Chapter 9

Design for Automotive Panels Supported by an Expert System

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Additional information is available at the end of the chapter

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1. Introduction

The production process for automotive panels (Fig. 1) has changed dramatically with advances in computer technology. To shorten the automotive development schedule, industry has been using computer-aided design (CAD) and digital model analysis to replace the traditional design method based on human experience. This can reduce the design error rate and improve production efficiency (Choi et al., 1999).

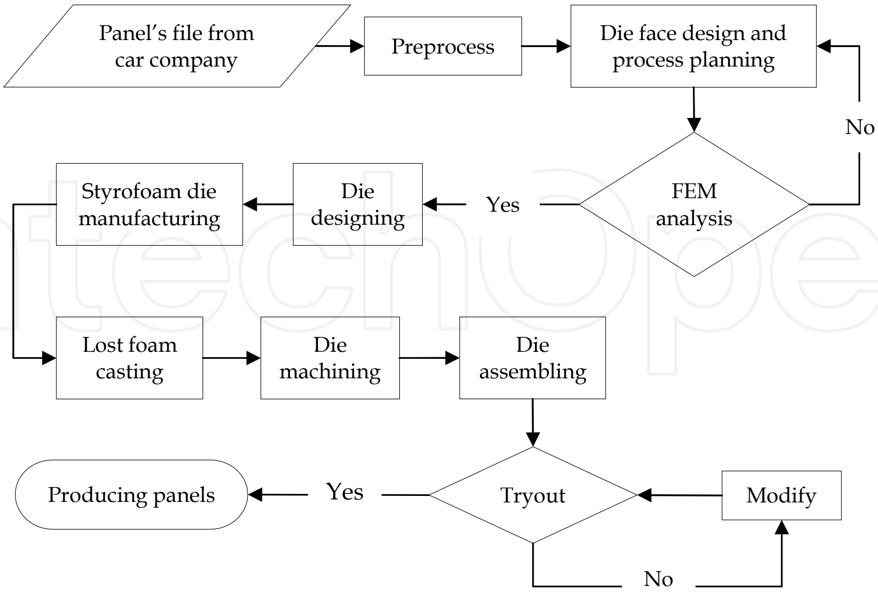

Figure 1. Production process for automotive panels

The entire process from obtaining a panel's file to producing that panel takes about one year, or even much more time. Die design companies that have the shortest schedules and highest quality can occupy a dominant position in the automotive industry.

The stamping die for automotive panels is a cold stamping die; the input is a plane blank; and the output is the panel shape required by a car company. During production, the punch closes the upper mold and lower mold for various tasks. The goal of process planning is to determine how many dies are needed and the content of each die, including stamping direction, tasks, cam type, and other information that is necessary when designing a die.

This study combines practical experience with an expert system, and focuses mainly on preprocess steps and process planning. The system, which is called computer-aided process planning (CAPP) (Marri et al., 1998), is programmed in Java language. The system uses the Spring Solid System developed by the Solid Model Laboratory, National Taiwan University, as the backbone of the CAD system to read the digital surface model, and then output the die layout using Java3D.

2. Expert system

The concept of artificial intelligence (AI) was proposed in the 1980s, and the processing method for computer information is evolving toward that of the human brain. Because many difficulties are associated with the use of AI, an expert system is used to solve problems in particular fields. Generally, it can provide such information as the judgments of experts. Unlike Dynavista and CATIA/VAMOS, which are expert systems developed for die design, no software exists that uses an expert system for process planning.

An expert system mainly consists of a reasoning engine, knowledge database, user interface, and developer interface (Fig. 2).

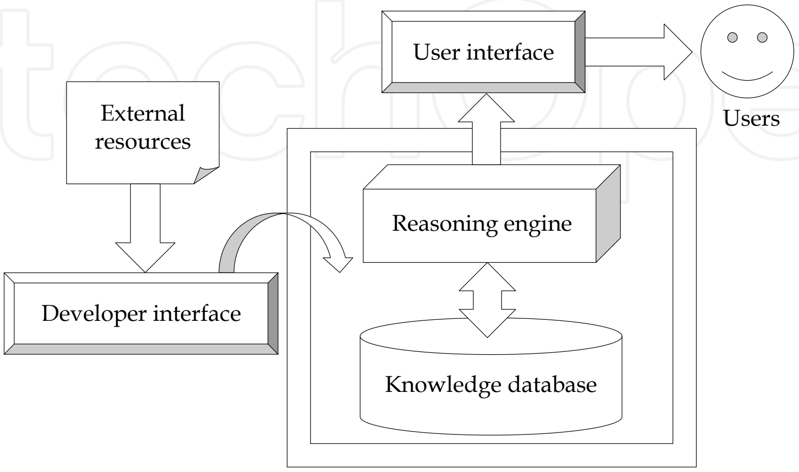

Figure 2. Framework of expert system

1. Knowledge database: This database stores such knowledge as empirical rules, analyzed cases, parameters, and other information used while reasoning.
2. Developer interface: The developer interface allows experts and system developers to modify the knowledge database and reasoning engine from external resources.
3. User interface: This interface allows users to describe questions through a user-friendly operation.
4. Reasoning engine: This engine uses information from the knowledge database to diagnose questions asked by users and search for suitable solutions.

A reasoning engine is widely used with both rule-based reasoning (Lau et al., 2005) and case-based reasoning (Tor et al., 2003; Yuen et al., 2003), and other reasoning methods exist such as neural networks, genetic algorithms, and data mining.

2.1. Rule–based reasoning

The knowledge database of rule-based reasoning stores reasoning rules. After a user enters problems, the reasoning engine starts to reason according to rules and outputs its result (Fig. 3).

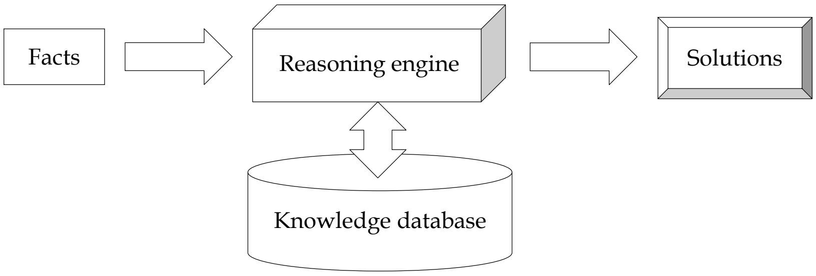

Figure 3. Reasoning process of rule-based reasoning

The judgment rule and boundary rule are typical rules. A judgment rule is represented in the form of “if P then Q,” and two types of Boolean and index exist. Judgment by Boolean is used only when two corresponding results exist, and judgment by index is used when more than two results exist (Fig. 4). For instance, a knowledge database contains the rules “if x, then y” and “if y, then z.” When a user enters “x is true,” the reasoning engine will reason that the result of “z is true.”

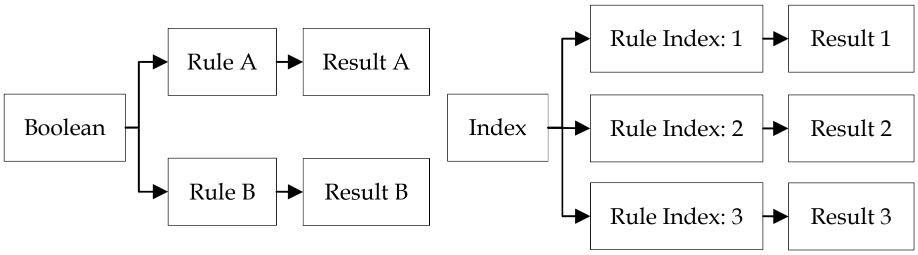

Figure 4. Judgment rule

The boundary rule result is limited by multiple number sets. For instance, if the input number is less than 6.0, 5.0 is output, and if the input number is in the range of 6.0–8.0, 9.0 is output (Fig. 5).

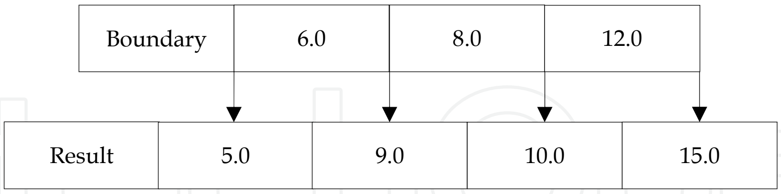

Figure 5. Boundary rule

Using these two rules can increase the number of judgment modes for a system, and enhance its reasoning ability.

The problem of rule-based reasoning is that converting knowledge into rules is difficult. Knowledge can be separated into explicit knowledge and tacit knowledge (Polanyi, 1958). Explicit knowledge can be converted into rules explicitly, while tacit knowledge cannot. The knowledge associated with process planning is almost always tacit knowledge.

2.2. Case–based reasoning

The knowledge database in case-based reasoning stores previously analyzed cases. After users enter a new case, the reasoning engine compares it with all previously analyzed cases in case base, and then searches for the most similar case and reasons for results based on the case (Fig. 6).

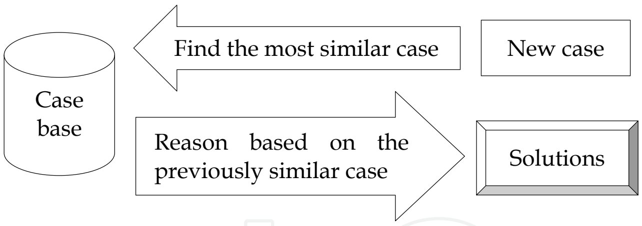

Figure 6. Reasoning process of case-based reasoning

Case-based reasoning has the functions of retrieve, reuse, revise, and retain, called the 4Rs (Kendal & Creen, 2007). After retrieving the most similar case from case base, the information of this case is reused to the new case, and then the proposed solution is revised. Finally, the new case is retained in the case base as a reference for subsequent reasoning (Fig. 7).

3. Die layout design

Automotive panels can be classified into appearance parts and structure parts. Appearance parts can be seen after assembly, including door, hood, fender, roof, and trunk lid; however, structure parts cannot be seen after assembly.

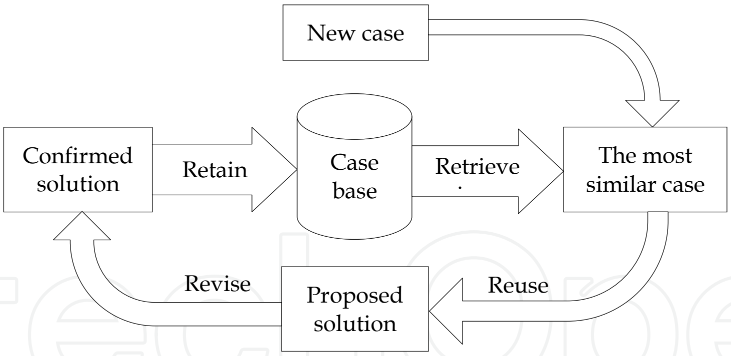

Figure 7. The cycle of case-based reasoning

First, this study uses the left side of a fender (Fig. 8) to illustrate the die layout design process (Fig. 9), including feature recognition, machining center searching, drawing direction optimization, and process planning.

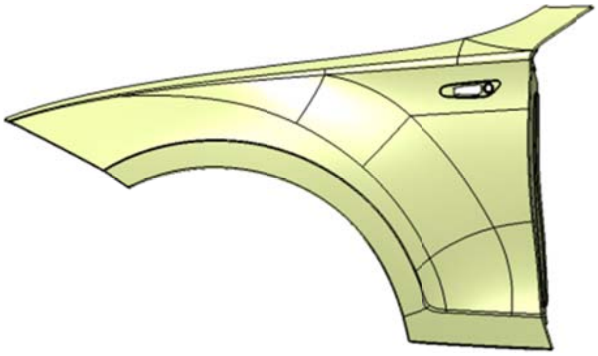

Figure 8. Left side of fender

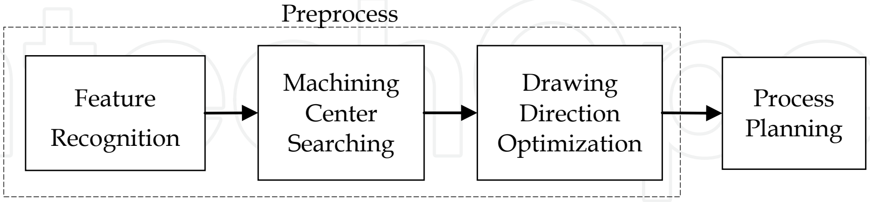

Figure 9. Die layout design process

3.1. Feature recognition

The purpose of feature recognition is to categorize a panel into different sections to establish a bridge between a CAD model and the CAPP system (Zheng et al., 2007) because a panel model without feature recognition is merely unsorted surface data.

If the curvature of single surface exceeds a critical value, it is called a bend surface; otherwise, it is called a flat surface. Bend surface whose curvatures in two domains both exceed critical values is also called a corner surface (Fig. 10).

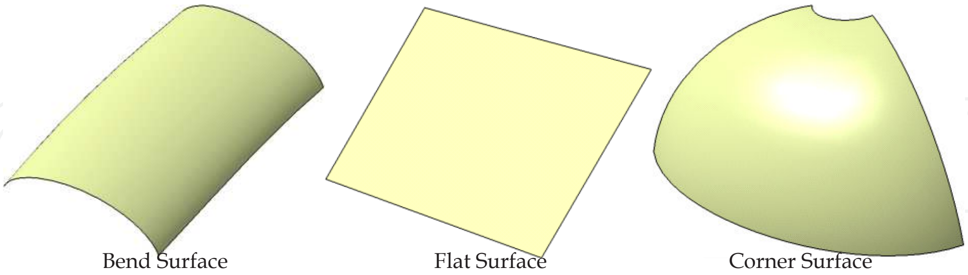

Figure 10. Bend, flat, and corner surface

A group contains parts with the same surface type that are in contact. A panel can be separated into several groups. The group that is shaped during the drawing operation is called the product-in group or main group (Zheng et al., 2007), and the other groups are collectively called the product-out group, which is separated into corners and subgroups (Fig. 11).

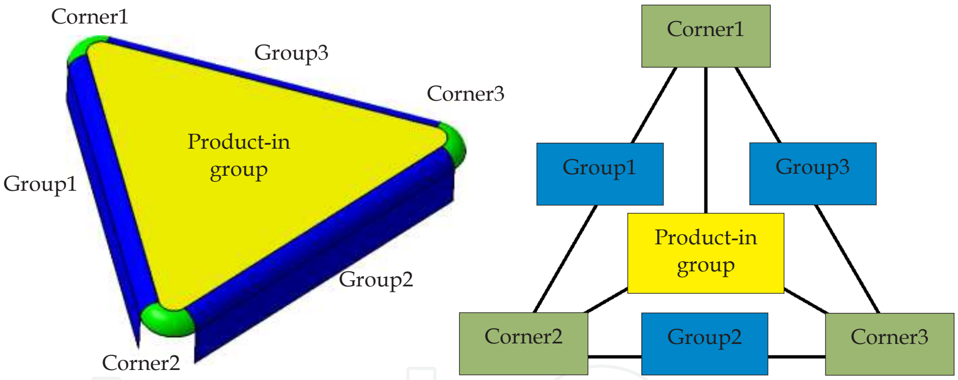

Figure 11. Relationship between features

The flat group with the largest area is a product-in group, and the bend group in contact with the product-in group is the main bend group. Corner surfaces are used to separate the main bend group into several smaller main bend groups, and the flat groups in contact with the main bend groups are the main flat groups. If other groups are in contact with the main flat groups, they are regarded according to the order of bend groups and flat groups (Fig. 12).

The final step in feature recognition is to search for hole features. After finding all edges of a surface, edges shared with another surface are called shared edges; otherwise, they are called single edges (Fig. 13). All single edges for a closed-loop comprise a hole feature; however, the longest closed-loop of single edges is the outer boundary of a panel.

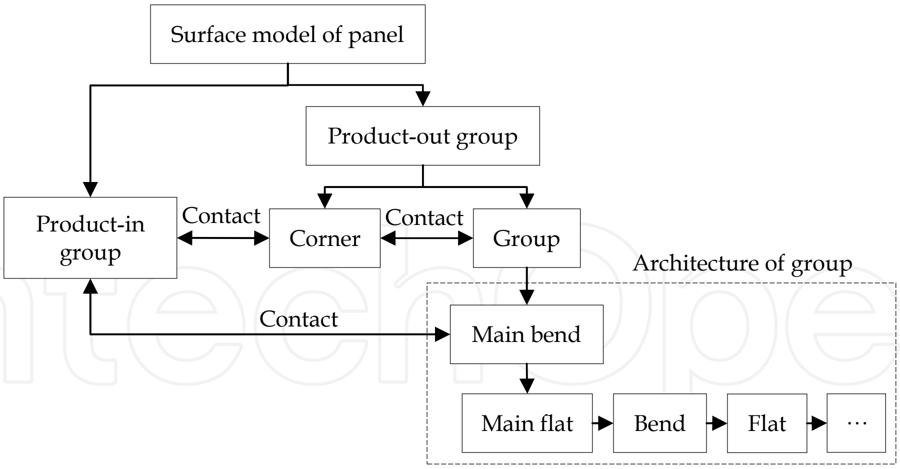

Figure 12. Framework of features

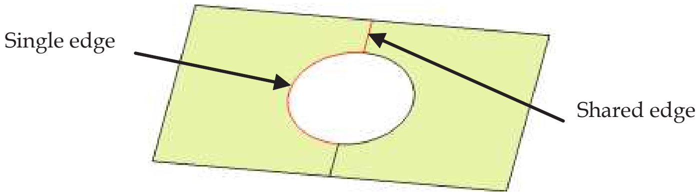

Figure 13. Single edge and shared edge

Finally, the feature recognition result for this sample panel has six groups and six corners (Fig. 14).

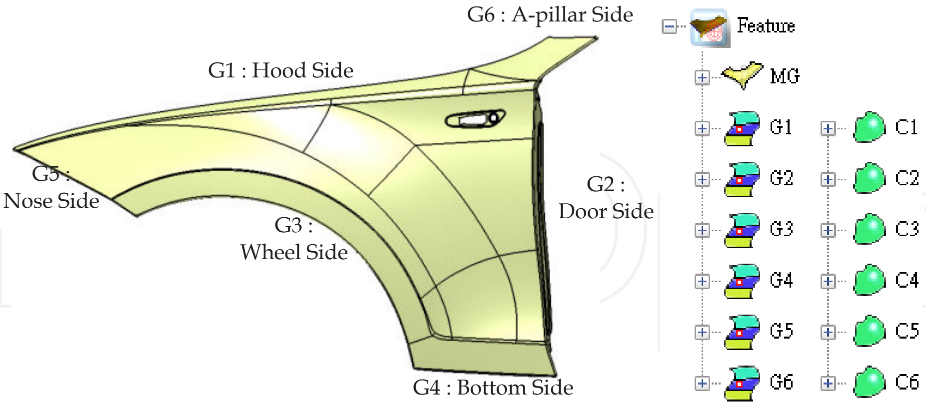

Figure 14. Feature recognition result for fender

3.2. Machining center searching

The file of a panel from a car company is related to the origin of a car (always at the center of the left front wheel, but differs among car companies). Before deciding the drawing direction, one should first search for the machining center as a new origin, which is a reference point of dimensions marked while designing the die and a machining center while assembling the die.

The method of searching for the machining center is to find the minimum bounding box first, and to define the longest side to the shortest side as the x-, y-, and z-axis in sequence. The direction of the x-axis is used as a reference when designing the longest side of a die and the direction of the y-axis is used as a reference when designing the shortest side, which is the feeding direction. Finally, the center of the upper rectangle is regarded as the machining center (Fig. 15).

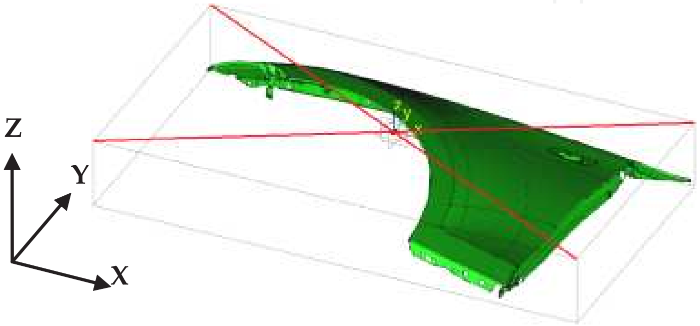

Figure 15. Minimum bounding box and machining center of fender

3.3. Drawing direction optimization

Before introducing the drawing direction optimization method, this study introduces the drawing task. The drawing procedure differs markedly from other tasks. A plane blank is placed on the piston, and the punch drives the upper die downward to clamp the blank with the piston, and then continues its downward movement with the piston to form the blank with the lower die (Fig. 16); notably, other operations are conducted without the piston.

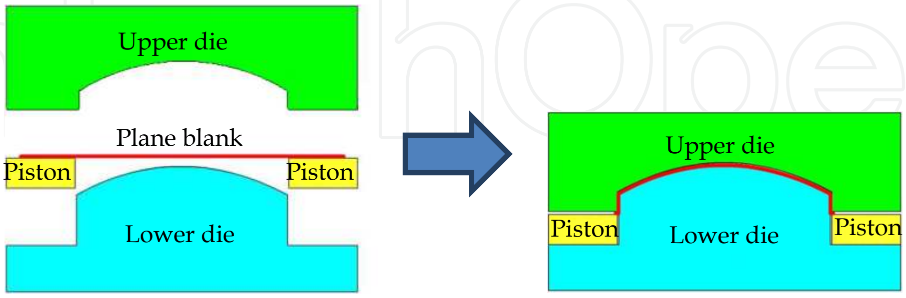

Figure 16. Procedure of drawing operation

The drawing task is always the first operation, and it is the most important task because it shapes the entire product-in group and a little other groups. The key factors in the drawing task are stamping direction and modeling of the die face (You et al., 2011). The stamping

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direction affects the forming ratio of a panel and product quality, and the modeling of the die face affects the difficulty of follow-up tasks and number of operations. Only after one identifies the drawing direction can the die face be designed and the process planned.

Drawing direction optimization can be summarized using the following three principles: minimum depth, equal angle, and without an undercut. These principles are only for the product-in group, not other groups, because forming the product-out group is not within the scope of the drawing operation.

1. Minimum depth

Drawing depth is the distance on a panel in the drawing direction (Fig. 17). A large depth can cause cracking and increase the height of a die, thereby increasing cost. Thus, minimizing drawing depth can reduce the degree of cracking; and it means that a shallow drawing is used instead of deep drawing.

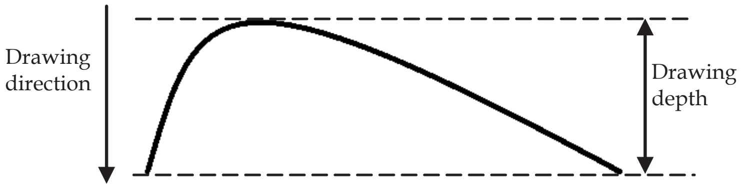


Figure 17. Drawing depth

The method of searching the drawing direction with the minimum depth divides the range 0–180° into five equal parts (i.e., 0°, 45°, 90°, 135°, and 180°), and the depth in each direction is calculated. If the depth in the first direction is the shallowest, then the first direction and second direction are divided into five equal portions and each depth is calculated again. If the depth in the second direction is the shallowest, then the first direction and third direction are divided into five equal portions and each depth is calculated again (Fig. 18); this process continues until the search range converges to <0.1 to determine the angle rotated along the x-axis and y-axis, and the direction of z-axis after rotating is the drawing direction with minimum drawing depth.

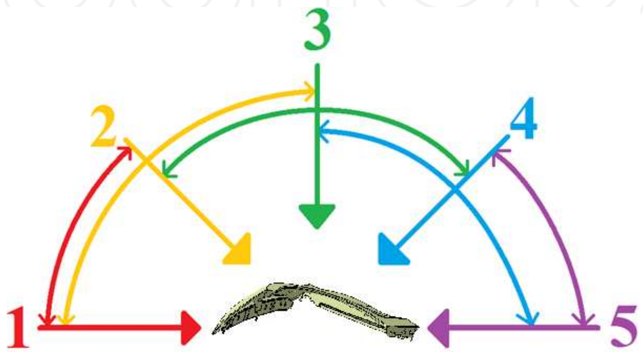


Figure 18. Searching drawing direction with minimum depth

2. Equal angle

Characteristic lines (Fig. 19) are very important in the product-in group of appearance parts. If characteristic lines are offset from the original position, it will be very obvious from the outside of a vehicle.

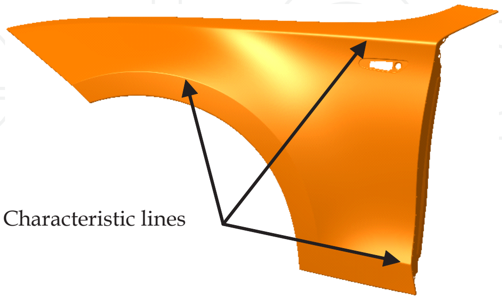


Figure 19. Characteristic lines on fender

The reasons for the offset of characteristic lines are that non-uniform forces exist on both sides of characteristic lines. When the slope of one side is larger than that of the other side, characteristic lines will be offset to the more oblique side because the material flow rate is slower than that of the other side. However, automotive panels always have irregular, asymmetric, and complex shapes. The method for preventing offset of characteristic lines is to make all slopes from boundaries to characteristic lines as close as possible (Fig. 20). This study sums all normal vectors in the product-in group and calculates the average normal vector, which is the drawing direction with equal angle.

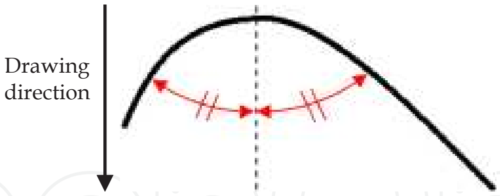


Figure 20. Equal angle

3. Without an undercut

An undercut is an area that cannot be reached by the upper die and lower die during stamping (Fig. 21), and the die will damage at that area. If an undercut area is unavoidable, cams must be used or follow-up operations are needed to shape the undercut area.

In this study, two novel methods are applied for detecting undercut areas after determining the drawing direction, and the range of detecting is not only product-in group but also product-out group because some groups with simple modeling without an undercut are still shaped during the drawing operation.

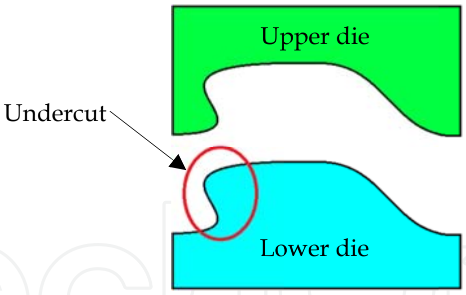


Figure 21. Undercut

The first proposed method calculates the angle between all normal vectors of point data and the drawing direction. If the angle is 0–85°, the area around the point is safe without an undercut. If the angle is 85–90°, and then the area around the point is close to an undercut, such that one should pay special attention to the draft angle. If the angle exceeds 90°, the area around the point is certainly an undercut, such that this area cannot be shaped during this operation, and other tasks are needed to shape this undercut area (Fig. 22).

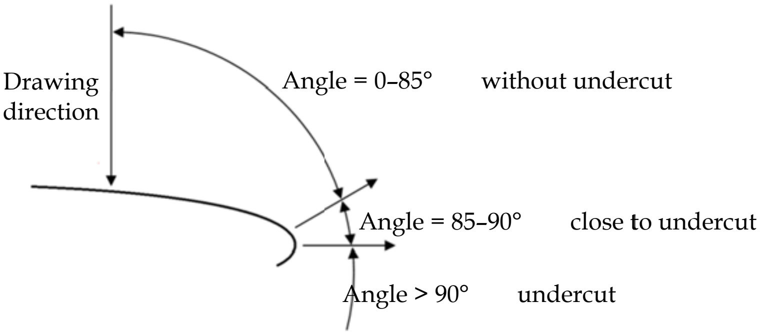


Figure 22. Detecting undercut by angle

This method can determine whether undercut areas exist, but cannot detect the undercut area accurately (Fig. 23). Section (a) is detected correctly as an undercut, but section (b) is not because the angle between the normal vector and drawing direction is <85°. In fact, section (b) still belongs to the undercut area.

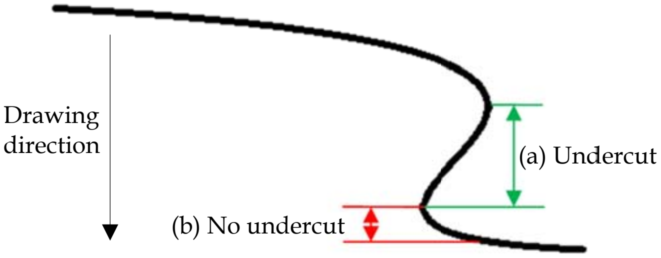


Figure 23. Fail to detect the undercut area by angle

To overcome the detection problem, this study applies another novel method that detects all undercut areas accurately. All point data are adopted as start points and the drawing direction is adopted as the direction vector to establish a ray. If no points exist at the intersection between the ray and the panel, the area around the point is safe. If points exist at this intersection, the area around the point is an undercut (Fig. 24). Section (b) is also detected as an undercut as section (a) correctly by the intersection between the ray and the panel.

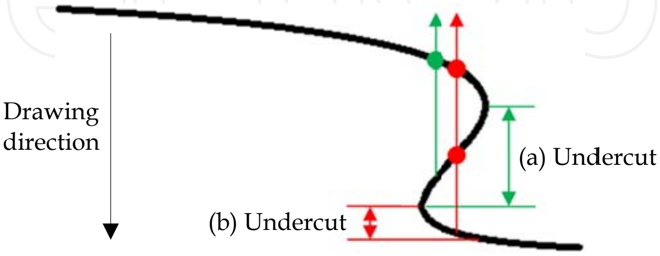


Figure 24. Detect the undercut area correctly by intersection of ray

The drawing direction result for a fender (Fig. 25) is determined from the half minimum depth and half equal angle methods.

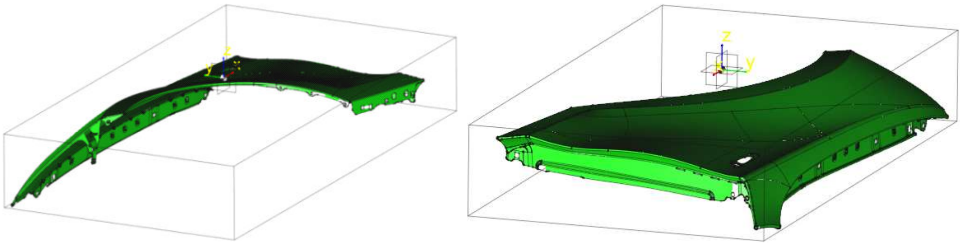


Figure 25. Drawing direction of fender

3.4. Process planning

The purpose of process planning of automotive panels is to identify the number of operations, the tasks in each operation, and the content of each task. This researching proposes an automatic reasoning procedure based on expert experience and the laws of physics. First, the essential tasks based on the feature recognition and drawing direction results are searched and reasoned and then arranged in each operation. Finally, the most suitable stamping direction of each operation is analyzed, and the machining direction of each task is based on the stamping direction.

Common tasks in die layout of automotive panels are drawing, trimming, restriking, flanging, piercing, and burring (Table. 1). These tasks are characterized as follows:

Type	Task	Simplified Description
Forming	Drawing(DR)	Form the product-in group and some other groups
	Flanging(FL)	Flange the unformed groups to position
	Restriking(RST)	Form the groups whose precision is not enough
	Burring(BUR)	Flange the boundary of hole feature
Cutting	Trimming(TR)	Cut the redundant material
	Piercing(PI)	Cut the hole feature

Table 1. Classification of common tasks

1. Trimming task

The trimming task is separated into two parts—one uses a trimming knife to trim outside the surface of a panel, which is called scrap material, and the other trims the scrap material into smaller pieces with the longest diagonal <500 mm to discharge from punch conveniently (Fig. 26). Based on the laws of physics, when the machining direction of the trimming knife is parallel to the normal vector of a trimmed surface, it will apply the optimal trimming force to make the situation of boundary well. If the angle between the machining direction and the normal vector is too large, the boundary will produce deckle edges and sharp phenomenon.

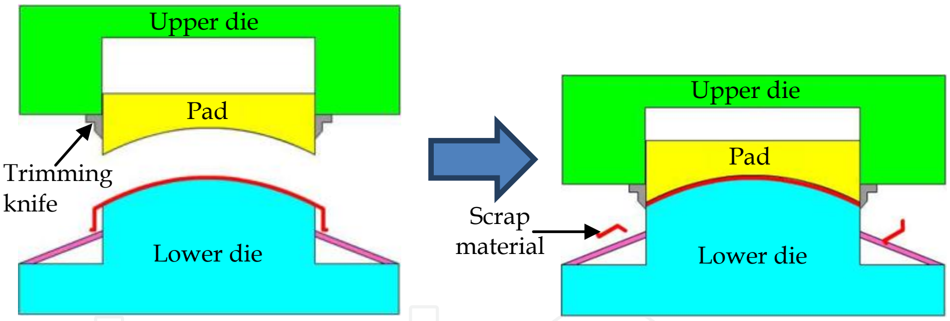


Figure 26. Procedure of trimming task

2. Restriking task

The contact between the restrike knife and surface is face to face (Fig. 27). The restriking task is necessary when surfaces deform because of springback after drawing and trimming, or the accuracy requirement is high because a surface overlaps another surface of another panel during assembly. If the machining direction of the restriking knife is parallel to the normal vector of a surface, the optimal restriking force is applied to the surface.

3. Flanging task

The contact between the flanging knife and surface is a line contact (Fig. 28). The flanging task is necessary when the position between the surface after drawing and the final shape of a panel

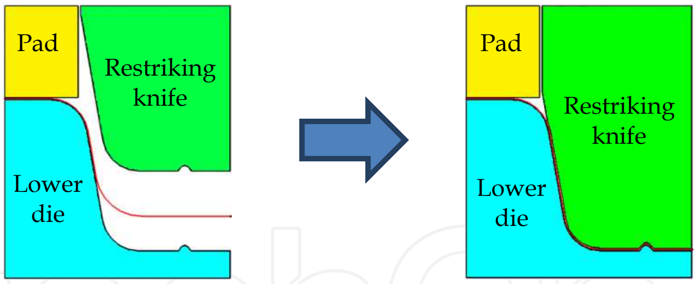


Figure 27. Procedure of restriking task

differ, and there are the effect of restriking when flanging to the end. The machining direction of the flanging knife perpendicular to the normal vector of a surface will apply the optimal flanging force for a surface.

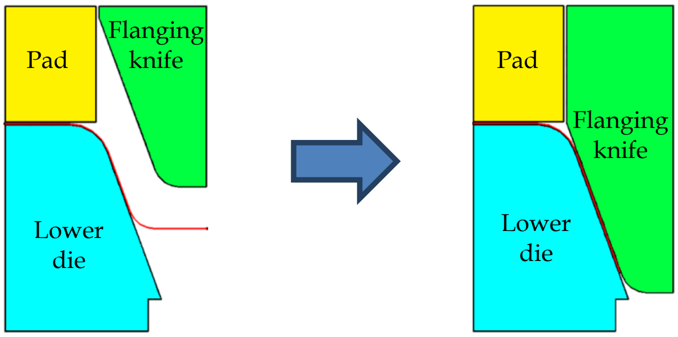


Figure 28. Procedure of flanging task

4. Piercing task

Each hole feature requires a piercing task (Fig. 29). Hole features can be classified as basic holes, lock holes, and enlarge holes based on their different functions during assembly. A basic hole is for locating the panel, and a lock hole is for locking panels. The accuracy requirement of both holes is high. A enlarged hole whose accuracy requirement is low for passing through the machining tools during assembly. The piercing principle is similar to that of trimming. The machining direction of a drill parallel to the normal vector of a hole feature will also make the situation of boundary of hole well, and the allowed angle is based on the size of the hole feature.

5. Burring task

The burring task is necessary when bending shapes exist at the boundary of a hole feature after piercing. The burring procedure resembles that of flanging (Fig. 30). The best machining direction is the same as the piercing direction.

This study now introduces the relationships among all tasks and specification of planning.

1. Trimming is arranged before restriking and flanging

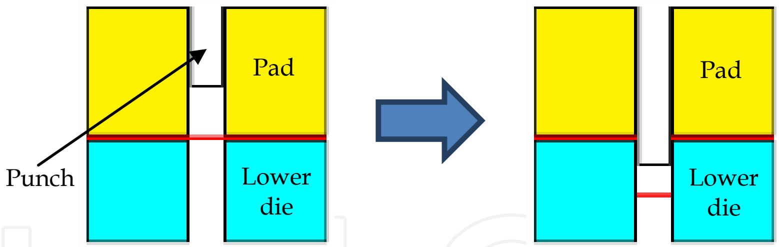


Figure 29. Procedure of piercing task

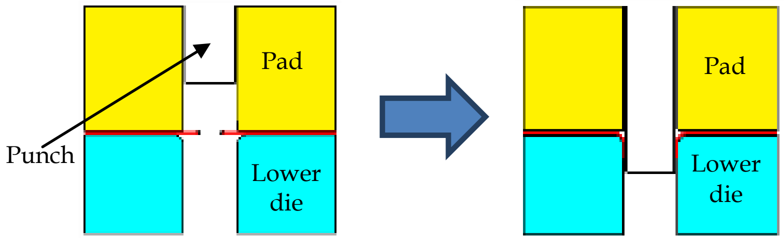


Figure 30. Procedure of burring task

If trimming is performed after restriking and flanging, residual stress will cause severe deformation after trimming.

2. As many trimming tasks as possible are arranged in the same operation

As the number of pieces of scrap metal is typically excessive, they could not be discharged from the punch easily, and the difficulty in die design will increase; however, if trimming tasks are arranged in a backward order, then the restriking and flanging tasks will also be arranged in a backward order, such that the number of operations will increase, thereby increasing production cost.

3. As many piercing tasks as possible are arranged in the same operation

Positional errors always exist in each piercing task. If piercing tasks are conducted in different operations, and then the error among all holes will likely increase because offset directions differ. Thus, arranging piercing tasks in the same operation can reduce error because all offset directions are the same.

4. Piercing is arranged after restriking and flanging

When restriking or flanging, the position, shape, and size of a pierced hole will change; thus, piercing tasks are usually arranged after restriking and flanging. However, enlarge holes whose accuracy is low are acceptable before restriking and flanging to prevent generating an excessive amount of scrap material from holes, which increases discharge difficulty.

5. Cutting tasks are not arranged with upward flanging tasks

If upward flanging tasks exist, the pad is mounted on the lower die. However, it is relatively unstable during production, such that arranging cutting tasks, such as trimming and piercing, will increase the magnitude of errors.

6. Burring is arranged after piercing

A hole feature with a bending boundary requires two tasks. Although a new task combining piercing and burring exists, it is used rarely as it is associated with increased cost and a short service life; thus, it is not considered by this study.

7. Determining the machining direction of each task

Using cams increases production cost, such that using the stamping direction as the machining direction is best. Additionally, if difficulty is associated with the stamping direction, cams can be used to change the machining direction. Cams are generally classified as suspension cams and non-suspension cams (Fig. 31). The knife of the former is mounted on the upper die, increasing cost and reducing service life. Thus, this study first considers non-suspension cams. However, if problems in discharging scrap material or feeding the blank exist, then suspension cams are used to increase the space of the lower die.

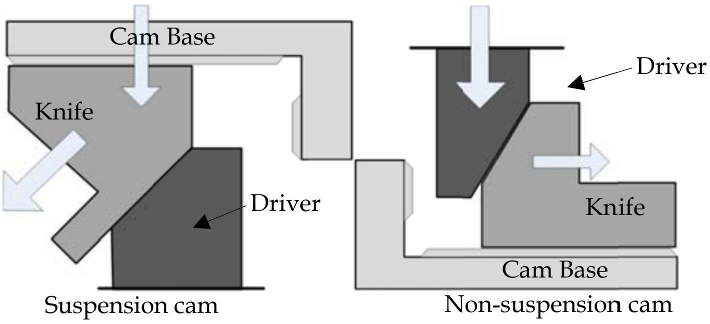


Figure 31. Suspension cams and non-suspension cams

Based on the specifications described above, this study summarizes the sequence of all tasks (Fig. 32). However, the stamping direction and detailed tasks in each operation must still be confirmed according to the panel models.

Figure 32. The sequence among all tasks

Before arranging tasks into operations, one must determine which tasks are needed. Piercing and burring tasks are easier than other tasks to reason. Each hole feature needs a piercing task, and when the normal vector of a hole is not parallel to the normal vector of the boundary, the hole feature also requires a burring task (Fig. 33).

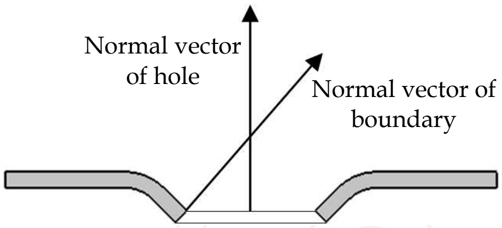
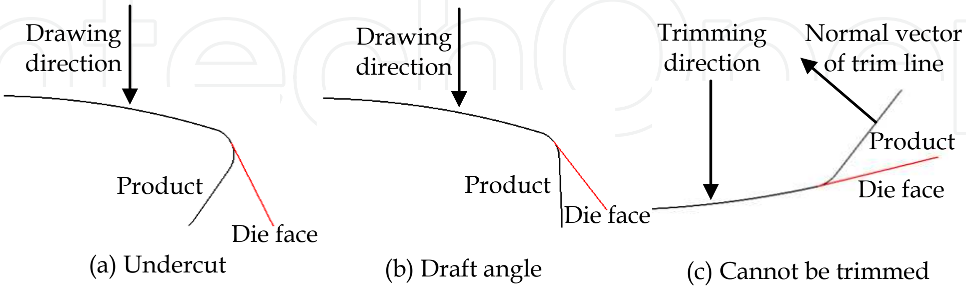


Figure 33. Reasoning whether the hole feature requires a burring task

Hole feature classification is based on the product drawing from a car company. However, this study simplifies this classification to a enlarge hole with a lower accuracy when the boundary length exceeds 50 mm because the area of enlarge holes is much larger than that of other holes.

Because drawing and trimming results affect the assessment of forming tasks, this study arranges drawing and trimming operations first. The first operation is only for the drawing task, such that other tasks are not arranged. In addition to trimming tasks around the panel, this study also considers all piercing tasks of enlarge holes of the product-in group in the second operation, and searches for the stamping direction that maximizes the number of piercing tasks without cams. If any piercing task of an enlarge hole cannot be conducted in the stamping direction, it should be arranged in follow-up operations because cams will interfere with trimming knives.

If some groups cannot be shaped while drawing (e.g., undercuts exist in the drawing direction or the draft angle is too small), this study designs the die face with a shape that can be drawn successfully and the follow-up flanging task is used to shape the groups. Even when groups can be drawn successfully, they cannot be trimmed in the trimming direction because of the normal vector of the trim line, and they still need a flanging task by designing the die face with a shape that can be drawn and trimmed successfully (Fig. 34).



(a) Undercut (b) Draft angle (c) Cannot be trimmed

Figure 34. Some reasons for flanging task

If a group can be drawn and trimmed successfully, restriking tasks are only needed to increase accuracy. The complexity of modeling of a group affects the forming result. Applying a flanging task to groups whose modeling is complex will result in cracking or wrinkling easily.

The restriking task result is better than that of flanging task because most modeling is done while drawing.

When a group cannot be drawn or trimmed successfully and modeling is complex, the group is shaped by two forming tasks. A flanging task is first used to bend the die face into a transitional shape and the restriking task is then used to form the transitional shape to product shape (Fig. 35).

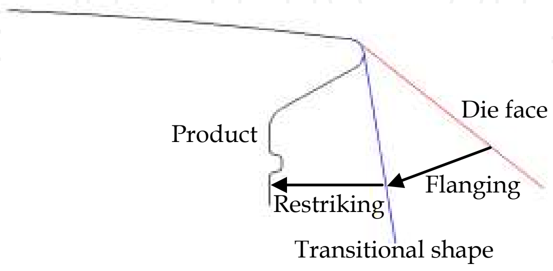


Figure 35. Two forming tasks: restriking after flanging

After drawing and trimming operations, each group requires at least one forming task, such that all remaining piercing tasks are not considered currently, but burring tasks, whose hole features are already pierced, are arranged. The best stamping direction of the forming operation minimizes the number of cams needed and has the best forming effect.

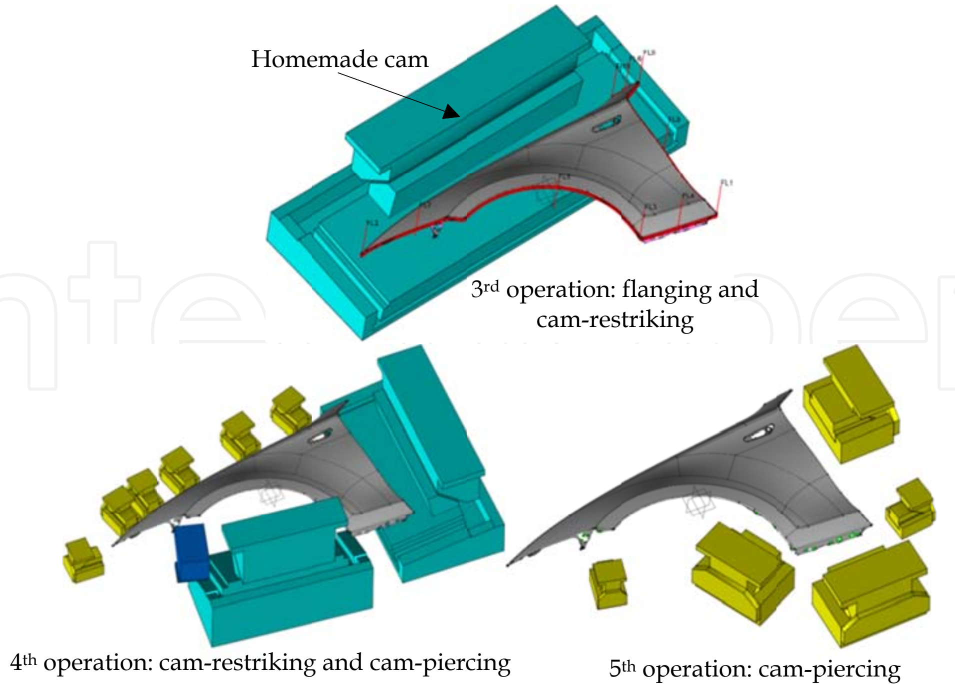
If other second forming tasks exist, they should be arranged after the forming operation. If all forming tasks are arranged, then one must consider the remaining tasks of the hole feature according to the order of piercing and burring tasks, and the best stamping direction for follow-up operations is the same as that in the forming operation.

The sample fender requires five operations in the result of process planning. First two operations are for drawing and trimming, and suitable standard cams are chosen or the size of homemade cams is reasoned based on features (Fig. 36).

The operating time of this example is taken about twenty minutes, and it will change with the file size and panel shape. The actual cost time except die face design from the experience engineers on the factory is taken about three to five days.

4. Sample of structure parts

This section introduces another sample of a structure part (Fig. 37). The procedure and concept of process planning for appearance parts and structure parts differ little. However, the functional differences among structure parts make that drawing direction optimization is needed for the entire panel, including the product-in group and product-out group, rather than for the product-in group only as appearance parts, because there are fewer undercut areas in structure parts and most product-out groups are shaped while drawing. The emphasis for



3rd operation: flanging and cam-restriking

4th operation: cam-restriking and cam-piercing

5th operation: cam-piercing

Figure 36. Process planning result for fender

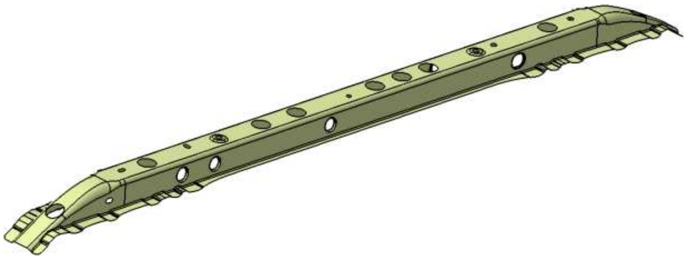


Figure 37. Sample of structure parts

structure parts is strength and rigidity, not appearance, such that the offset of characteristic lines is not important. Thus, the equal angle principle is not used to search the drawing direction of structure parts.

Furthermore, feature recognition procedure differs from the appearance parts and structure parts because structure parts do not have the constant modeling rules that appearance parts have. For instance, the area of the product-in group may not be the largest; the main bend group may not constitute a closed-loop; corner surfaces for separating the main bend group into smaller pieces may not exist; and the single surface, even when its curvature exceeds a critical value, should be classified as a flat surface. Thus, the automatic recognition procedure for appearance parts does not apply to structure parts.

Although this system supports manual feature recognition, too much time is needed to click on all surfaces. Thus, this study applies a novel procedure that uses both automatic and manual operations for feature recognition for structure parts. Users must establish only the framework of the features based on panel model and click on one or two surfaces in each group as start surfaces to identify automatically all surfaces with the same feature.

The most significant problem when searching a bend surface is the direction of the connection between bend surfaces (Fig. 38). Although the curvature of surface (a) and (b) both exceed the critical value, surface (a) should be deemed a flat surface instead of a bend surface based on the panel model.

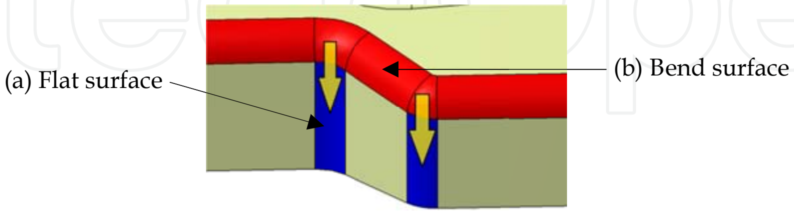


Figure 38. Connecting direction between bend surfaces

First, users click on at least two adjacent surfaces in the bend group. The surface that will be judged to be in the same bend group must satisfy the following three conditions: its curvature exceeds the critical value; it contacts the selected or judged bend surface; and the connecting angle between bend surfaces is less than a critical value (Fig. 39).

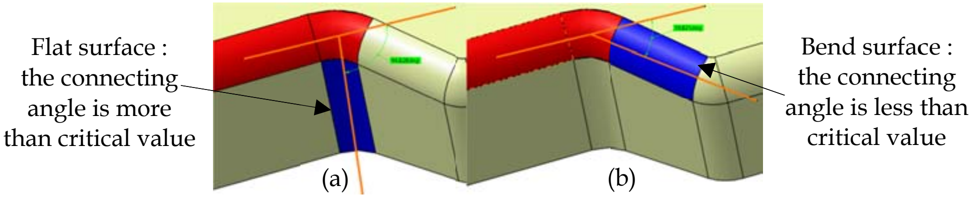


Figure 39. Connecting angle between bend surfaces

Fig. 40-42 show feature recognition result, the optimized drawing direction, and process planning results for structure part, respectively.

5. Protocol

The foundations of a knowledge database are knowledge acquisition and knowledge representation. Knowledge engineers retrieve knowledge from experts, books, or other sources, and then represent it on computer systems. The process of retrieving knowledge is called knowledge acquisition, and the process of representing knowledge on a computer system is called knowledge representation.

This research develops feature protocol and process protocol to record feature recognition and process planning results (Lutters et al., 2000), respectively. According to the process level, the

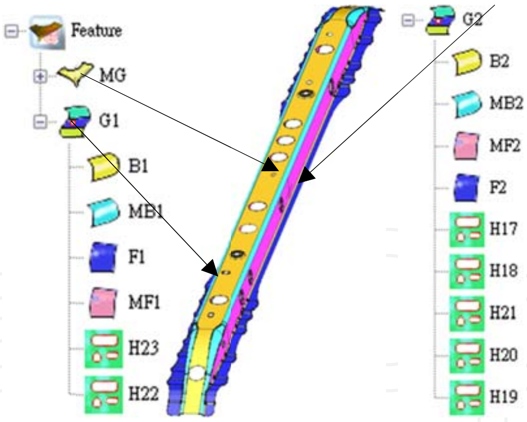


Figure 40. Feature recognition result for structure parts

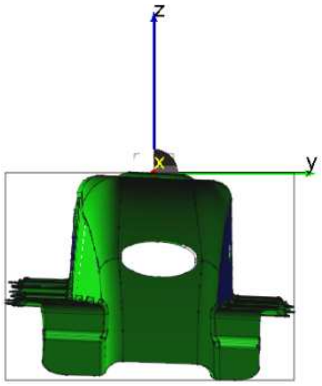
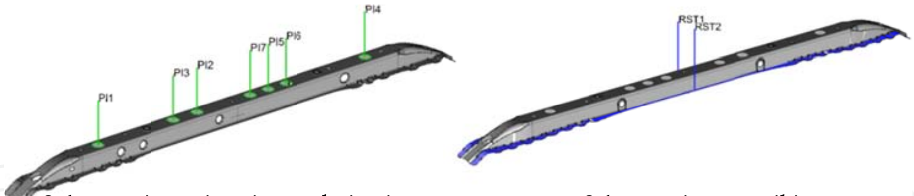
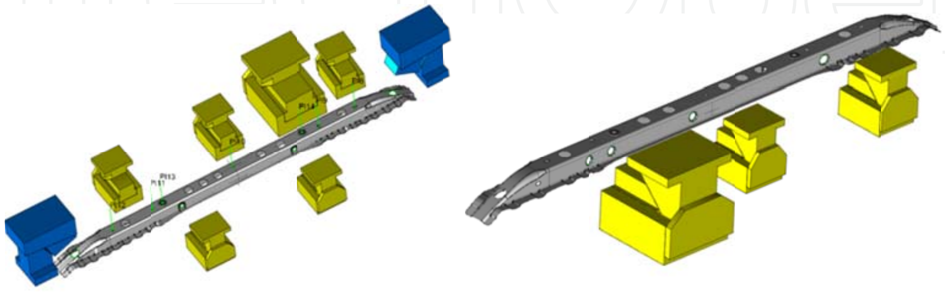


Figure 41. Drawing direction for structure parts



2nd operation: trimming and piercing

3rd operation: restriking



4th operation: piercing and cam-piercing

5th operation: cam-burring

Figure 42. Process planning result for structure parts

information is split by characters “! ; : <>,”. Each operation should contain an ID, type, stroke, die center, die dimensions, shoe height, and arranged tasks (Fig. 43). Notably, each task type has its own information that must be recorded (Fig. 44).

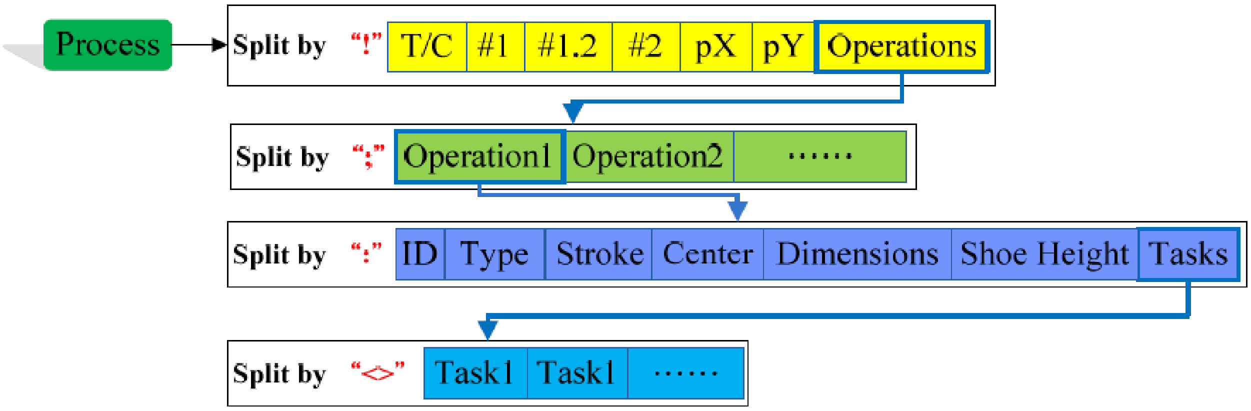


Figure 43. Process protocol

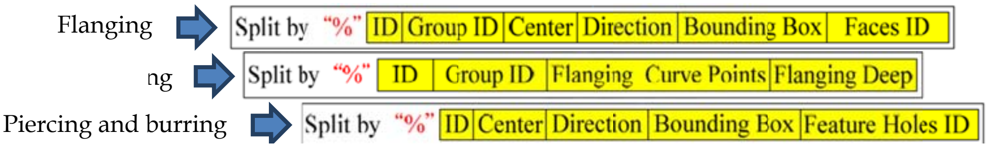


Figure 44. Protocol of each task

6. Conclusion

The process planning result is not unique, and such results will vary based on specifications from different die design companies and different designers. If a die design company and its designers are the same, even when the panel is the same, process planning results will also vary due to different client demands and different cost considerations.

Therefore, this study is based on the premise of compliance with the principles set forth in section 3.4 to reason the acceptable and enforceable process, and allow users to modify the content of process manually in response to different conditions and circumstances (Chapman & Pinfold, 1999; Ciurana et al., 2006).

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