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A Case-based Reasoning Method Including Tooling Function for Case Retrieval and Reuse in Stamping Tooling Design

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Abstract. Design of sheet metal forming tooling is currently based on that experienced tooling designers with good knowledge of how stamping tools previously have been designed and operated in production, apply their knowledge when making a new design. For retrieving former designs, they often need to rely on their good memory. In this paper, an automatic method for retrieving relevant former cases is presented. A major challenge is defining the similarity between the current and the former cases i.e., finding the relevant parameters to include in the CBR (Case-based reasoning) search. This is here addressed by using CAD model parameters both from former components and the tooling for their production. By interviewing tooling designers in industry, a set of relevant parameters has been identified. To arrive at the correct weight of each parameter, a genetic algorithm has been used to optimize the search results. This resulted in a quick and automated way of retrieving the most relevant former cases and presenting them to the designer. The method has been tested on actual cases with promising results. This has the potential of making sheet metal part and tooling design less reliant on memory and experience.

Keywords: Sheet metal forming, Case-based reasoning, CBR, Genetic algorithm, CAD model, Tooling design
DOI: https://doi.org/10.14733/cadaps.2023.839-855

1 INTRODUCTION

Sheet metal forming by stamping is an efficient and economical way of manufacturing many different types of sheet metal products. However, the design and manufacturing of the stamping tools represents a large part of the component cost and lead-time and therefore it is desirable to improve the efficiency in this process. This is becoming especially important with demands on customization and the increasing number of product variants. Thus, design tools for supporting and increasing the efficiency in stamping tool design have emerged. When a new stamping tool is designed, the tooling designer seldom starts with a blank sheet of paper. There is often a collection of former cases to be considered for retrieval and adaptation to the task at hand. The tooling designer will perhaps have printed files in an archive to search and retrieve the most

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relevant cases from. However, finding these past solutions is very much dependent on the experience and good memory of the tooling designer. The outcome is therefore unpredictable. To alleviate the situation, a searchable database of former cases can be created. By employing search algorithms, the most relevant existing solutions can be automatically retrieved. This gives the tooling designer a selection of former cases to re-use by adapting them to the task at hand.

In this paper, a method for automated and systematic retrieval of previously designed stamping tools is proposed. The retrieval of candidate stamping tools is based on finding the geometric similarity between the current and the former CAD-models automatically. This has been tried previously, but there are still some challenges regarding how similarity should be defined, as geometric similarity is ill-defined, Kumar and Singh [16]. A relevant metric of similarity depends on the application context, the objective, and what knowledge the designer is searching according to the same authors [15]. In the stamping tool design process, the information and knowledge sought for at different stages are different, Kumar and Singh [14] and require individual similarity metrics and parameters to be effective. An example of this is that the relevant stamping tools to retrieve when designing the functionality for part ejection from the tool is different from the relevant models when designing forming dies of the same tool. The design of the part is related to the function of the tool. This is taken into consideration in this paper by considering not only the geometry of the part but also the function of the stamping tool and the orientation of the strip. An application example is carried out showing that the relevance of the search results can be increased. The application example is limited to two tooling firms involving 1-2 tooling designers at each firm. The tooling firms do not currently have a structured case-base, so the work involved compiling small case-bases. This is from a validation standpoint limited. However, the first objective of the paper is to demonstrate that the relevant cases can be extracted using the proposed technology and that the size and retrieval accuracy can be gradually improved.

2 RELATED RESEARCH

There have been many different attempts to automate and support the design of progressive dies for sheet metal stamping using different approaches. The more common ones are Knowledge-based approaches and case-based reasoning (CBR) as described below.

2.1 Knowledge-based Approaches

A knowledge-based system (KBS) was developed and described in [14-17]. It is used for assisting the tool designer and automating certain parts of the process. The system is structured in different modules and implemented in AutoCAD®. The modules serve different purposes and solve problems using different methods. The tasks that are supported by the system are: flattening of the sheet metal part, nesting (to minimize scrap and balance the punch forces), determining the shapes of punches, determining the shapes of the bending dies, sequencing the tool operations, piloting, process plan including idle stations, detail design of all the tool components, and material selection of tool components.

Different methods, systems and algorithms have been developed by researchers to automate or optimize the results of some of these tasks. Most commercial CAD-systems can flatten shapes based on developable surfaces. Some can flatten more complex shapes. Automatic nesting and piloting are discussed by Ghatrehnaby and Arezoo [5] and later by Moghaddam et al [27]. Their nesting algorithms are similar in that they are both placing two copies of the flattened shape next to each other and rotate the shapes in small increments identifying possible collisions and repositions the parts. Then, for each rotation increment the scrap rate is calculated and lastly the angle with the minimum scrap is chosen. In tooling design, efforts are made to minimize the amount of scrap. However, there are several other considerations to be taken. One example is the force balance of the punch and the bending operations. This is considered in actual tooling design but not in automated systems to the authors knowledge. The pilot selection has different approaches as the algorithm in [5] gives the designer areas where direct, indirect, or semi-direct

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pilots could be placed and the approach by Moghaddam et al can give specific points for were to place these pilots. The same authors have in [6, 7] later developed a different piloting system that is based on calculation with medial axis transform (MAT) of the geometry.

Sequencing of operations in the progressive die have been approached from different angles. Li et al [23] developed a system that identifies bends from a CAD-model and uses CBR to determine the best bending sequence. Abedini et al [1] automated the sequencing of bending operations with fuzzy set theory. This was followed by Ghatrehnaby and Arezoo [8] with a system for sequencing punching operations with a main set partitioning (MSP). Here the punches are partitioned into the stations of the die with the help of priority sequences that the designer provides. Lin and Sheu [25] developed a method for the sequencing of punches using clustering of them to do a modified exhaustive search followed by scoring of the variants. This was later used by the same authors in [24] to make the complete layout planning of both punching and bending operations. According to Lin and Sheu [25] and Kumar and Sing [14] the previous work on sequencing had not taken simultaneous operations and tolerances of specific features into account sufficiently. Therefore, authors Kim et al [13] continued developing the system making the sequencing of both bending and punching using fuzzy set theory.

2.2 Case-based Reasoning

CBR can be described as a methodology for problem solving by reusing solutions from previously solved problems. See for example Watson [33]. When a new problem is encountered, comparison to already solved problems is made for similarities to see if already tested and proven solutions are available for reuse. This is somewhat similar to how designers and other problem-solving professions approach their problems. A CBR-system in its simplest form consists of a case-base of previously solved problems where each case has a problem part and a solution part. A good overview of this cyclic process is given by Agnar and Plaza [2]. In addition to the cases and the surrounding processes, the methodology also utilizes general background knowledge to varying extents. Here the cycle is described in terms of four processes and is shown in Figure 1 (in the figure a typical starting point and ending is indicated):

1. Retrieve – where the new problem is compared with similar problems in the case base one or more cases are retrieved.
2. Reuse – the information from the retrieved cases together with general knowledge about the problem is used to propose a solution to the new problem.
3. Revise – the proposed solution is tested and validated. Adjustments to the solution is made as needed.
4. Retain – the relevant information in the confirmed solution and its problem description is structured so that it can added to the case base.

In each of these four processes, a variety of different methods can be used to carry out the tasks that they involve. Depending on what methods are used, the structure of the case base and how problems and solutions are described can vary.

CBR-systems in engineering design can be applied on different levels of granularity. This can be from a parameter level of CAD-models to dimension parts, to a system level to select specific modules of a complex product. CBR is widely used in tooling design as for example by Lee and Luo [20] who developed a system for supporting die design in casting applications. They modeled their cases in terms of product shape, type, filling system, and functional components in the die, and ejector system type, where each category had several features. The adaption of the similar cases was done in two steps, adaption on a structural level (modules), and adaption of the modules from the first step.

There has been research done in applying CBR in the design of fixtures in manufacturing. Li and Wang [22] proposed an idea for how a system could be structured for modular fixture configuration. In Hashemi et al [9] an initial template-based search is utilized. This reduces the search space by using features such as the type of workpiece, machine type, clamping mode, etc.

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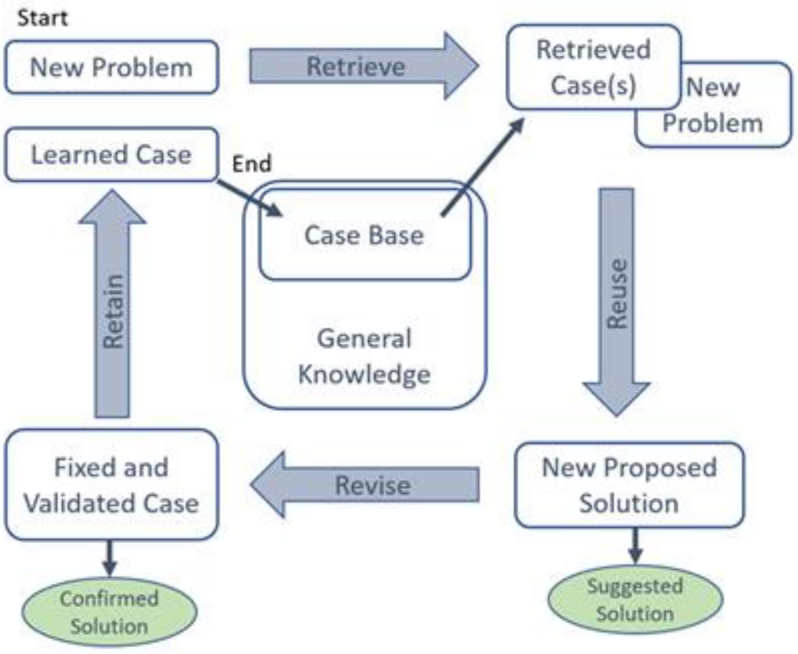

Figure 1: The working principle of a CBR system.

In this case, the retrieval is enhanced by including more detailed features. Another example is Zhang et al [34] where the fixtures cases consist of non-design features and design features. Examples of non-design features are Clamping Mode and Location Mode and of design features, dimensions, number of pins and opening direction. The adaption of the retrieved case is accomplished by utilizing parametric template models for the different categories of fixture types that can then be modified using a rule-based system.

Similar approaches have been used by others, such as Farhan et al [4] who applied CBR to special purpose machine design. Here, the cases were represented with workpiece features and machine features. The workpiece features are for classification, such as: shape type, number of machined surfaces, material, etc. while the machine features describe the type of machine through, for example, machining type, number of workpieces, fixturing mechanism, etc. When the best match is retrieved the structure and layout can be reused by the user and modifications can be made. Kim et al [12] used hierarchical decomposition to derive platform types of design modules that are then combined to create a specific variant of the product. The cases in the case-base are then represented based on the mapping of their properties to requirements. Adaption of the cases is accomplished through adding, removing, or replacing compatible modules to the platform to fulfill the requirements. In the application of CBR to the design process of aluminum extrusion dies Butdee and Tichkiewitch [3] use features of predetermined significance in order to reuse CAD-models more efficiently. An added use of the case base is the training of a neural network to predict production outcomes based on parameters in the cases.

Kwong and Tam [18] represented the problem part of the cases of low power transformers with features to describe the performance and requirements such as voltage, current, and safety standard. Once input from the user had been received, a rule-based system is used to select proper core material before the case retrieval is carried out. Adaption of the cases is also made mainly based on rules and equations.

In sheet metal stamping applications Tor et al [32] proposed an indexing approach for sheet metal parts and an associated retrieval method. The sheet metal part is represented by stamping

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features and feature relation graphs. The features are categorized in four categories, primary, positive secondary, negative secondary, and connective secondary features. Examples of features are flat, tab, curl, hole, and bend. Leake et al [19] described a system for feasibility analysis of sheet metal parts. The cases were represented by features regarding general project information, numerical encoding of the part's style and shape, and features describing aspects that can cause problems in manufacturing and their associated solutions.

Design analysis and evaluation is an area where CBR has been applied to speed up or automate the process. Examples include estimating the cost of a product, assessing a part or component, or putting together quotations. Moghaddam et al [28] represented the cases with information about customer requirements, product complexity, etc. The system uses neural networks both to calculate feature weights and calculate the cost based on the retrieved cases. Relich and Pawlewski [29] estimate the cost of sheet metal parts by combining a rule base to validate inputs and assist users with a CBR process where process plans and operations in manufacturing are reused as a basis for cost estimation.

Many other applications have also been suggested such as the prediction of spring-back in sheet metal forming Liu et al [26], design suggestions that comply with rules and norms in building design Lee et al [21], estimation of similarity and adaptability of products in order to reduce carbon foot print Renet al [30], improving the data flow in terms of feasibility of manufacturing, design space, and simulations in new manufacturing technologies Siqueira et al [31], and finally quality estimations in production Zhou et al [35].

3 METHOD

This paper has been written as a part of a five-year research project. The project has the overall objective of addressing challenges in stamping tooling design and knowledge reuse. Five different tooling companies took part in the study of the current state of practice in tooling design at these companies. The study was conducted mainly by interviews with tooling designers. 1-2 very experienced tooling designers from each of the companies were interviewed. This gave a detailed view on how the design of stamping tools is conducted. The results were reported in Jonsson et al [10]. The work continued by addressing the identified need of knowledge re-use. This was done by investigating how relevant former cases in tooling design could be automatically retrieved from the companies' databases. In this part of the study, the method was to set up an experimental system including a case-base of former cases and letting the tooling designers review a case that had been singled out by the researchers and select the most relevant former cases from the case-base and rank them in a descending order of relevance. The system was thereafter trained to replicate the same outcome as was obtained by the designers. The designers where thereafter interviewed to understand what they thought could be the effect on the design process of having such tool.

4 IMPLEMENTATION OF CBR FOR STAMPING TOOLS

As described in the previous study in the tooling project, the reuse needs for different parts of the tool design process differ depending on what information the tool designer is looking for. The publication [10] investigated the design process for stamping tools, finding what tasks the designers perform when designing the stamping tools. 13 conceptual design tasks (A-M) and 7 detailed design tasks (N-T) were identified. They are shown in Table 1. When planning for CBR, parameters that efficiently can identify former cases needs to be identified to begin with. Among the design tasks of table 1, it is the conceptual ones that through their associated design parameters can identify the similarities between the current and former cases most efficiently. In particular G "the approximate shape and number of forming operations" together with C "orientation of the part on the strip" are good candidates for automation with CBR because their design parameters indicate the general shape and complexity of the part. C and G were consequently selected for this study. Also D "orientation on the strip" has been used in some cases

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as a support. The design parameters pertaining to each task and how they are used to identify former cases is explained below.

Reference	Conceptual Design task
A	Review of drawing tolerances and other requirements
B	Formability evaluation/simulation
C	Orientation of the part on the strip
D	Part connection to the strip
E	Piloting
F	Approximate shape and number of punches
G	Approximate shape and number of forming operations
H	Tool station order, including idle stations
I	Use of special solutions/functions
J	Functionality and verification for lift of the strip
K	Conceptual design of die set, punch and die holder, etc.
L	Scrap removal and part ejection
M	Material selection and surface treatment of tool components
	Detailed design tasks
N	Punches and dies
O	Forming dies
P	Dimensioning and placement of springs
Q	Punch and die holders, stripper plate
R	Sensors and controllers
S	Die set, guideposts, stop blocks, press
T	Special solutions/functionality

Table 1: Tasks is stamping tool design [35]. C, G and partly D have design parameters that efficiently identifies former design cases.

The intended workflow for the tool designer together with the components of the proposed method is shown in figure 2. When presented with a new sheet metal part the tool designer carries out the tasks. In each task there are different reasons for reuse as for for example: complexity of the geometry of the part, similar shape of parts, and existing standardized solution. If the tooling designer sees a need to reuse information from previous designs, relevant parameters are extracted from the CAD-file of the sheet metal part together with parameters that can be provided by the tool designer (1 in figure 2). Note that parameters are taken from both the tool and the part. Thereafter, a task specific retrieval of relevant CAD-models is made (2) from the case-base of tools. The list of returned models is sorted according to descending similarity. The highest similarity appears first in the list and in then given in descending order. The tool designer can browse the list and review the suggestions and extract the information needed for reuse (3). The information that is reused is different for the different tasks. It can range from reusing complete CAD-models, to ideas and inspiration for solutions, and to values of specific dimensions.

The storage retrieval of the former cases in the case-base is carried out as shown in figure 3. It starts by taking the design suggestions represented in the new sheet metal CAD models prepared by the designer. They are indexed by automatically extracting the parameters. With these parameters, a search in the case-base is made resulting in a list of cases. The tooling designer selects one or several former cases and develops the new part and its corresponding tooling accordingly. This new case is thereafter added to the case-base.

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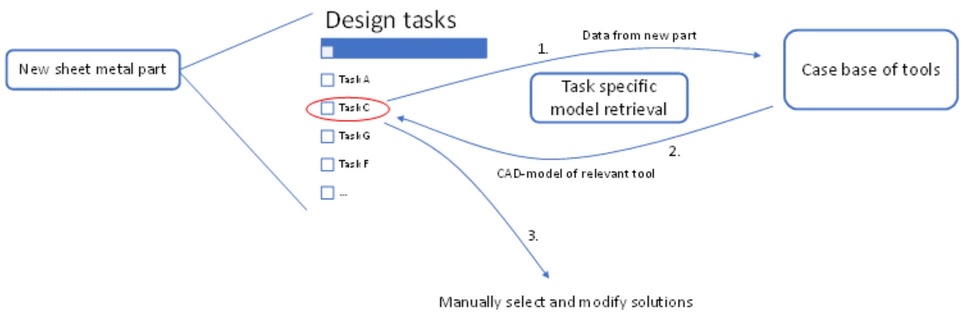

Figure 2: Process for retrieval of formers solutions.

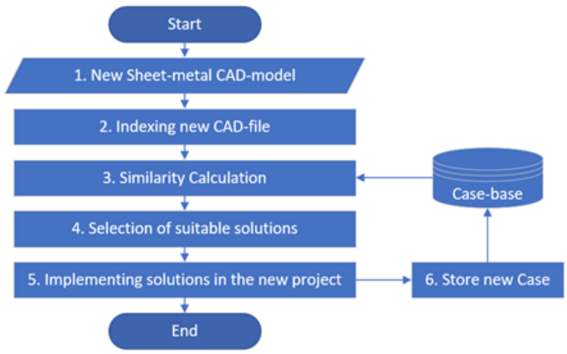

Figure 3: Retrieving former solutions from the case-base.

4.1 Retrieval Mechanism

The relevance of the retrieved list of cases depends on the retrieval mechanism. The similarity metric is based on a set of parameters derived from both the part itself, and the stamping tool. These parameters are presented in section 4.7 - case-indexer. The similarity calculation begins by calculating the total similarity of the two components regarding a specific task using a weighted Euclidian norm, given by Equation (4.1).

$$similarity = \sqrt{\frac{\sum_{i=1}^{n} w_i (m_i)^2}{\sum_{i=1}^{n} w_i}} \tag{4.1}$$

Here n is the number of parameters for the specific similarity metric. The weight for a particular parameter is denoted w_i, and mi is the match score, given by Equations 4.2 and 4.3 depending on if they are numeric or Boolean parameters. The match score is a number between 0 and 1 indicating the degree of resemblance. The role of w_i is to determine the importance of the parameter. By adjusting w_i the system can be adjusted to give a similar response as the human designers. It will be shown how the weights are determined using genetic algorithm (GA) so that for a given query, the relevant models of previously designed stamping tools are identified and retrieved.

$$\begin{aligned} &\text{(numeric)} \qquad m_i = \frac{a_i}{(p_i - s_i)^2 + a_i} \\ &\text{(boolean)} \qquad m_i = \begin{cases} 1 & \text{if } p_i = s_i \\ 0 & \text{if } p_i \neq s_i \end{cases} \end{aligned} \tag{4.2}$$

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(4.3)

The match score is calculated for each parameter in the new part being designed. The value of ai is determined for each parameter to allow for different shapes of the match score function as seen in figure 4.

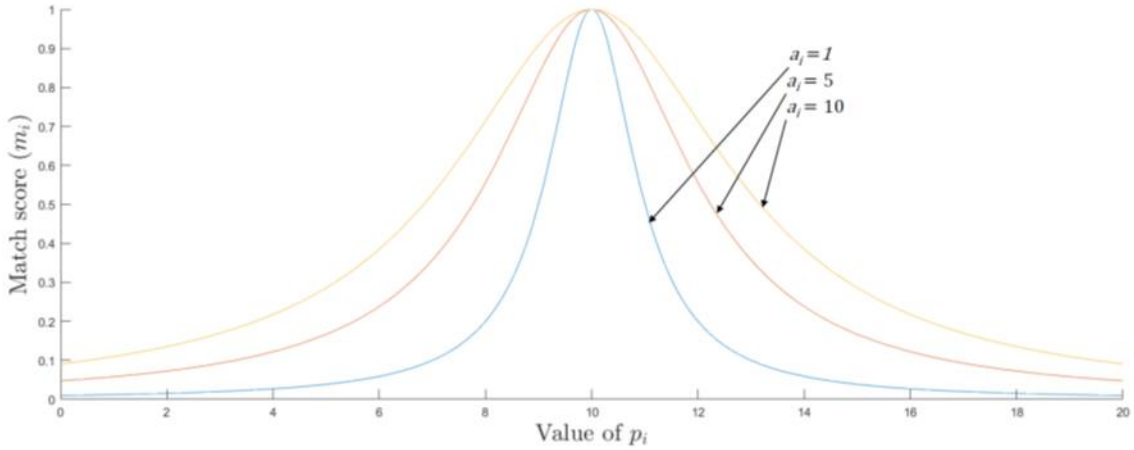

Figure 4: The match score characteristics.

This will enable adjustment of the similarity criterion. The *a* value is determined by evaluating the variation ranges of each parameter s_i for all the parts in the case-base. Figure 4 shows examples of the shape of the match score for a values of 1, 5 and 10.

4.2 Selecting the Parameters

The parameters have been selected to accurately capture the important aspects of each task that is to be supported. A certain degree of knowledge engineering and tooling expertise is required to describe the cases and select appropriate parameters. For stamping tools, there are three different levels of each case to select parameters from, the sheet metal part, the strip, and the tool itself. Most common is to formulate parameters from the sheet metal component being manufactured. For some tasks it is relevant to describe how the parts are connected on the strip (task D of table1). These parameters are only used when considering the strip. Likewise, several different parameters are only connected to the tool and dies. However, the parameters coming from the strip and tool are not readily available in the early phases of tool design. So, these must be derived by the tool designer during conceptualization of the tool to utilize the support.

4.3 Determining the Weights

To get relevant results from the retrieval algorithm, the weights w_i in equation (4.1), needs to be decided so that for a given query, the relevant models of previously designed stamping tools are identified and retrieved. To do this in a structured manner, using a method that are accessible for tool designers, a data set of examples can be created and used to calculate the weights. This data set consists of two parts, the first is a selected representative portion of the complete case-base, here called the case-base-set. The second part is a collection of cases selected from the remaining cases in the complete case-base that acts as query-cases, here called the query-set. Note that for the sake of evaluating the system, the query-set represents the new case being designed. For the sake of determining the weights, the query set was randomly selected from the case-base. For

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each case in the query-set the tool designers of two different companies were asked to select the three most similar cases in the case-base-set, these cases were denoted as the "top-matches". Having a case-set and a query set made it possible to formulate an objective function with the purpose of setting the parameters weights so that the preferred selection of the tooling designs will be retrieved in the search.

4.4 The Objective Function

The process of determining the weights in the retrieval algorithm is viewed as an optimization problem. The objective is to set the weights so that the score list as much as possible resembles the outcome preferred by the tooling designers. Thus, the objective is to minimize the difference between the actual and the preferred outcome of the search by altering the parameter weights. This is done by maximizing the difference between the total number of cases in the database minus the actual placement. This is divided by the preferred placement multiplied by the size of the query set and the size of the case-base. The objective function is formulated following way:

Let score be the total score for a particular set of weights. For every part in the query-set, calculate the similarities with all parts in the case-base and sort the case-base in descending order of similarity. For each of the selected top matches, calculate the difference between the number of cases in the database and the placement and divide by the preferred placement multiplied by the size of the database multiplied by the size of the query set, i.e. (#TopMatches*case-base size * Query_set size). The reason for the division is to relate the ratio to the case-base size. The pseudo code snippet below shows how the objective function is evaluated. Note that "Database" below is used to denote the case-base-set.

```
for each (Individual in population)
{
    score = 0;

    for each (Part in QuerySet)
    {
        Get a list of all Similarities with the parts in the Database;
        Sort Similarities in descending order;

        for each (Match in Part.TopMatches)
        {
            Get the placement of Match in Similarities;
            Increment = (Database_Size - placement) / (#TopMatches * Database_Size
            * QuerySet_Size);

            score = score + Increment;
        }
    }


    Individual_score = score;

}
```

The increment assumes a high value if the placement and the #TopMatches is the same. This means that the preferred outcome has been achieved. In this way the precision in determining the preferred placement is maximized.

4.5 The Genetic Algorithm

The GA optimization method is used to find how the weights should be set to replicate the search results preferred by the tooling designers. It can be seen as training the system to replicate the same selection as the designers. The GA optimization process is shown in figure 5.

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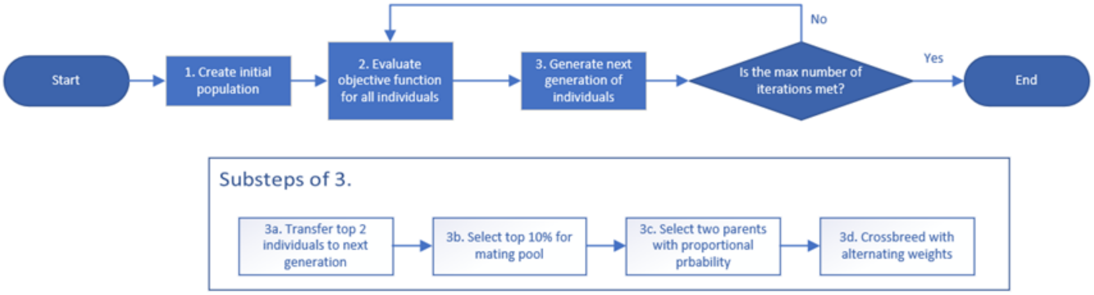

Figure 5: Optimizing the parameter weights.

The first step is to create an initial population with randomly selected weights between 0 and 1. For all individuals of this this initial population, the objective function is evaluated. Next, truncation selection is applied with a selection ratio, and the top fraction of the population selected for breeding the next generation. From that selection, a proportional selection scheme is used to select two individuals for creating a new individual for the population of the next generation. Crossbreeding is used so that alternating-position crossover is used so that every other parameter comes from the respective parent individual. The algorithm also contains random mutations. The optimization terminates when the maximum number of iterations is reached.

4.6 Implementation

To test the proposed methodology, an implementation has been made in using SolidWorks® as the CAD-tool. The implementation was coded in C# (C-sharp). The main parts of the prototype system are the case-indexer, case-base, and case-retriever. When a new design suggestion will be compared to the case-base, the case-indexer gets the parameters from the CAD-models of the case. It creates the **p** parameter vector as described previously from the CAD models. The cad-retriever searches the cad-base and retrieve the most relevant cases and sort them in descending order. Datasets for determining weights were created for each of the companies with CAD-models from the CAD-libraries of each of the companies. A total of 53 CAD-files were used during the development of the case.

4.7 Case Indexer

The case-indexer is implemented using the SolidWorks application programming interface (API) and relies on the feature recognition capabilities of SolidWorks to find the sheet-metal features in, for example, a STEP-file. The process of running feature recognition needs to start with the user pointing out a fixed face. A fixed face is the part that is not bent in the forming process. It is used to hold the sheet in a fixed position while the forming is done. The case-indexer then identifies the sheet metal features in the file and extracts and calculates the parameters used by the case-retriever and stores it in the case-base.

As mentioned, the work task C and G of table 1, have been selected for implementation. This was done in collaboration with tool designers. To capture the characteristics of a sheet metal component that affects the orientation on the strip (task C), several parameters have been chosen through discussions with the tool designers. The triggers for reuse during this task are based on when there is a high similarity in shape of the current part and old parts, and/or if there is no obvious preferred orientation. Based on this, the chosen parameters are: (1) aspect ratio of the flat pattern bounding box (larger value divided by the smaller), see figure 5 (a), (2) number of different orientational directions of bends, figure 5 (b), (3) and (4) the largest and smallest number of bends in up or down direction relative to the fixed face figure 5 (c), (5) longest series of bends

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from the fixed face figure 5 (d), and (6) minimum distance to the bounding box in the normal direction from the fixed face in folded state, figure 5 (e).

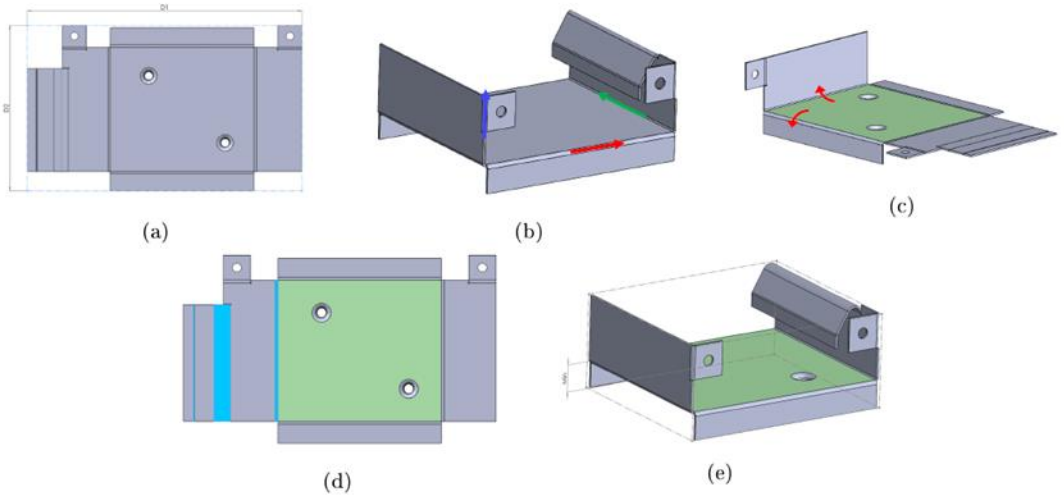

Figure 6: The parameters for determining the orientation of the strip.

On the other hand, capturing the relevant characteristics of models when designing the forming dies (task G) requires a different set of parameters. The parameters used for this purpose are, (1) sheet thickness, (2) if the part has overbend, figure 7 (a), (3) has overhang (could be achieved with multiple bends with small angles), figure 7 (b), (4) largest bend radius, (5) has hole flange feature (sub parameters), figure 7 (c), (6) has drawn features (sub parameters), figure 7 (d). Here the parameters for hole flange and drawn features are treated differently from the overbend and overhang Boolean parameters in that they are excluded from the similarity calculation if they are false, since that would mean that they do not have the necessary parameters to compare. They can also be manually excluded from the similarity to narrow the search somewhat to specific aspects of the geometry.

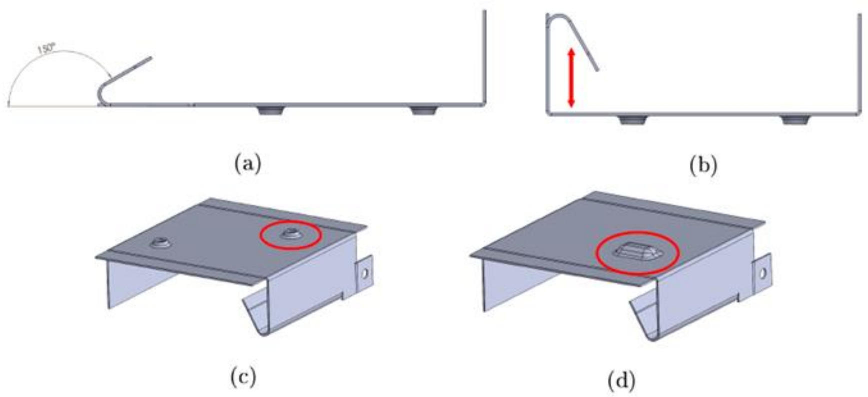

Figure 7: Characteristics for the forming die.

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4.8 Case-base

The case-base is kept on XML-file format in this implementation. The case-indexer keeps the xml-file up to date. In a commercial setting in a company, the xml-file could be replaced by for example a PLM-system containing the parameter information for each case in the case-base. Since the stamping tools consists of many CAD-files and additional data, such as cost calculations, change data, etc., only a search path to the location of the stamping tool data is stored in the case-base. Other metadata of the tool such as some identifier that can be company specific, for example article number or customer, can also be stored.

4.9 Case Retriever

The case-retriever calculates the similarities between the new case and each case in the case-base and adds them to a list. An example of such list is seen in figure 8 showing a list sorted in descending order of similarity and presented in the user interface along with pictures of the CAD-models.

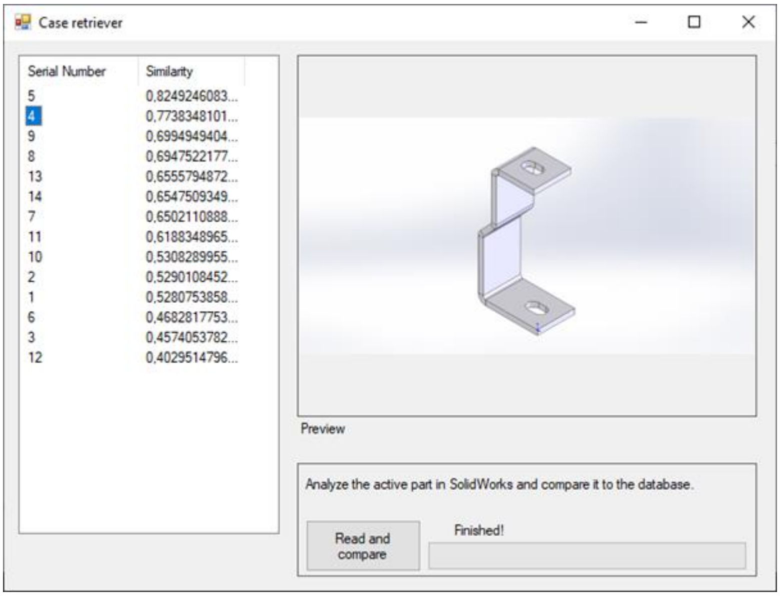

Figure 8: A list of cases sorted in descending order of similarity.

4.10 Calculating Weights with Collected Datasets

Datasets from the two companies were created for the task concerning the orientation of the part on the strip. Each dataset contained a "query-set" of nine sheet metal parts. For each query-part the top three matches from the case-base were determined through group discussions with tool designers at each company respectively. A sample of one of the datasets is shown in figure 9.

An implementation of the genetic algorithm was run for both datasets. A number of runs were performed with different parameters for the genetic algorithm to evaluate the sensitivity and the ability to find better solutions. The best results were obtained with the following parameter settings:

- Population size = 10000
- Selection ratio = 0.1
- Mutation probability = 0.2

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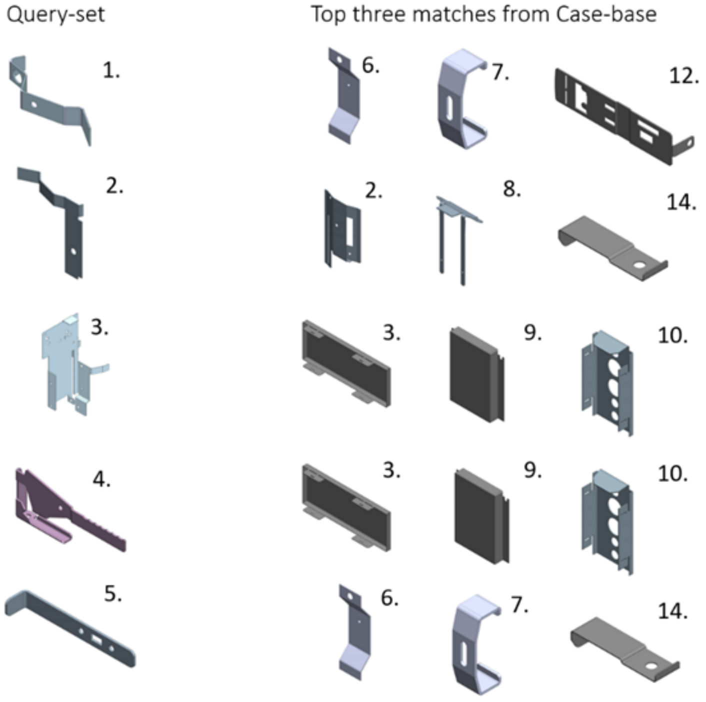

Figure 9: Retrieval of top candidates for 5 different cases.

The high value for the mutation probability was proved to have a positive impact on the results, not only to prevent getting stuck in local maxima, but also to find values of weights with high influence only in local regions of the space. The algorithm was generally run for 400 generations.

To get a sense of the convergence of the algorithm the average distance of the individuals to the center point of the population was used. In figure 10, the evolution of the distance for each generation is shown.

5 DISCUSSION

It has been demonstrated that relevant former tooling designs can be successfully retrieved by the augmented CBR using a limited number of carefully selected parameters from the tool, strip and component CAD-models. The weights of each of these parameters were determined by GA optimization to come up with the same set of relevant designs from the case-base as where preferred by the tooling designers. As mentioned, it can be seen as a type of training of the CBR system. There likely exist several different parameter weight sets which will give the same set of relevant cases. As the case-base grows and the preferred tooling solutions are further developed, the training needs to be done again. Indeed, setting the weights is one of the challenges with the method, since it requires some manual work in selecting sample query models and evaluating good matches from the database. The proposed methodology has the advantage of automatically indexing all new designs as they are added to the case-base. Adding new cases to the case-base require very little encoding enabling constant extension of the system. However, a mechanism for "quality assurance" is expected to be needed. The former designs perform differently in production and service, so somehow the performance should be indicated to the designer to avoid reusing problematic designs and instead encourage the designer to address known problems in the next design. Examples of feed-back include quality data from manufacturing and warranty claims.

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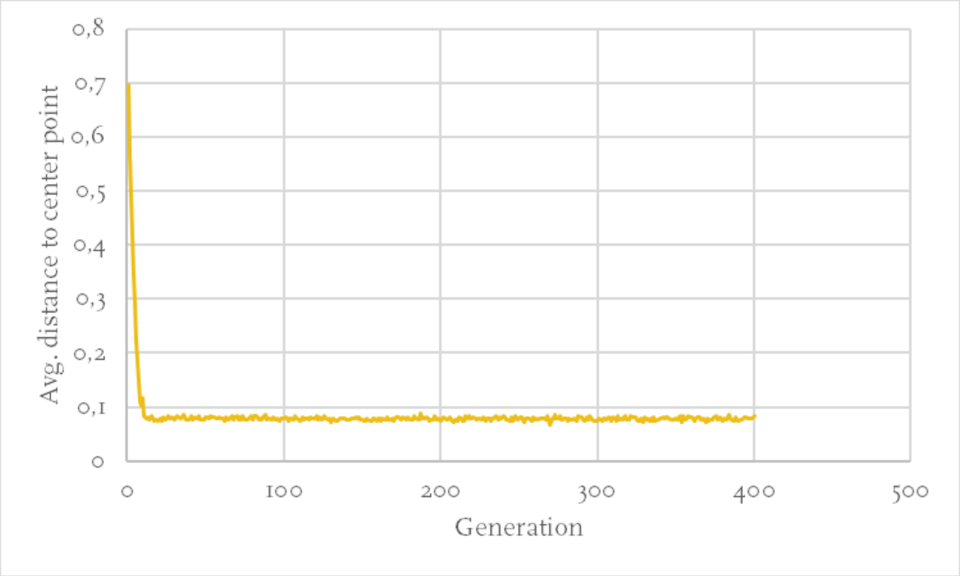

Figure 10: Convergence in the GA optimization of the weights.

The prototype system was presented to four tooling designers i.e., two from each company who stated that the tool would be useful for them to enable quick retrieval of the most relevant former designs. It would make them feel confident that the search had been done in a structured way and not only relying on the memory. The method will also have the advantage that designers will be presented with tooling solutions they have not been involved with previously.

What makes this approach different from former approaches is that parameters are taken from the part and considering the stamping tool and the strip orientation. Apart from the CAD models, one can assume that there is more information available in the supporting documentation on the tool that potentially also could be indexed. Other sources of information could be sensory data from the operation of the tool such has deflection and tool wear. This would make it possible to further refine the relevance of the search by not only relying on the statements of the tooling designers but also including production data.

6 CONCLUSIONS AND FUTURE WORK

By automatically indexing and retrieving relevant CAD-models of previously designed parts and tools, tooling designers can reuse information and solutions in a more systematic manner than just relying on memory. In the study, former cases were selected from the pool of former designs. Thereafter, a case-base search with novel cases was performed finding the most similar cases in the case-base. This gave valuable insights in the selection of parameters and the weight optimization procedure. The method makes knowledge retrieval less dependent on the memory and experience of the designers and letting them consider solutions that they formerly have not been involved with.

The plan for continued work is to further evaluate the methodology and system at the tooling firms. One issue is to gain more understanding of the effect of the proposed method by benchmarking against alternatives. The assumed advantages must be better understood and quantified.

It will be necessary to adapt the retrieval of models to the different challenges and needs occurring at different stages of the tool design process to provide the most relevant CAD-models to

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reuse solutions from. It will also be necessary to include a quality assurance mechanism for the solutions.

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