adapt a recent case to the new case, "what-if" analysis can be conducted using the KBE system. The contributions of this work can be summarized as:

- Helping the designer to design for manufacturing, providing a potential for reducing costly design and manufacturing iterations due to design flaws.
- Showing the industry potential by basing the approach on a KBE-system that often already exists in the computer-based design environment. CBR also becomes more available, since a KBE system is used to enter the computer environment.
- Showing how to combine KBE and CBR to reduce the programming demands on the design support developer as feature recognition is facilitated.

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