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# Design Automation Systems for Production Preparation

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**ABSTRACT**

Intensive competition on the global market puts great pressure on manufacturing companies to develop and produce products that meet requirements from customers and investors. One key factor in meeting these requirements is the efficiency of the product development and the production preparation process. Design automation is a powerful tool to increase efficiency in these two processes. The benefits of automating the production preparation process are shortened led-time, improved product performance, and ultimately decreased cost. Further, automation is beneficial as it increases the ability to adapt products to new product specifications with production preparations done in few or in a single step. During the automation process, knowledge about the production preparation process is collected and stored in central systems, thus allowing full control over the design of production equipment's. Three main topics are addressed in this thesis: the flexibility of design automation systems, knowledge bases containing conflicting rules, and the automation of the finite element analysis process. These three topics are discussed in connection with the production preparation process of rotary draw bending.

## INTRODUCTION

### The importance of design automation for production preparations

Four critical factors for being competitive on the global market have been pointed out: low cost, short lead-time, improved product performance, and the possibility to adapt products to different costumer specifications (French, 1999). An automation of the production preparation process will shorten lead-time and make the adaptation of products to different specifications easier. An automation of production preparation would help improving product performance since it enables a common knowledge base, to which quality assurance issues can be targeted. The automation makes it possible to evaluate a big number of solutions.

The ultimate reason for doing research on design automation is to avoid using human engineers from doing routine-like work and instead freeing them to do what they are really good at, creative thinking. Design automation for the production preparation will also help optimise products against production criteria since the production preparation is done in the same step. The design, evaluation and adjustment of toolsets are done automatically to new product specifications. When optimising the product, production criteria are hence available objectives. At the end, the automation of the production preparation process will make companies more competitive on the global market where constant, large economic pressure is the reality today.

### Mass-customization and variant rich products

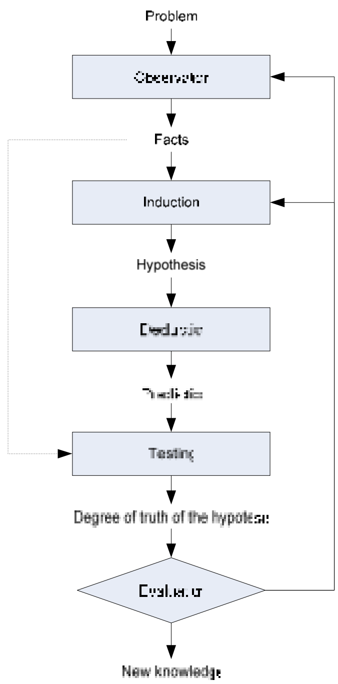
One of the critical factors for being competitive mentioned above is the possibility to adapt products to different customer specifications. This has led to mass customization, defined as "producing goods and services to meet individual customer's needs with near mass production efficiency" (Kaplan and Haenlein, 2006). Design automation helps the development of mass-customized products since they have many variants and are a good automation target. Many of the variants can be achieved by configuring components, but many times more advanced tasks need to be completed. Examples include dimensioning using advanced formulas or verifying using simulations. Design automation supports the mass-customization by automating these tasks.

**Research project and case of application**

The application of rotary draw bending of aluminum profiles has been the target of design automation. This application is beneficial because rotary draw bending is a common forming process in the industry. Adding knowledge on how to automate the design of toolsets for that process is of great importance itself. Further, the rotary draw bending process is representative of other metal forming processes, making them plausible applications for design automation using the same methods.

## RESEARCH METHOD

It has been stated that research conducted on computer systems needs to be empirical (Simon, 1996). This is especially true for large computer systems, since they are too complex to build mathematical theories around without first building and observing them. A method to conduct empirical research is described by Groot (1969) as: Observation – supposition – expectation – testing – evaluation. This method has been adapted in the field of design and in the field of design automation. The adapted process is shown in Figure 1, and is taken from Roozenburg and Eekels (1995). This process starts with a problem definition, followed by observations resulting in a collection of facts. The facts are used to do an induction, resulting in a hypothesis. The hypothesis is use to deduce a prediction. To evaluate the level of truth in the hypothesis, the deduced prediction is tested against the real world.
New knowledge is the result of the process.




**Applying the research method**

Adapting the mentioned research method into the project resulted in the process shown in Figure 2. As seen, the first step is the problem definition, i.e. the selection of research topics. Then engineers are observed to see what activities, rules, and methods are suitable to be automated in the design process. Knowledge about how to create the knowledge base is then induced using the observations of the design process. The induced knowledge, together with background knowledge about design automation systems, is used to plan a design automation system for the selected product development sub- process. That step can be viewed as stating a hypothesis and deducing the system plan.

## FRAME OF REFERENCE

**Design automation**

Research done in the field of design automation is concerned with questions regarding how to automate the design process by means of computer implementations.

Recent research in design automation has concerned the planning of design automation systems (Cederfeldt, 2007), how to make use of product information in the early phases of the product development process (Boart, 2007), the design process of functional products (Löfstrand, 2007), how to automate producibility aspects from a costing perspective (Elgh, 2007), and design for manufacturing (Sandberg, 2007). A design automation system affects many individuals in a product development company and organizational aspects need to be considered. Research concerning that problem is found in (Catic and Malmqvist, 2007), where knowledge-based engineering is intended to be integrated into the product lifecycle management system.

**Knowledge Based Engineering**

Knowledge based engineering aims to automate engineering tasks by means of knowledge-based systems. The fact that the concept of KBE has many definitions might be due to the wide area of the knowledge-based systems and their many sub-categories. The definition of KBE adopted in this thesis work is the one stated by Stokes (Stokes and MOKA Consortium, 2001): "The use of advanced software techniques to capture and re- use product and process knowledge in an integrated way."

A general structure of a knowledge-based system is shown in Figure 4, adapted from (Hopgood, 2001). As seen in Figure 4, the two keystones in a knowledge-based engineering system are the knowledge base and the inference engine. The knowledge base is comprised of facilities to store knowledge in the sense of information in context. This means that structuralized data is stored with its context in a way that makes it possible for the inference engine to make use of it. Hence, the knowledge is separated from the routines (the inference engine) that make use of the knowledge.

**A rule-based system**

Abdel-Malek and Maropis (1998) performed the earliest of the research works found. In that work, theories from seamless design to manufacture (SDTM) were used to build a system for manufacturability analysis. That work presents an automated system for design-to-manufacture which can perform post-fabrication operations concerning bending and other processes. The system is a rule-based system integrated with a CAD-system (see Figure 7). The system enables the automatic design of the toolset assembly and generation of blue prints and NC code for appropriate mechanical parts. To make it possible to create and edit rules, a user interface was developed using three different types of "nodes" for displaying/retrieving data to/from the user, for performing calculations, and for branching to other "nodes". The user interface was developed using the development tool Symbologic Adept, the rule base was developed using AutoLisp, and routines for the generation of drawings and NC-code were developed using the C language.

**A goal-driven system**

Jin et al. (2001) performed the second work found describing the design automation of toolset for the rotary draw bending. It describes an object-oriented approach combined with an inference engine using a goal driven search mechanism. The objects created to build the knowledge base were collections of rules as they appear in a rule-based system. Semantic networks were used to describe the objects internal rule-set. The development language LEVEL5 OBJECTS was used to build the system. Figure 8 shows an example of the internal rule-set of an object for determining whether the final wall thickness will meet product requirements. Figure 9 shows how the inference mechanism in LEBEL5 OBJECTS connects different objects.

## DESIGN AUTOMATION SYSTEMS WITH A HIGH DEGREE OF FLEXIBILITY

**Knowledge objects**

Object-oriented programming offers the possibility to develop highly flexible programs, and a class of objects called knowledge objects* is proposed (see Figure 12). The least amount of information a knowledge object contains is a list of input parameters, a list of output parameters, and a method for process input parameters to output parameters. Other fields may be added to a knowledge object. Proposed additional fields are constraints, owner, categories, precision, and comments. Owner is used to trace who are responsible for the knowledge object and its method (the task it performs). The field categories can be used to sort knowledge objects into groups. Comments are used to add information usable for explanation extractions and debugging facilities. Finally, the list of constraints and the precision value is used to allow knowledge bases to contain conflicting knowledge objects (see further in Chapter 5.2.1).

When implementing the knowledge objects, they should be defined in a way that makes them autonomous. Since the methods used to process information preferably are external software applications, the applications should be selected keeping in mind the list of requirements imposed on the design automation system: low effort of developing, user readable and understandable knowledge, longevity, and ease of use (Cederfeldt, 2007).

**Inference engine**

An inference engine is needed in order to use the knowledge stored in the knowledge base. The engine is used to arrange the knowledge in the knowledge base in an executable order. Two main types of search-based inference engines exist: forward and backward-chaining (see Figure 13). A forward-chaining (also called data-driven) mechanism uses the information initially presented to fire all rules it can ever find. The method has two steps. In the first step, triggered rules are listed. In the second step, an appropriate rule from the triggered ones are selected and fired. After firing the selected rule, all triggered rules are listed again and so on, until no triggered rules are found. If knowledge objects are used to build the knowledge base, the inference engine searches for knowledge objects with all input parameters known and selects one of the found knowledge objects to execute the method defined in that knowledge object to calculate output parameters using the input parameters. When the method has run, the stock of known parameters is updated and a new search for executable knowledge objects is begun (see Figure 14).

A backward-chaining mechanism (also called goal-driven) is fed with information of a final state. The mechanism then searches backward to see how to end up at that state. When knowledge objects are used, this means searching the parameter dependencies to see what information is needed to retrieve wanted output parameters.

**An event driven inference engine**

Event handling is available in today's operating systems. And here it is proposed that the inference engine should make use of these advanced functions in the operative systems. That gives an event-based forward chaining search mechanism working as follows. When a parameter is changed, an event is raised in the system notifying that a change has occurred. This triggers an update of the conflict set. If there still are objects left in the conflict set, an object is selected according to implemented rules for selection in order to execute the object. When the object is executed, its output parameters are changed and the conflict set is updated, and so on (see Figure 15). The benefits of using events are the following: when implementing the inference engine, a lot of loop algorithms are avoided and when running the system the inference engine is triggered automatically on change, no extra button clicks are needed (unless functionalities for avoiding automatic updating are implemented and activated in the system).

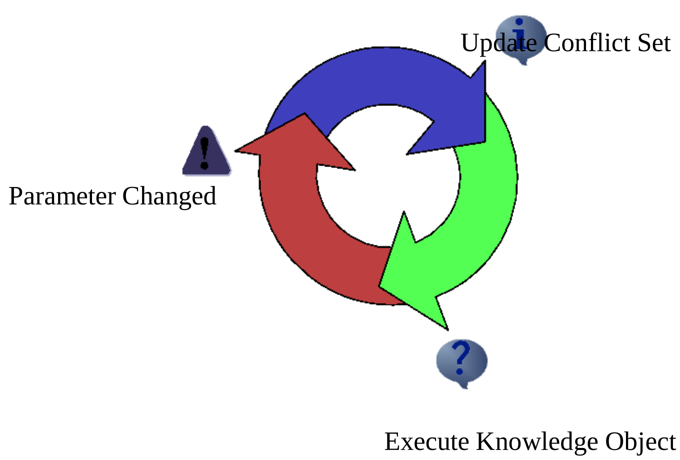



**Figure 1: Using event handling when implementing an inference engine means that routines are run on changes. The change of a parameter triggers the system to update the conflict set. If it is not empty, a knowledge object will be fired causing parameters to change and so on. The loop is driven by parameter changes.**

## HANDLING THE SITUATION WHEN MULTIPLE TYPES OF KNOWLEDGE COEXIST

**Different sources of knowledge and meta-knowledge**

It is possible to calculate a single variable in different ways. Sometimes a heuristic rule can be used, or rules analytically derived from fundamentals. But it is also possible to do FEM-calculations or experiments to evaluate an interesting design variable. In addition to these four types of knowledge, an engineer also needs to have the capability to decide when to use what knowledge; this is called meta-knowledge or knowledge about knowledge.

When more than one type of knowledge source is available in a knowledge base, the question of when to use what rule arises. In one state, the system may be executed in order to do a quotation calculation with only a small set of input parameters available. In the next step, detailed design is the purpose of running the system, with high accuracy as the main focus and with a larger set of input parameters available. Different kinds of knowledge are used in those different contexts, and implementing meta-knowledge would allow for flexible use of the system. A description of the different types of knowledge is presented below.

**Finite element analysis**

There exist a number of numerical methods for solving different engineering problems. Probably the most common method is the finite element method (FEM). FEM can be used to solve many engineering problems. However, the results depend greatly on what mesh density and elements are used, what boundary conditions are prescribed, what material model is used, and what time step is set.

Using FEM appropriately will give highly reliable data. The drawback is that, compared to heuristic and analytical knowledge, FEM is costly to use both in money, competence, and time. In addition, it does not explicitly answer the question of why things happen. The benefit is that FEM allows full control over the process so it is easy to scroll in time and space, doing sections and plotting different parameters.

Worth mentioning in this context is that simulation-tools are comparable to instruments for measurements, i.e. they must be calibrated. This calibration is done via result feedback. Over time an accurate model will be developed.

**Evaluating the knowledge adaptability**

In order to evaluate the knowledge adaptability, a knowledge base with conflicting knowledge objects was developed and solved, and the product preparation of the rotary draw bending was targeted. To speed the process of defining the knowledge objects and to make an overview of the solve process, a graphical user interface was developed. The user interface contains two main controls, one tree view showing the knowledge objects and parameters, and one frame showing the conflict set (see Figure 25). Functions for developing and maintaining the knowledge base were also developed and added to the graphical user interface.

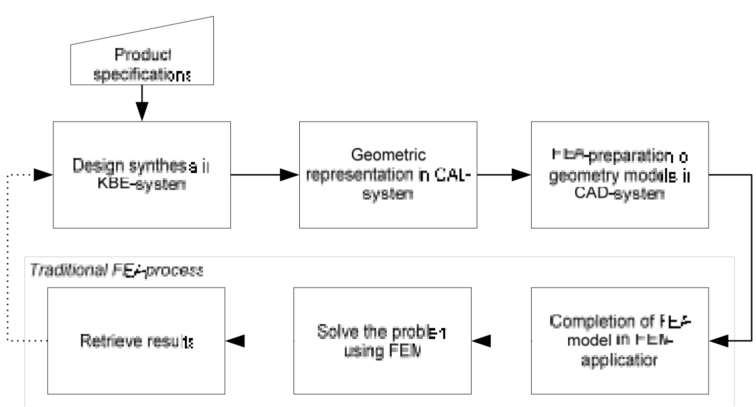
## FLEXIBLE AUTOMATION OF THE FINITE ELEMENT ANALYSIS PROCESS

**Running an automated FEA-process within the global KBE-system**

Automating the FEA-process and adding the supporting methods to the KBE-system is the same as adding a local automation system into the global design automation system. The execution process of the global design automation system will then be as shown in Figure 26. What starts the process is the presentation of product specifications. This will trigger the inference engine to execute directly available knowledge objects, ending up with a design proposal. The design proposal is represented in a CAD-system where idealizations are defined as well. The design representation with its idealizations is interpreted to generate a FE-model. Knowledge objects in the global design system are used to generate a recipe for how to execute the FE-model. The FE-model and the recipe are sent to a FEM-solver. When the solver has finished, other knowledge objects in the global design system interpret the results by evaluating whether the design proposal was good. The different steps are described in detail in the subsections below.

**Geometric representation**

The geometric representation of the design proposal can be established by a generative or a template approach. The former approach is usually achieved by using macro programming in the CAD-system, while the latter uses pre-defined CAD-models that are configured. Combinations of the two approaches are possible.




One benefit of the template approach is user friendliness. It is easy to make pre-defined models using feature-based modelling in a modern CAD-application and make the system do the configuration. One drawback with the template approach is that it can be hard todo the design automation systems general.

## CONCLUSIONS

In this thesis, methods for automating the production preparation of rotary draw bending toolsets have been presented. In the introduction, an overall research question was stated and divided into three sub-questions. The answers are detailed below. How to apply the concept of design automation to rotary draw bending toolsets for aluminum tubing? Experience dictates that, depending on the intended level of automation and intended flexibility of the automation system, it is possible to implement heuristic and analytical knowledge into KBE-systems using feed forward chaining and rule-based or object-based knowledge representation. A decision has to be made whether the system should allow multiple rules for a parameter (m to n mapping) or if a parameter may only be calculated from one rule (one to n mapping). If the m to n mapping is found beneficial, experiments have shown that object-oriented programming can be used to define knowledge objects as the knowledge representation and a search engine can be used to interpret the knowledge base in different situations.

It has proven to be possible to make the system able to analyze its design proposals through the automation of FEA-process for tube bending. How should design automation systems be built to allow a high degree of flexibility? Using object-oriented programming has proven to be a fruitful way to make the design automation system highly flexible. Each rule or knowledge chunk is defined as an independent object with two lists containing inputs and outputs and an attached method for processing the inputs to outputs.

**The flexibility of the design automation systems**

In this thesis, it is stated that the flexibility of a design automation system will increase if the object-oriented view is adapted to the knowledge base. This has been verified through the implementation of an inference engine and a knowledge base using the object orientation. In that implementation, it is possible to create, edit, suppress, and remove knowledge chunks without breaking the system. The operations can be done regardless of what order the knowledge was added in (i.e. there is no history). When editing the knowledge base, the execution sequence will change automatically according to changes. The drawback with the system being that flexible is that it is hard to foresee what effects changes in the knowledge base will have.

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