Int J Adv Manuf Technol (2002) 19:898–904
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The International Journal of Advanced Manufacturing Technology

Development of a Knowledge-Based Process Planning System for an Auto Panel

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Challenges and pressures from the growing globalisation of markets have made automotive enterprises shorten the product development cycle time and reduce costs through the increasing use of mathematics-based tools and processes. In order to bridge the gap between experience-based design and science-based engineering, this paper establishes a knowledge-based process planning system to fully support auto panel die development and design automation. The framework of this novel system is proposed, and key issues, such as knowledge acquisition, knowledge representation and knowledge-based design are described in detail. The function model of the system is proposed to illustrate the architecture and functionality of the system. The system provides users with just-in-time access to the appropriate knowledge and information to reduce the search burden. A practical example is used to show the great advantage of the knowledge-based process planning system.

Keywords: Auto panel; Knowledge acquisition; Knowledge-based engineering; Process planning

1. Introduction

Fierce competition in the automotive market forces auto makers and suppliers to shorten product development cycle time and reduce costs through the increasing use of mathematics-based tools and processes. It makes auto panel die development undergo a historical transition from trial-and-error-based art to mathematics-based and technology-driven enterprise [1]. Nowadays, more and more advanced technologies, such as knowledge-based engineering (KBE) and direct engineering [2,3], have emerged to meet the high-technology demands.

In general, KBE is a computer-integrated processing technology that represents a fusion of artificial intelligence (AI) and CAX technologies. It presents the best solutions to engineering problems through knowledge-driven and knowledge-evolving techniques. It has been confidently predicted that KBE, combined with solid modelling and analytical prototyping will be the computer-aided engineering (CAE) process enabler for engineers. In the year 2010, KBE will be to companies what CAE/CAD/CAM was in the 1990's [4]. Boeing has stated that by 2016 they will be a true knowledge-based organisation that recognises the value of its intellectual capital and has successfully implemented efficient processes to capture, store, access, revise, and apply that knowledge. Ford has a direct engineering vision, to create an environment in which a single engineer can develop a "total product definition" [5].

Owing to the complexity of auto panel die design, there is an increasing need to integrate artificial intelligence (AI) such as knowledge-based systems more harmoniously with the designer intelligence for maximum benefits and expediting advanced design processes. As such, it is necessary to apply knowledge-based systems to the auto panel process design [6].

Our objective is to propose a knowledge-based approach and to develop an intelligent process planning system for an auto panel. Key issues in the development of computer-aided intelligent design system are addressed in greater detail, which include the system framework, knowledge-based design, knowledge representation and acquisition. Process planning of the rear bridge is chosen as an example to demonstrate the knowledge-based design system.

2. Framework of the Knowledge-Based Process Planning System for an Auto Panel

The conventional CAPP systems for an auto panel can eliminate a large amount of work such as looking up data and process form filling which may be tedious and time-consuming. However, they may have the following drawbacks:

1. They depend heavily on the experience and knowledge of designers or users.
2. There are no built-in ways for knowledge representation.
3. They are difficult to modify.
4. There is no mechanism to use the given knowledge and explain the results.

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For implementing the knowledge-based design scheme, a novel knowledge based panel process design system (KBPPDS) has been developed; the overall structure is shown in Fig. 1.

2.1 System Structure

The system is composed of three subsystems: process planning; forming analysis; and knowledge base. These subsystems associate with each other based on the integrated product model of an auto panel. Case-based and rule-based reasoning techniques are applied in each stage of the design process to help die engineers to make right decision. Compared with the traditional CAPP system, KBPPDS includes:

1. *Knowledge-based and process-based design guideline*. The system captures the intuitive creation sequence of most auto panel components and provides proper design guidelines, which is parallel to the die engineer's own problem-solving process. Followed by the appropriate design procedure and process assistant approach, the system will become more convenient to use than most traditional CAPP systems.
2. *Knowledge-driven design assistant and advisor*. In order to guarantee the high forming quality of auto panel components, a variety of design experience and knowledge are required in the process planning procedure. Therefore, KBPPDS provides not only modelling tools, but also design rules, spreadsheets, technical memory, best practices, and constraints during engineering process. This knowledge facilitates the process planning procedure and proposes the way to avoid possible formability problems. For example, after the die-tipping angle is selected, based on design rules, KBPPDS prompts the information about whether the tipping angle causes severe stretching to part forming or not. If forming failure occurs, KBPPDS helps the user to rotate the tipping angle until the panel meets the quality demands.

2.2 System Overview

The prototype KBP2DS integrates rule-based and case-based support with the CAD tool, UGII, already used to create the process planning for auto panels. The benefit to the knowledge engineer is that the new capabilities of the UGII system and its deeply imbedded KBE language, Intent™, allow the designer to put more knowledge into the model. Intent™ is a declarative, demand-driven, object-oriented KBE language containing a rich set of mathematics and engineering functions. UG/KBE can capture and recycle knowledge that exists in many forms at each process planning stage, and then reuse that knowledge to enhance the engineering and manufacturing process. Integration of CAD and KBE enables KBPPDS to be a "design workbench" where designers are guided through the process guideline, aided by the provision of tools for rapidly accessing relevant information.

3. System Implementation

According to the established framework, KBPPDS is dedicated to provide modelling tools and design knowledge for the die engineer. The function model for an auto panel process planning system is illustrated in Fig. 2 and Fig. 3, which links functional needs to the individual process model.

These desired functions have been implemented through some well-developed submodules. In this section, the implementation details of the main modules for knowledge representation, knowledge acquisition and knowledge-based design are discussed.

3.1 Object-Oriented Knowledge Representation

The knowledge representation describes the knowledge with symbolic encoding in a computer. It deals with how to organise

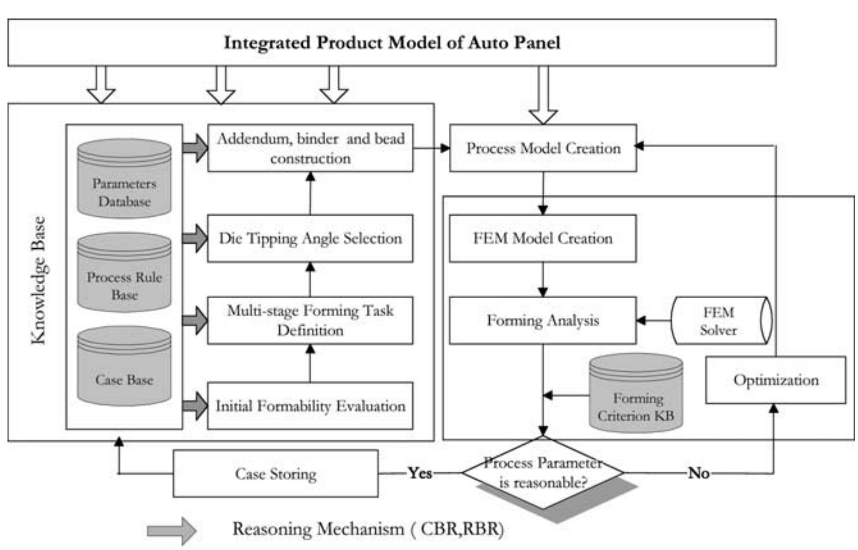

Fig. 1. Framework of the knowledge-based process planning system.

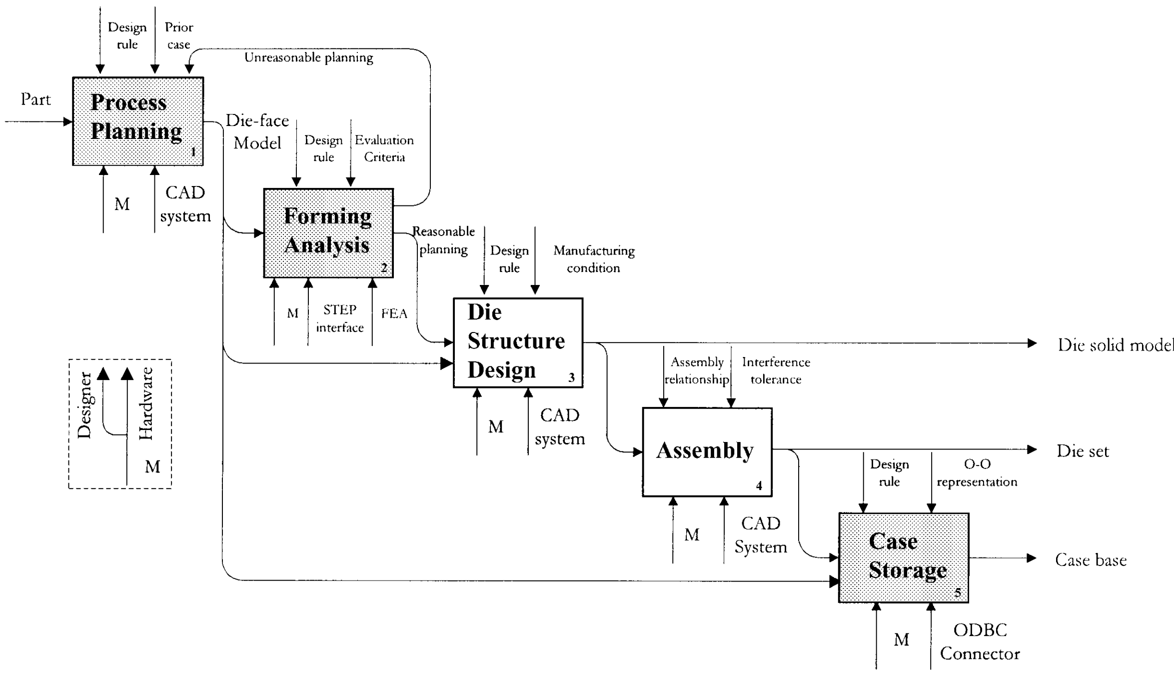

Fig. 2. Function model (AO) for the process planning system.

and encode knowledge in the best form so that the problem can be solved easily. Many representational methods such as semantic networks, procedure modes, frameworks, knowledge units, production systems, and predicate modes, have been reported in AI to meet the requirements of the specific problems [7].

In auto panel process design, a major objective is to combine the different kinds of data, such as calculating function, design rule, spreadsheet, and prior cases, and to attach the design knowledge to relevant geometric features. As such, the object-oriented representation scheme is employed so that both model creating and reasoning work in a design can be carried out.

The basic structure of this representation is described as a unit. The class of object and its instance are described by using the unit structure. An object-oriented unit is composed of following types of slot:

1. The relation slot is used for describing the relation among objects or problems. The forming characteristics of a whole auto panel can be categorised into five types: drawing and bulging; deep drawing; shallow drawing; bending; and flanging. With the help of the relation slot and the forming classification, the design object can be described as a hierarchical structure. The knowledge existing in the superclass can be shared by its classes and subclasses.
2. The attribute slot is used for describing the static parameters of geometric features.
3. The rule slot is used for storing sets of design rules. The design rules can be classified according to the differences among objects and stored in the form of slot values.
4. The method slot is used for recording the design case, numerically calculating and performing control. To record the design case, information such as part name, part number, part classification, problem descriptions, and key features are stored. In order to refine the case representation in the knowledge base, different semantic elements for describing part characters, part forming problems and resolutions are classified.

3.2 Knowledge Acquisition

The method used in building most knowledge-based systems requires the knowledge engineer to form the general rules from the way that experts would solve the problem. As a high-level language for KBE implementation, Intent™ provides easy-to-use facilities to define rule-based knowledge.

In this paper, the proposed approach requests the necessary design knowledge from the designers before and during the design process. Handbooks and books of auto panel process planning are the main source of the knowledge used in building the knowledge base for the whole process. Other sources come from the rules extracted from the simulation results [8,9]. After bidirectional exchange between CAD and CAE, the simulation results pertinent to the forming failure are mapped to the related geometric features in the CAD model through the product based analysis model (PBAM). EXPRESS-G, an object-oriented data modelling language, is used to set up this data model. CAD and CAE information in PBAM are associated with corresponding topological and geometric features. CAD information, such as draw bead, punch open line and the addendum section, are fully structured and mapped into PBAM with forming features. In order to map CAE information into PBAM, four classes, FENode, FEMaterial, FEExtremaSet and FEElement, are created to reorganise finite-element analysis results and build a connection with CAD modelling based on STEP AP214 [10]. Integrated PBAM will then play a role in transforming bidirectional information. Subsequently, the data mining technique is used to extract the rules pertinent to forming failure from this integration model [11,12].

3.3 Knowledge-Based Design

The computer-aided design support system is a knowledge-based auto panel intelligent process planning module from feature-based and functional specifications. The function model is shown in Fig. 3. It is implemented by incorporating CAD tools, knowledge base and KBE language. Therefore, this system provides a feature-based, constraint-based, knowledge-based and object-oriented design environment. The first step in KBPPDS is to trace around the part boundary looking for portions that raise feasibility issues. Then, the system provides information about the problem involved and solutions to resolve the problem. Each aspect to be considered is associated with a set of lower-level features relevant to determining forming feasibility. These key geometric features can be classified into contour feature, bottom face feature, and wall side feature, etc. According to the forming type and feature classification, design rules and prior cases stored in the knowledge base are employed to give advice for multistage process definition and addendum surface creation. In this paper, the feature library in UG/Open API provides functions for creating and manipulating solid components as well as for interrogating and evaluating the geometric and topological properties of process models. Rules defined in Intent™ and cases stored in the knowledge base are embedded into UGII and API functions. The run time of Intent™ can be loaded and executed within UGII, which creates and examines solid objects simultaneously.

4. Application of KBP2DS

Process planning for the rear bridge of the Shanghai GM Buick GLX is used as a design case to illustrate the characteristics of KBPPDS. The product model is shown in Fig. 4. According to the prior case, the typical forming process of the rear bridge can be regarded as a combination of drawing and bulging. As a result, the most common forming failures are a fracture in the bottom face and a wrinkle in the corner boss.

After defining the main forming features and part boundary in the input dialogue, as shown in Fig. 5(*a*), KBP2DS creates an integrated product model for the real bridge. In this model, features are considered as a description of a part that captures and stores information, essential for downstream reasoning processes such as process planning and manufacturing. In this description, features are defined as a set of knowledge, fact-features and rule-features, described by object-oriented techniques.

In order to avoid possible forming problems in the process design stage, the system offers design rules and similar cases while the user clicks the "Advisor" button in the dialogue. Accordingly, "Die Design Rule" dialogue, as shown in Fig. 5(*b*), pops up and provides the corresponding rules at the early design stage.

Consequently, the multistage operation for the rear bridge has been sequenced by flanging, hole and boss features. Prior cases have also shown that the forming operation includes five

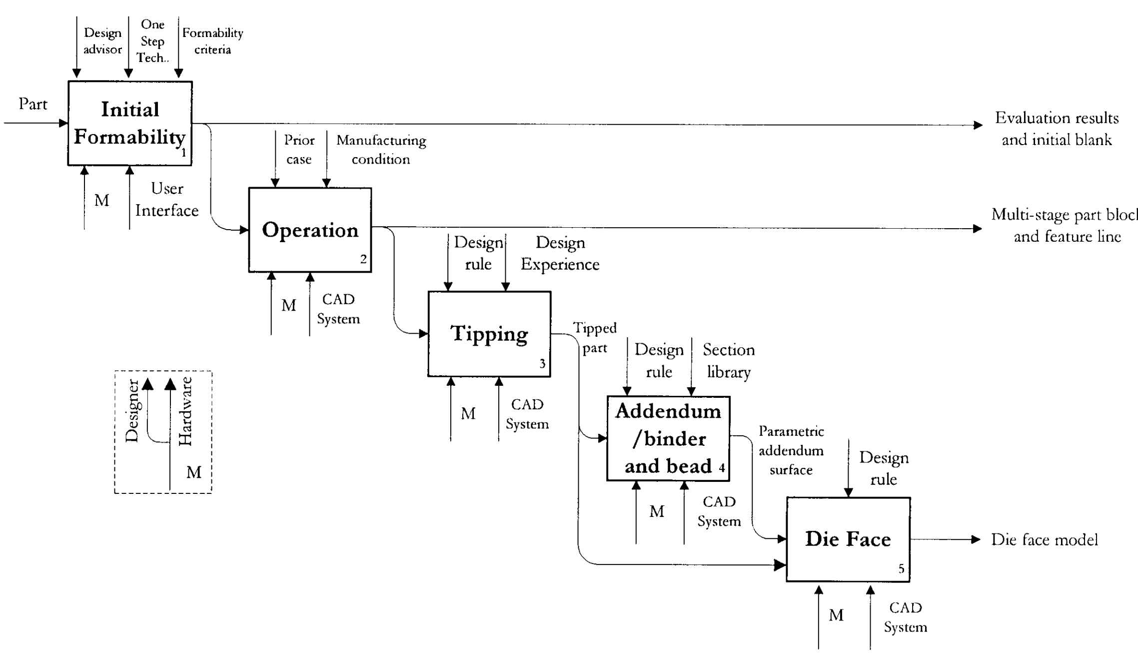

Fig. 3. Function model (A1).

Fig. 4. Production model of the rear bridge.

processes; they are drawing, boss forming, trimming and piercing, flanging, and restriking. The knowledge-based addendum design module is then used to create the binder and addendum surface for the rear bridge. Our module adopts the Wizard UI style to make the die addendum function flexible and easy to use. It provides "Interactive" and "Automatic" methods to create sections along the part boundary.

Figure 6 shows the process model of the drawing and boss forming created by KBP2DS. Forming analysis is then conducted to validate the feasibility of the process planning and to find the optimal set of design parameters. PBAM is created to build the connection between CAD and CAE. In this example, the following design knowledge has been elicited from PBAM.

Design knowledge 1. If drawing height exceeds 120 mm, the thinning reaches 20%.

Design knowledge 2. Draw beads in four corners should be positioned in boss forming. The larger the restraining force is, the better is forming condition.

This application indicates that through KBPPDS, the process planning of an auto panel can be flexibly configured based on the knowledge base. It provides just-in-time access to the appropriate knowledge and information to reduce the search burden on the designer. Adopting KBPPDS, design time and cost have reduced greatly and the process planning and process models are successfully used in production.

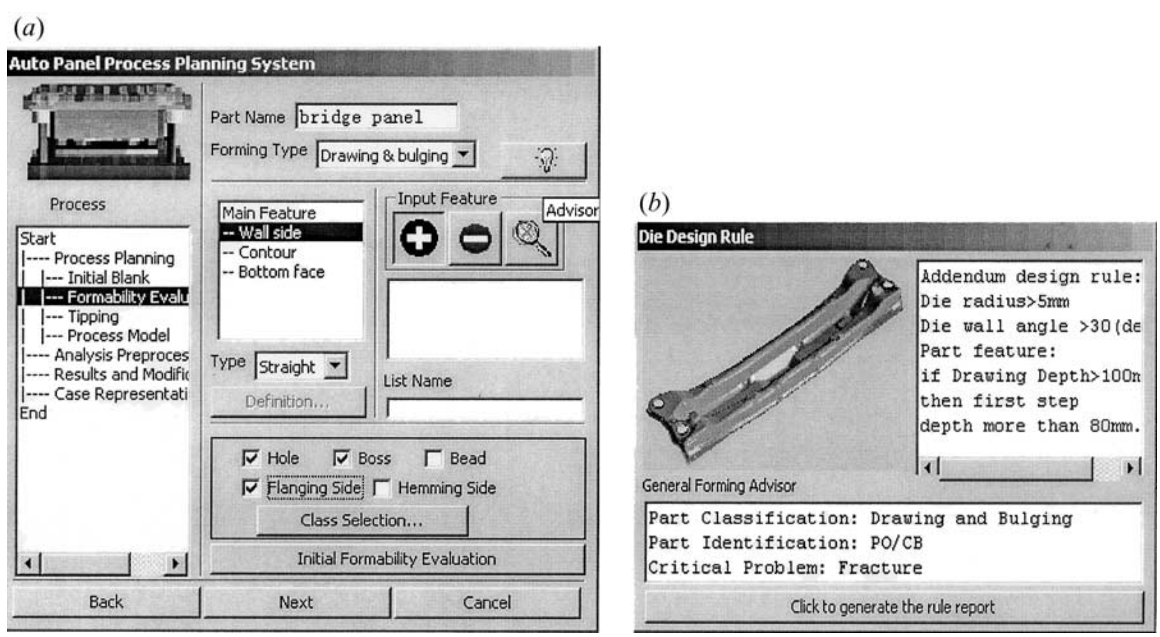

Fig. 5. Formability evaluation.

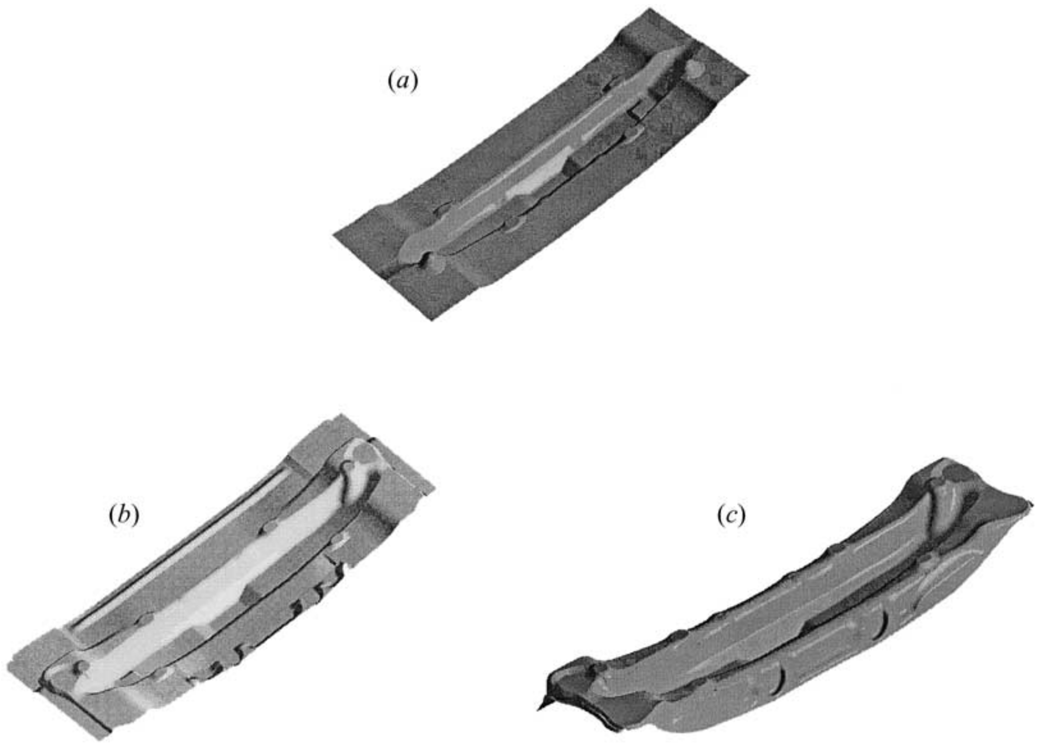

Fig. 6. Main process model of the rear bridge.

5. Conclusion

In this paper, a novel knowledge-based process planning system for an auto panel, KBPPDS, is introduced. A case study has shown that the concept and methodology discussed in this paper are realisable. The process planning system is able to provide process planning and main process models by using design rules and the case base effectively. The developed system can reduce design time and costs owing to the efficient use of knowledge.

It is established that the successful introduction of a knowledge-based process planning system is a demanding and long-lasting process. A great problem preventing its widespread application is the difficulty in establishing accurate design rules and cases. Future work will focus on data mining from CAE results and knowledge-base refinement. Integration of knowledge-based engineering and other enabling technologies will become established and provide a broad range of functionality to support the entire life cycle of industrial products [13–15].

Acknowledgements

The authors wish to express their gratitude to the editor, Professor B. Davies and the reviewers of this paper for their valuable suggestions and comments.

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