Title:
Method for Task-based Model Retrieval for Reuse in Stamping Tool Design

Authors:
Carl-Johan Jonsson, carl-johan.jonsson@ju.se, Jönköping University
Roland Stolt, roland.stolt@ju.se, Jönköping University
Fredrik Elgh, fredrik.elgh@ju.se, Jönköping University

Keywords:
Sheet Metal, Stamping Tool, Model Retrieval, Knowledge Reuse,

DOI: 10.14733/cadconfP.2022.189-193

Introduction:

Shorter lead-times are a constant driver for improving efficiency in the design and manufacturing of stamping tools for sheet metal components. Finding and reusing past solutions in design is an important way for improving efficiency and quality in stamping tool development. This can be done in the form of retrieving CAD-models of relevant past tooling designs. This type of knowledge reuse is standard practice among tool designers through remembering past problems, and solutions from previous projects, or having a collection of good examples of tools of different varieties, to reuse solutions from. Automatically indexing and retrieving relevant CAD-models of the tools can enable the tool designers to conduct the search more systematically and automatically. Retrieving relevant similar CAD-models automatically, however, has some challenges regarding how similarity should be defined, as geometric similarity is ill-defined [4]. A relevant metric of similarity depends on the application context, the objective, and what knowledge that the designer is searching for [3].

In this work, focus is on variations in the different use cases and situations of the stamping tool design process. The existing work done in the application to stamping tools has provided retrieval mechanisms for blanking dies [1], deep drawn features [6], and overall similarity [5]. In the stamping tool design process, the information and knowledge sought for at different stages are different in nature [2] and require individual similarity metrics and parameters to be effective. An example of this is that, the relevant CAD-models 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.

Task-based retrieval:

As mapped in a previous study [2], the reuse needs for different parts of the tool design process differ quite a lot regarding what information the tool designer is usually looking for. The design process for stamping tools can be divided with respect to design tasks for different aspects of the tool (see Tab.1). Based on the specifics of each task, a suitable retrieval mechanism can be created for each task in the process. In this work task C and G have been selected for implementation as a proof of concept.

The intended workflow for the tool designer together with the components of the proposed method is shown in Fig.1. When presented with a new sheet metal part the tool designer carries out the tasks described in Tab.1. In each task there are different reasons for reuse, for example, complex geometry of

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Reference	Conceptual Tasks
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 mounting adaptions
T	Special solutions/functionality

Tab. 1: List of tasks during tool design.

the part, similar shape of parts, existing standardized solution, etc. [2]. If the tool designer sees a need to reuse information from previous tools, relevant parameters are extracted from the CAD-file of the new sheet metal part together with parameters that can be derived by the tool designer (1), and a task specific retrieval of relevant CAD-models is made (2). The list of returned models is sorted according to similarity with regards to the specifics of the current task. The tool designer can then browse the list and review the tool of their choice and reuse the information needed (3). The types of information that is reused are also different for different tasks, and can range from reusing entire CAD-models, to ideas and inspiration for solutions, to values of specific dimensions.

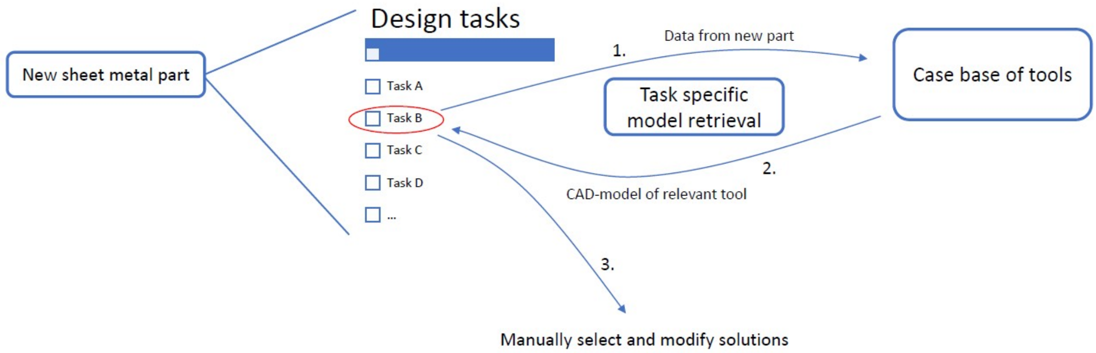

Fig. 1: Overview of the workflow for task-based model retrieval.

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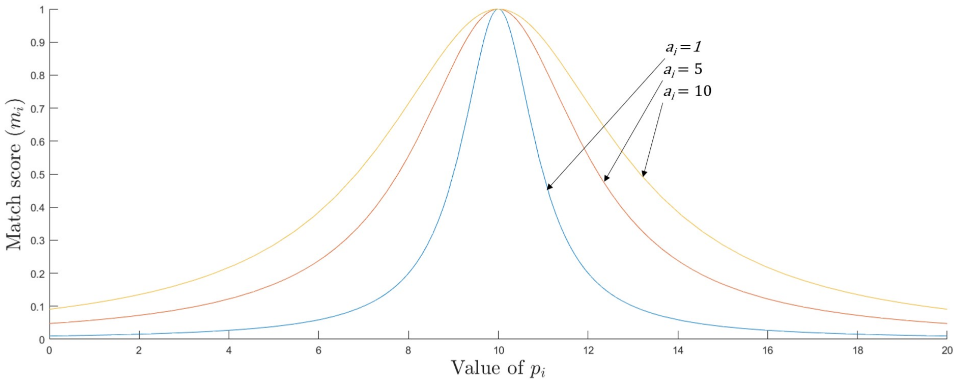

Fig. 2: Match score curve for different values of a with $s_i = 10$.

The quality of the method depends on the retrieval mechanism. Here the main principles are inspired by those of case-based reasoning, where the parameters that is used in the retrieval is not necessarily from the tool, but also from the sheet metal part being manufactured. The mechanisms presented here uses a similarity metric based on a set of parameters. The similarity calculation between two parts in the retrieval mechanism is made by calculating the total similarity of two components with regard to a specific task using a weighted Euclidian norm, which is given by Eqn.(2.1):

$$similarity = \sqrt{\frac{\sum_{i=1}^{n} w_i (m_i)^2}{\sum_{i=1}^{n} w_i}} \tag{2.1}$$

Here n is the number of parameters for the specific similarity metric. The weight for a particular parameter is denoted w_i, and m_i is the match score, given by Eqn.(2.2) for numeric parameter types (continuous and discrete) and Eqn.(2.3) for boolean parameters.

$$\text{(numeric)} \qquad m_i = \frac{a_i}{(p_i - s_i)^2 + a_i} \tag{2.2}$$

$$\text{(boolean)} \qquad m_i = \begin{cases} 1 & \text{if } p_i = s_i \\ 0 & \text{if } p_i \neq s_i \end{cases} \tag{2.3}$$

The match score is calculated for each parameter in the new part, represented by the parameter-vector **p** and a given part in the database, represented by the vector **s**. The value of a_i in Eqn.(2.2) is different for each parameter to enable different shapes of the match score function, to better capture what is considered similar in each case. This is done by evaluating the variation ranges of each parameter s_i across the parts in the database. Examples of what the match score function looks like for different values of a_i, when $s_i = 10$, is shown in Fig.2. In the implementation of the method described in this paper the values of all a_i was set manually.

Parameters:
In this work task C and G from Tab. 1, have been selected for implementation in collaboration with tool designers from four different companies, as a proof of concept for the method. The tool designers were asked to order the tasks in terms of what would be most beneficial for them in their process.

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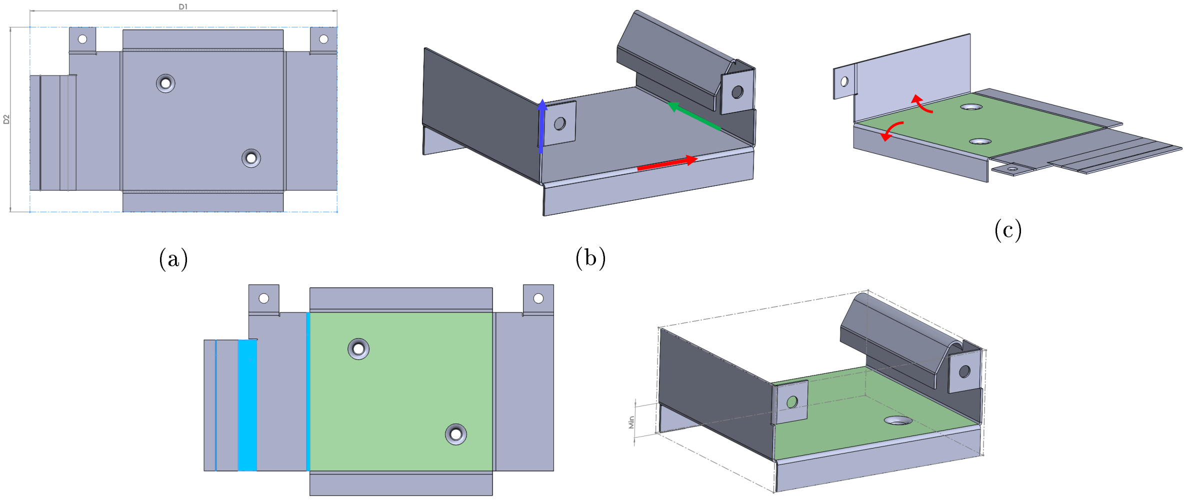
To capture the characteristics of a sheet metal component that affects the orientation on the strip (task C), a number of parameters have been chosen through discussions with the tool designers. The triggers for reuse during this task are based on when there is a high similarity in shape of the current part and old parts, and/or 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, Fig. 3(a)), (2) number of different orientations of the fold lines of the bends shown in Fig. 3(b), (3 and 4) largest and smallest number of bends in up or down direction relative to the fixed face, Fig 3(c), (5) longest series of bends from the fixed face, Fig 3(d), and (6) minimum distance to the bounding box in the normal direction from the fixed face in folded state, Fig 3(e).



(a) (b) (c) (d) (e)

Fig. 3: Visualizations of the parameters for orientation of the part on the strip task.

On the other hand, for capturing the relevant characteristics of models when designing 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, Fig. 4(a), (3) has overhang (could be achieved with multiple bends with small angles), Fig. 4(b), (4) largest bend radius, (5) has hole flange feature (sub parameters), Fig. 4(c), (6) has drawn features (sub parameters), Fig. 4(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.

Weights and method evaluation:

To get relevant results from the retrieval algorithm, the weights w_i in Eqn.(2.2), needs to be decided so that for a given query, the relevant models of previously designed stamping tools are identified and retrieved. For the similarity for orientation for task C, two datasets were created with representative CAD-models from two different companies respectively. The datasets have a "case-base" and a "query-set". For each model in the query-set, tool designers at the companies, specified the top three most relevant models in the case-base. A genetic algorithm was used to find the weights that returned the relevant models as high as possible for the similarity metric.

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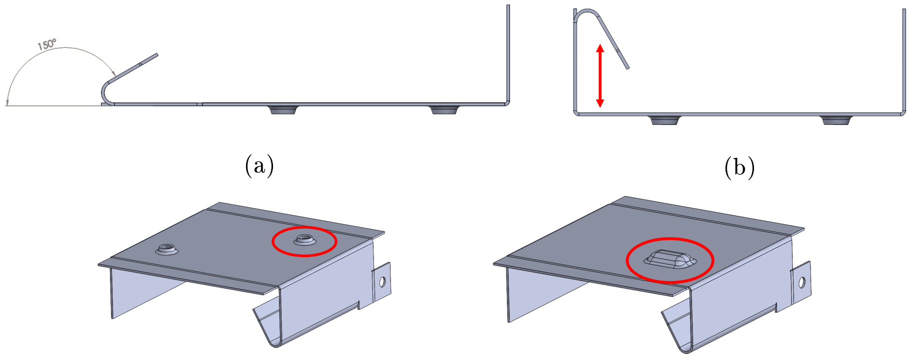

(a) (b) (c) (d)

Fig. 4: Visualizations of the parameters for forming die design task.

The performance of the method, applied to task C, could then be evaluated quantitatively using the datasets collected and metrics for search performance, such as "precision" or "recall".

Conclusions:

By automatically indexing and retrieving relevant CAD-models of previously designed tools, tool designers can reuse information and solutions in a more systematic manner. But it is 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 reuse solutions from. it has been shown, relevant models can be retrieved based on the situation at hand. Challenges with the method is setting the weights, since that requires some amount of manual work in selecting sample query models and evaluating good matches from the database. However, with a relatively small dataset and the genetic algorithm good performance can be achieved.

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