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A CAD-Driven and Cloud-Based Autonomous Process Planning Framework for Reconfigurable Bending Press Machines

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Abstract

Sheet metal part manufacturers are increasingly under pressure to meet highly variable consumer demands. As product customization increases, the production process for sheet metal bending parts becomes more complex. This article proposes a fully integrated cloud-based system for sheet metal process planning. The system is developed based on a computer-aided design application and has the capability to rapidly convert a standard for the exchange of product data (STEP) file manufacturing instructions. A new mathematical model for calculating the overall production cycle time is also formulated. Two sheet metal components are used to test the system. The results demonstrate that the proposed cloud-based framework can display the 3D model, its face relationships, and a table containing the manufacturing information.

Keywords: digital manufacturing, process planning, sheet metal, reconfigurable bending press machine (RBPM)

1. Introduction

The rapid advancement of the manufacturing process has led to the adoption of cloud-based, reconfigurable, flexible, and autonomous systems in process planning. The increase in mass customization and the dynamic nature of the global market have added significant complexity to the process of manufacturing products. This requires emerging technologies to process the manufacturing data, increase product quality, and reduce lead time. Sheet metal bending an environmentally friendly industrial process, is widely used to shape metal parts into desired shape configurations. To support these demands, a reconfigurable bending press machine (RBPM) was developed, enabling machine length adjustments [1].

The RBPM manufactures sheet metal parts (bends) with a maximum length of five meters by adding modules to the machine. This development created a need to formulate a comprehensive process plan to address the limitations of traditional process planning methods. Conventional approaches to process planning are typically disconnected from the design and manufacturing phases, relying on computer-based methods where planning is conducted in isolation and then handed over to operations for implementation. In this study, the proposed sheet metal process planning method involves meticulously generating the manufacturing process, including the recognition of bend features, selecting appropriate bend tools, generating an optimal bending sequence, and calculating the bending cycle time, bending force, and the number of flips and rotations.

Since smart, adaptive, distributed, agile, and integrated process planning systems have gradually emerged, a digital twin process planning systems framework has been proposed to enable simulation, predictions, and control of the connection between process planning and product manufacturing [2]. Cloud-based process planning (CBPP) systems have revolutionized the way companies integrate and automate manufacturing processes. Cloud-based platforms offer a range of features and

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capabilities, allowing manufacturers to collaborate, exchange, share, and store data more effectively. Cloud technology has been recommended for machining process planning to extract and generate knowledge, improving querying and reasoning [3].

Next-generation vision inspection systems are evolving and have incorporated advanced technologies that streamline the inspection process from analyzing images and 3D modeling to creating reconfigurable files (ReCo files) [4]. Reconfigurable support vision inspection systems have been utilized for automated feature recognition applications by extracting parameters from real images and retrieving information from the CAD files to generate a ReCo file in extensible markup language (XML) format [5]. Flexible vision inspection systems (FVIS) and a reconfiguration support system (RSS) are introduced to enable easy reconfiguration for new part types. However, despite the availability of modern smart technologies to automate manufacturing and process planning, the sheet metal bending process has received limited attention.

The recent research on sheet metal bending mainly focused on theory-guided deep neural networks for verifying the shape of the workpiece after spring-back [6], optimizing bend parameters [7], and automatically creating process layout plans for parts manufactured using progressive dies [8]. However, in recent years, autonomous process planning systems have not been developed to address the complexity of feature recognition, tool selection, and process sequencing in sheet metal bending. Therefore, it is necessary to fill this gap by developing an autonomous, reconfigurable, cloud-based process planning framework for sheet metal bending press machines. A well-structured process plan ensures product quality, optimizes production time, and achieves cost efficiency.

The contribution of this study includes an independent cloud-based process planning framework for reconfigurable bending press machines capable of performing all the operations without integrating with any CAD or computer-aided manufacturing (CAM) software. The cloud-based systems integrate process planning activities which consist of feature recognition, the selection of tools, the generation of the machining sequence, and the calculation of the total production time. In summary, developing the cloud-based computer-aided process plan (CAPP) for sheet metal bending enhances manufacturing accuracy, efficiency, and adaptability, ultimately improving product quality and reducing production costs.

The remainder of the study is organized as follows: the literature review is presented in Section 2; the functional requirements of sheet metal bending process planning and the architecture of the CBPP and the CAPP system are discussed in Section 3; the design of the CBPP system is explained in Section 4; the testing and validation of the developed CBPP prototype are detailed in Section 5; Section 6 summarizes the discussion and the future research directions; lastly Section 7 concludes the article.

2. Related Works

This section reviews research relevant to this study, including sheet metal bending, cloud-based process planning systems, other process planning approaches applied to sheet metal parts, and the existing research on the critical stages of the sheet metal bending process plan. It is crucial to consider process planning for the reconfigurable bending press machine. Traditionally, process planning techniques have been applied to conventional sheet metal forming and machining operations. Table 1 presents research that has focused on a comprehensive integrated sheet metal bending process plan. It is evident that a few recent studies have developed an automated process plan for sheet metal bending, with most of the research being outdated. A comprehensive process plan encompasses a feature recognition system, tool selection, and bending sequence system.

Although research on a fully integrated sheet metal bending process planning has not made significant progress, recent studies have focused on the critical stages of the sheet metal bending process plan. These stages include feature recognition systems, tool selection, and bending sequencing, which are studied independently. A system is developed to extract and recognize sheet metal features from a 3D CAD model and display the features in the AutoCAD prompt area [17]. However, this system requires integration with AutoCAD to function. Another proposed system, the sheet metal V-bending feature recognition system, can identify bend line relations, geometrical features, and a flat pattern from a STEP file [18]. However, it is limited to generating flat patterns and identifying bent lines. Additionally, Kannan and M. Shunmugam developed a feature recognition system [19]. It displays the 3D central plane of the sheet metal part after running a script in AutoCAD. For the tool selection, researchers have developed a tool selection system integrated with the bending sequence generation [20-22].

Table 1 Sheet metal bending process planning

Year	Ref	Title	Article summary
2023	[9]	Prediction of bending parameters and automated operation planning for sheet-metal bending orientated to graphical programming	This article mainly focuses on the generating bending sequence, and the number of times the sheet metal part will be turned over.
2006	[10]	Automatic production planning of press brakes for sheet metal bending	The study investigated the possibility of automating the process plan for a bending press machine
2005	[11]	Computer-aided process planning for sheet metal bending: A state-of-the-art	This article provided a summary of all the research conducted up to the year 2002
2002	[12]	Constraint-based process planning in sheet metal bending	This article discusses a sophisticated approach that utilizes predefined constraints and geometric satisfaction to address the complexities involved in bending operations
2000	[13]	Process planning for small batch manufacturing of sheet metal parts	This article focused on sheet metal process plans for manufacturing parts in small batches. It uses the geometric and technical modules to determine the setup of the machine and the bending sequence
1999	[14]	Critical tolerance-oriented process planning in sheet metal bending	This study focused on identifying the order of bends subject to critical tolerance constraints. Two rules for achieving the optimal sequence were formulated.
1999	[15]	Algorithms for the design verification and automatic process planning for bent sheet metal parts	This article focused on optimizing the bending sequence for complex using a combination of rule-based, geometric constraints and the travel sales problem.
1998	[16]	Automated Process Planning for Sheet Metal Bending operation	This article presented a generative micro and macro process plan for a bending press machine operated by a robot. This system determines the sequence of bends and the tool and the motion of the robot

Whilst some researchers, as mentioned earlier, have focused on sheet metal bending, others have concentrated on computer-aided process planning for different sheet metal processes. For instance, an automated process planning system for laser forming and laser cutting is developed to extract part features from a 3D model, schedule cutting and bending tasks, and interconnect two processes [23]. An analytical process plan is also proposed for laser peen forming and shot peen forming [24], primarily focusing on the surface decomposition of parts with complex geometries. Additionally, a complete process planning system for laser peen forming is developed to generate geometric shapes using a partial differential equation constraint optimization method [25]. Most recent studies on sheet metal process planning focus on laser peen forming and cutting, relatively few have addressed sheet metal bending. One study presented a technique for automatically creating the process layout plans for parts made using progressive dies [8]. However, during feature recognition, the system cannot read the dimensions of each feature on the sheet metal part for tool selection, it only generates a sequence plan.

To effectively integrate the critical stages of the process plan it is essential to leverage cloud technologies and services. Previous research on cloud-based adaptive process planning spans various areas, including process planning for multi-tasking machine centers [26], the generation of nonlinear process plans and machine tools using sensors [27], distributed process plans, and machine monitoring services [28]. The approaches for full sheet metal bending process planning remain complex due to the intricacies of each process planning stage. The reviewed studies on the bending process planning of sheet metal components highlight both the complexity and significance of this manufacturing process. However, some research gaps must be addressed when developing a complete autonomous integrated cloud-based process plan for reconfigurable bending press machines or any sheet metal bending press machine. These include:

(i) A comprehensive analysis of existing literature reveals that research on cloud-based process planning is currently focusing on turning and milling operations there has been no previous research on cloud development for reconfigurable bending press machines.

(ii) Previous research on automated sheet metal process plans has primarily concentrated on bending sequencing. No article has focused on developing and integrating all the stages of the sheet metal bending process plan.

(iii) Although feature recognition systems for sheet metal bending parts are available, these systems are typically integrated with AutoCAD software to view the 3D model.

(iv) CAPP services must be provided on the cloud due to the high volume of data generated during the sheet metal bending process planning, especially for bending sequencing.

To address these gaps this study presents a novel autonomous cloud-based process plan for reconfigurable bending press machines.

3. Methodology

This study focuses on the bending process, one of the forming processes, using a reconfigurable bending press machine. Sheet metal bending is a manufacturing process that applies force to flat sheet metal to permanently deform it into a desired angular shape. It represents the final stage in sheet metal forming. The bending process involves numerous alternatives, which increase significantly with the number of bends in a part. Identifying the optimal process plan is more complicated due to the extensive search provided by the bending alternatives. However, not all alternatives are feasible, highlighting the need to determine the most feasible alternatives.

The problem addressed in this article is that sheet metal parts models are received in a single order at random intervals from various customers. There is a need to process the parts within the shortest time possible. The manufacturing facility operates in the following manner: All machines are capable of performing any bending operation. Each task must be completed on a single machine with no work transfers between machines while work is in progress. Each bend must be executed using a single tool, which can perform multiple bends. A job cannot be divided for processing by multiple machines. Each machine can be adjusted to accommodate the requirements of each sheet metal part.

A mathematical model was formulated considering the dispatch rule for orders on a first-come, first-served basis. It prioritizes customer orders based on their arrival to reduce lead times and optimize throughput. The model provides a system tailored to varying job complexities and customer demands.

Machine Setup: The total time to set up the bending press machine is the tool and machine setup time and is given by:

$$t_{ms} = n_{ti} \times t_{rm} + n_{ti} \times t_{ts} + t_{cf} + t_{sj} \tag{1}$$

Where n_{tl} is the total number of bending tools, t_{cf} is the total time to remove the previous component, t_{ts} the time to set up the tool including the modules, t_{cf} is the time to configure the machine, t_{sj} is the time to adjust the stroke.

Bending Sequence: The selected bending sequence determines the total bending time. The total bending cycle time, which represents the total time to bend the sheet part is expressed by the following equation:

$$t_{bc} = n_{bt} \times t_{bt} + t_{ps} + n_f \times t_f + n_r \times t_r + t_{pr} \tag{2}$$

Where n_{bt} the number of bends in a sheet metal part, t_{bt} the total time to bend all the angles of sheet metal, $t_{ps}$the time to position the sheet metal part, n_f is the total number of flips, t_f is the time to flip the part, n_r is the total number of rotations, t_r is the time to rotate the part, t_{pr} is the time to remove the part.

Dispatch rules and the production cycle time: The dispatch rules allow customer orders to be processed on a first-come, first-served basis. Therefore the total production cycle time is calculated by

$$t_{pc} = t_{ms} + n_{bp} \times t_{bc} \tag{3}$$

Where t_{ms} is the total time to set up the machine, n_{bp} is the total number of components to be processed, and $t_{bc}$is the time taken to bend each sheet metal part.

Bending force: To determine the bending force required to bend the part several parameters are considered, including the sheet thickness, bend length, and material properties. The following equations are used to compute the bending force.

$$F_{s_{\min}} = \frac{K_s L_b UTS_s t^2{}_s}{W_s} \tag{4}$$

where F_{smin} is the minimum bending force in Newtons (N), UTS_s is the tensile strength of the sheet metal, t_s is the thickness of the sheet metal in millimeters (mm), L_b is the bend length in mm, W_s is lower die opening, and K_s is the constant that depends on the die opening ratio.

3.1. The requirements of the CBPP

Cloud-based process plans for sheet metal bending parts involve leveraging cloud design patterns, data management strategies, sheet metal process design, and sheet metal process plan design patterns to create an efficient, scalable, and secure system in a cloud environment. To develop an effective solution the cloud-based environment is divided into four different layers as displayed in Fig. 1.

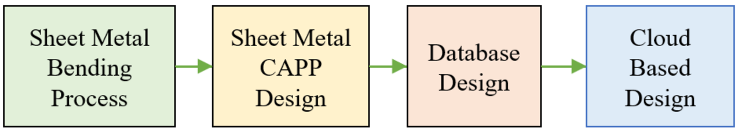


Fig. 1 The cloud-based design pattern

The major components of the proposed cloud process plan consist of the CAPP system, the sheet metal bending process, and the cloud-based system. To develop the most optimal CAPP system the characteristics of each design category are considered, as presented in Table 2.

Table 2 Features of the CBPP

Design Category	Characteristics
RBPM	versatile, reconfigurable, modular
The CAPP	in conformity, adaptable, compatible, dependable, reconfigurable, segmented, three-dimensional modeling, modular, interactive, generative
The Cloud-based environment	usability, cost-effectiveness, accessibility and collaboration, intelligent and interconnected, robustness and resilience, secure

The key attributes of the RBPM, CAPP, and the cloud-based system in Table 2 are essential for creating a high-quality CBPP system that effectively meets user needs. Each attribute plays an important role in the CBPP development process. The cloud process planning approach involves a collaborative process that links sheet metal design and sheet metal part manufacturing.

3.2. Sheet metal design product design process

The 3D models are designed in Autodesk Inventor and then saved as a standard for the exchange of product data (STEP) files. The file extension is .step or .stp. This is a 3D CAD model comprising the information about the sheet metal part to be manufactured including material types such as aluminum, mild steel, and stainless steel.

3.3. Computer-aided process plan

The CAPP system integrates inputs, constraints, and tools to achieve the required outputs. The context diagram representing the CAPP system is displayed in Fig. 2, illustrating the inputs, outputs, tools, and constraints. Tools used in the system include autodesk inventor for designing CAD models, databases for storing recurring information, and mathematical models for optimizing the system. Skilled labor represents the operator responsible for addressing cases requiring human intervention. Constraints, which govern the system's outputs, are variables that remain unaffected by the same system itself.

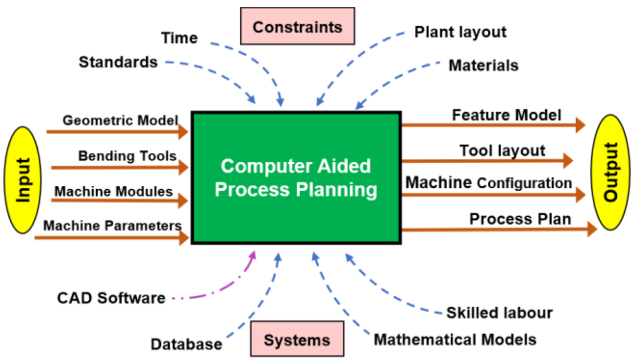


Fig. 2 Distributed CAPP

3.4. Sheet metal process planning

In this article, the sheet metal process plan includes the recognition of bend features, the selection of matching tools, the creation of a suitable sequence, and the calculation of production time for bending each sheet metal part. As presented in Fig. 2, the input of the sheet metal process plan is the STEP file through the use of systems and constraints. The output is the process plan consisting of bend features, matching tools, production cycle time, bending force, process planning time, and the number of machine modules essential to bend the part.

3.5. Architecture for the cloud-based process planning

The framework is constructed within the cloud-based system and comprises three core platforms: the visualization, the CAD processor, and the database server, as presented in Fig. 3. The cloud interface connects the user to the features and functions offered by the cloud-based system via the account manager The visualizer consists of an interface where the user can upload a CAD file and view it as a 3D model.

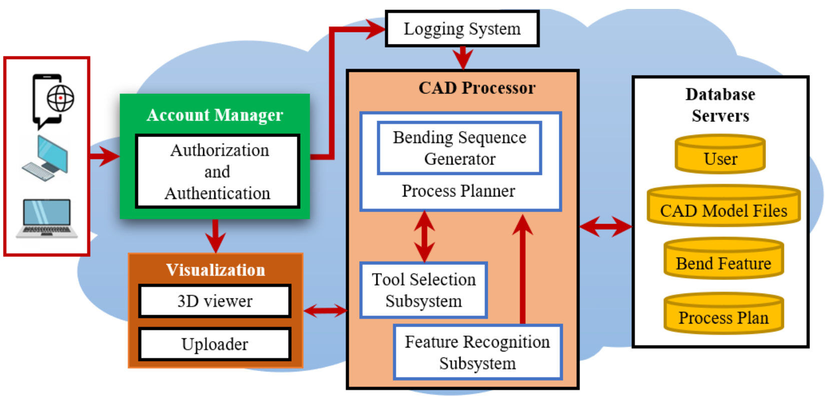


Fig. 3 Cloud process planning for sheet metal bending architecture

The CAD processor is the core component responsible for converting the geometric model data into manufacturing information. The subsystem consists of three subsystems: feature recognition and extraction, tool selection, and the bending sequence generator which generates the process plans. Every project's associated tasks, models, and user accounts are stored in the database. The database also stores the model features, materials, bending tools, modules, and process plan. The designs of subsystems and databases are explained in detail in the following section.

4. The Cloud-Based Process Plan System

The flow chart in Fig. 4 shows the entire CBPP system. The flow chart illustrates how the user will navigate through each subsystem. First, the user creates an account to log in to the system. Upon logging in, the user can initiate a project and upload a STEP file. Subsequently, the user is prompted to upload STEP files, view them, extract features, select matching tools, and generate the bend sequence and process plan.

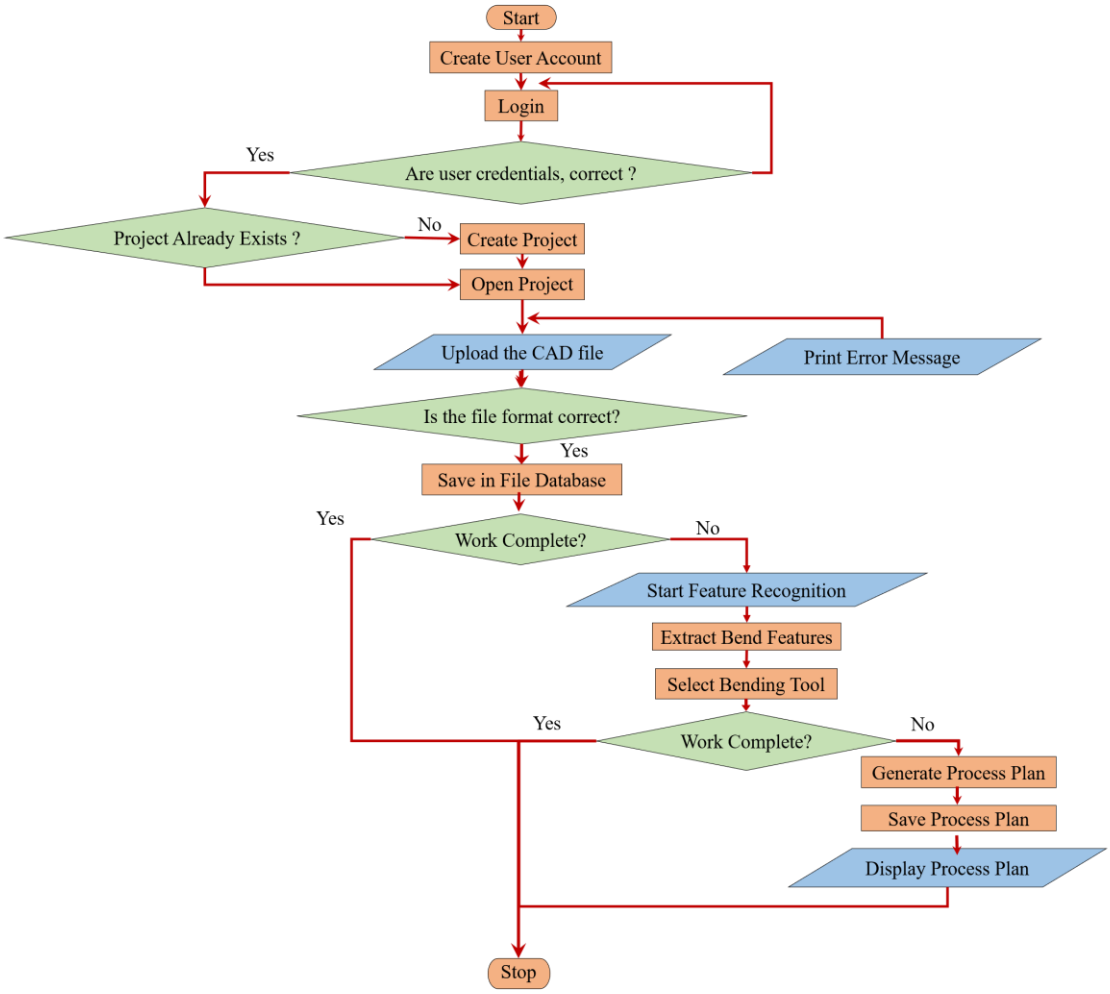


Fig. 4 Flow chart for the developed cloud process planning for sheet metal bending

4.1. Feature recognition

Feature recognition is the most integral part of the process plan. The importance of bend features in sheet metal bending cannot be over-emphasized. These features are critical to all tasks performed during the sheet metal bending process planning. It consists of two systems: one that detects features and another that extracts them. As presented in Fig. 5, the automated feature recognition system includes calculating the bend length, radius, angle, and bending force. A fully automated feature recognition system has been developed to classify planar and non-planar faces. The face types are grouped into thickness-defining faces, bent sides, and bending faces [29]. From recent research, a new feature recognition system has been developed to generate reconfigurable files (ReCo) from the synthetic images obtained from rendered 3D CAD files [5].

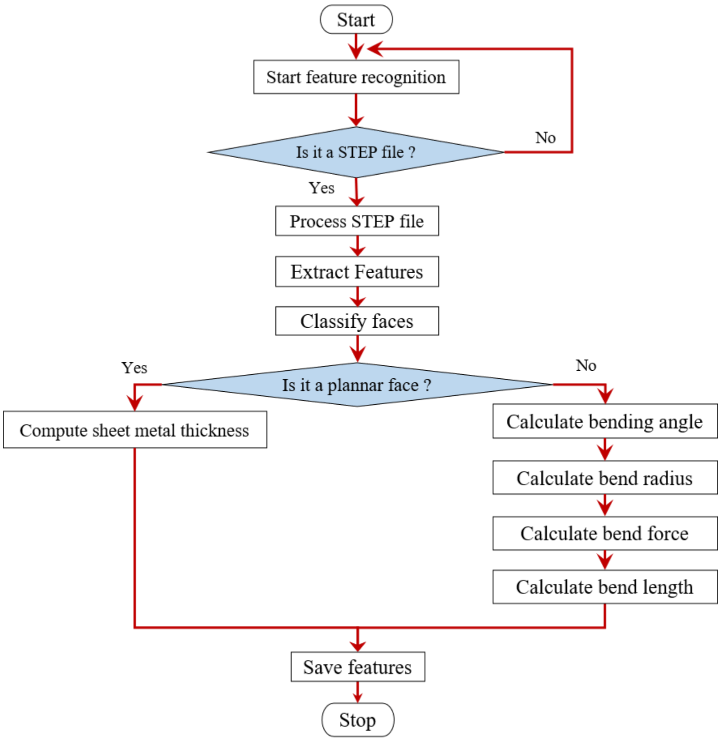


Fig. 5 Automated feature recognition

4.2. Bending sequence

The bending sequence subsystem is designed to minimize the number of flips, rotations, tools, and the sequence distance in the same sequence. To achieve an optimal bending sequence, various factors are taken into consideration, including the bend angle, bend direction, the sequence distance, the number of tools, and the orientation of the bends. A fitness function is computed to determine the optimal bending sequence, ranking each sequence based on the number of flips, rotations, and tools [30]. An optimal bending sequence is characterized by the shortest tool travel distance, as well as a reduced number of flips, rotations, and tools.

4.3. Reconfiguration

In this study, the sheet metal bending process involves bending sheet metal parts on a reconfigurable bending press machine. This cloud-based system has been designed for existing sheet metal bending machines and the reconfigurable bending press machine. The reconfigurable bending press machine is developed to bend parts up to 5000mm long. It consists of four modules, each module is 1000mm. Machine modules are added to the machine if the sheet metal part is more than 1000mm long, up to a maximum of 5000mm.

4.4. Database design

To design a database for a cloud-based process plan, a structured approach is used to align the cloud database for process plans. The structured approach enhances the design of a reliable, scalable, and secure cloud-based database. In this study, authentication is linked to a user account database containing data necessary to identify each user. The link between the database tables is presented in Fig. 6. The user account table provides information that distinctly identifies each user and is linked to an authentication token table. The token table stores "remember-me" cookies. Users can have multiple projects across different computers, and these projects are represented as a one-to-many relationship. Within each project, users can upload several CAD model files. Each CAD model must have at least one bend feature. For each bend feature, only a single tool is selected for processing the bend. The entire sheet of metal represented by the CAD model is made of a single type of material. Furthermore, each CAD model file has an optimal sheet metal bending process plan, which is saved in the database.

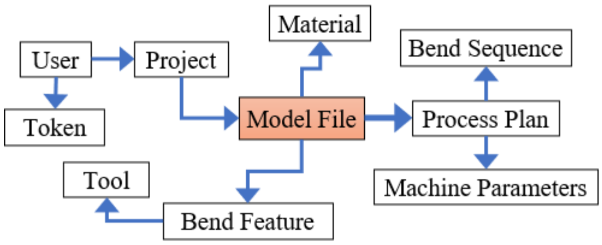


Fig. 6 Database design

5. The Implementation of the Cloud-Based Process Plan

To present the implementation of the cloud-based process plan system, a prototype is built in the form of CAD software. The developed cloud-based system is designed and validated. The system was initially tested using two STEP files. The CAD software was developed using C++ as a programming language and the overclock checking tool (OCCT) software development kit.

The cloud-based interface consists of two primary elements: the authorization and authentication modules. The authentication package provides the logic and widgets used to register customers in the software and safely authenticate them when the user logs in. This module is also accountable for displaying the present user's login status and propagating authentication notifications. The authorization module offers a means to grant or prohibit a user from accessing specific system functions based on their access.

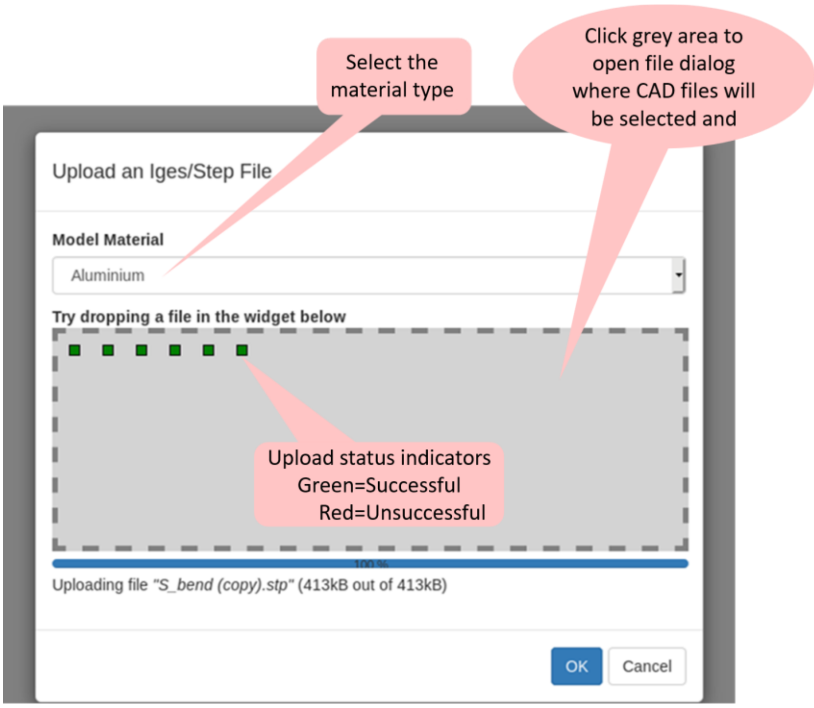


Fig. 7 Dialog for uploading the STEP file

After logging into the application, the user clicks the upload button to upload a CAD model. A dialog window, as presented in Fig. 7, pops up and enables the user to choose the CAD files to be uploaded and the material used to make the sheet metal. All geometrical models must be in the STEP file format.

In this case, two components are selected, one with a bend length of less than 1000mm and the other one with a bend length of more than 1000mm. A typical component with bends of more than 1000mm, as shown in Fig. 8, is uploaded to the developed sustainable cloud-based system for evaluating the system. The process planning generator considers the geometric model features, the type of material for the sheet metal part, the available tools, and the dispatch rules to generate the process plan.

(a) Inventor designed 3D CAD model

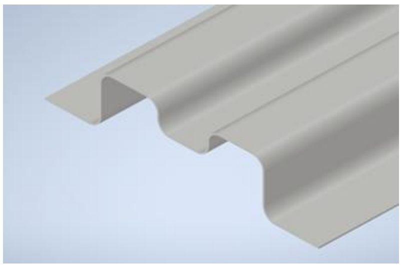

(b) The cross-sectional view of the left view

Fig. 8 3D CAD models

A sheet metal part is displayed in Fig. 8(a) and was designed in inventor. The part consists of eight bends all of which are 90 degrees and 2955mm long. Fig. 8(b) shows the cross-section of the left view to illustrate the shape bends. The side view shows the outside bends and the inside bends. From Fig. 9, it can be seen that the bends b2, b3, b6, and b7 are bent in the same direction, and bends b1, b4, b5, and b8 are in the same direction.

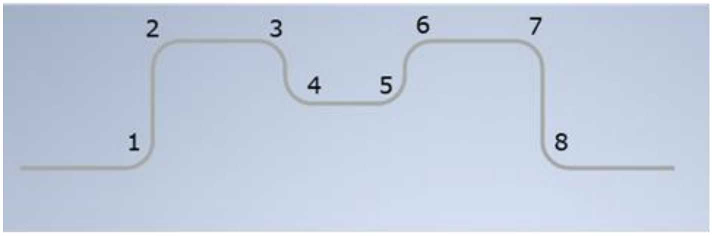


Fig. 9 The bends and the direction

The 3D CAD models produced by Inventor have been converted to STEP files and then uploaded into the system. As presented in Fig. 10, the model viewer pops up after uploading the STEP file, consisting of the 3D model and additional information extracted from the 3D model displayed on the left side of the window. The user can rotate and zoom in and out of the displayed 3D model.

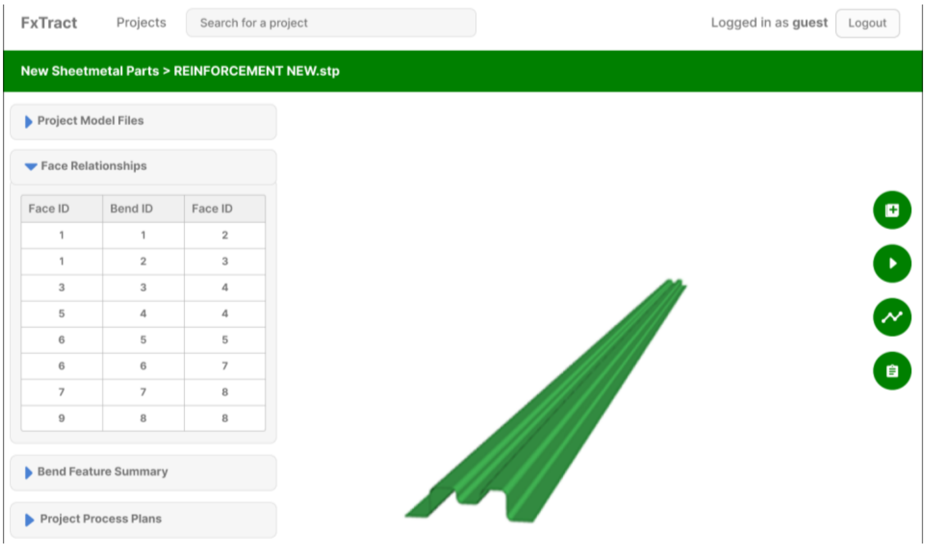


Fig. 10 The model viewer page

After clicking the process planning button, the output of the STEP file uploaded is displayed as shown in Fig. 10. All units are measured in mm, and the material for the sheet metal part is stainless steel. The 3D CAD models built with Inventor are exported as STEP files, The process plan outputs reveal the total number of tools, the thickness of the sheet metal, the bending force, the number of rotations and flips, the expected production cycle time, and the number of modules necessary to bend the component, which is then uploaded to the system. The quantity of the components can be changed to calculate the total production time.

The cloud-based system is able to generate a full process plan, as presented in Fig. 11, the part consists of 8 bends and each bend operation has an operation number. Each operation includes a bend Identifier (ID) bend angle, end radius, bend direction, bend length, and bend tool.

Processing Plan

PROCESSING PLAN SHEET : New Parts			PAGE : 1 / 1
Units : Degrees, mm, kN, sec			MODULES : 2
ENGINEER : guest	CHECKED BY : click to enter moderator name		DATE CREATED : 10/01/2025
PART No : click to enter the part number	PART NAME : REINFORCEMENT NEW.stp	MATERIAL : Stainless Steel	QUANTITY : 1
MACHINE PARAMETERS : No.of tools : 1 Thickness : 0.8 Bending Force : 67.1524	NO.OF ROTATIONS : 0 NO.OF FLIPS : 1	PROCESS PLANNING TIME : 5.76708	ESTIMATED PRODUCTION TIME : 0 d : 0 h : 4 min : 48 s

OPERATION NO.	BEND ID	BEND ANGLE	BEND RADIUS	BEND DIRECTION	BEND LENGTH	TOOLS
1	B1	90	4.8	Inside	2955	AC90
2	B5	90	4.8	Inside	2955	AC90
3	B4	90	4.8	Inside	2955	AC90
4	B8	90	4.8	Inside	2955	AC90
5	B7	90	5.6	Outside	2955	AC90
6	B6	90	5.6	Outside	2955	AC90
7	B3	90	5.6	Outside	2955	AC90
8	B2	90	5.6	Outside	2955	AC90

DOWNLOAD DONE

Fig. 11 Process plan for a 3D model in Fig. 10

For the Bend ID, the list of bends displayed is the most feasible sequence in this case the best optimal sequence ID b1, b5, b4, b8, b7, b6, b3, and b2 and the bends are 90 degrees, processed using the same tool. Since the bends are processed in different directions, flipping is required, resulting in one flip throughout the process. All bends in the same direction are classified as inside bends, while the opposite directions bends are outside bends. Specifically, b1, b4, b5, and b8 are inside bends, while b7, b6, b3 and b2 are outside bends . The sheet metal component also has parallel bends, so no rotation is required.

The sheet metal part has a length of 2955mm since it exceeds 1000mm, two modules need to be added to the machine. The system automatically selected the required modules for the machine. The obtained bending force for the model is 67.15 kilonewton (kN) and the estimated production time is 4 minutes and 48 seconds. Fig. 12 presents a sheet metal part with 8 bends, all of which are 200mm in length. Every bend has a 90° bend angle. It consists of two inside bends and six outside bends are all parallel. Based on this information, it can be deduced that the sheet metal must be flipped once during the bending process. Using a single tool, the stainless steel sheet metal must be bent with a bending force of 11.365 kN. As shown in Fig. 13, since the part length is less than 1000mm, no module is required.

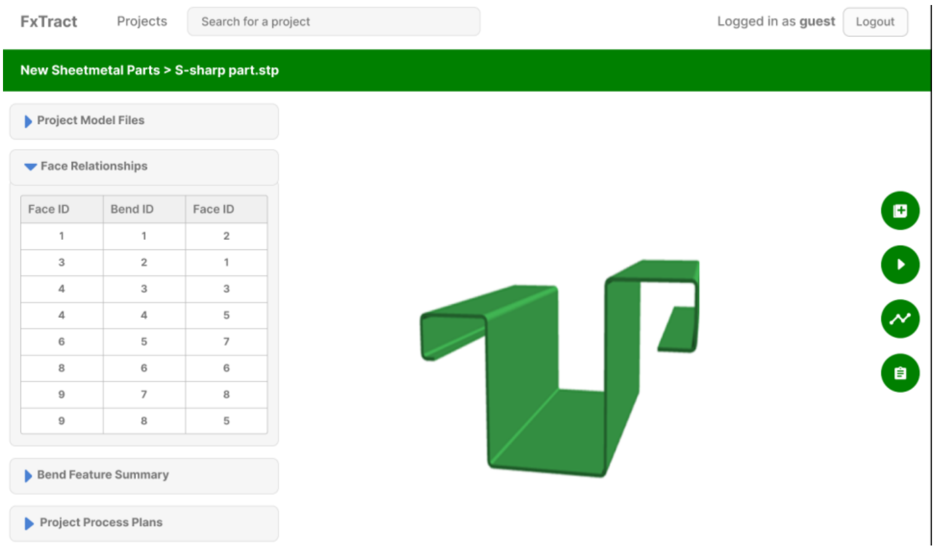
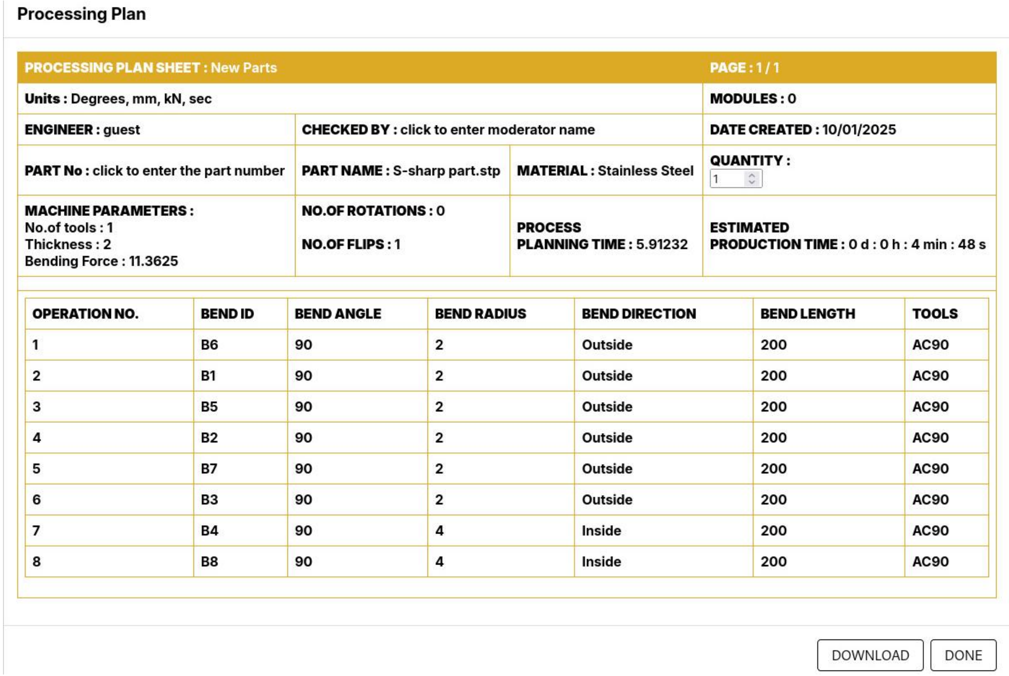


Fig. 12 The model viewer page

In this case, only one tool is required since the bends share the same bend angle. The bending force needed to bend for each bend is 11.3625 kN. No rotations are necessary as all the bends are parallel, and one flips is required because there are both outside and inside bends. The process planning time, the estimated production cycle time based on the press brake's specifications, and the number of parts to be processed are all listed in the corresponding fields. The bend features are displayed in the order determined by the bending sequence.



Processing Plan

PROCESSING PLAN SHEET : New Parts — PAGE : 1 / 1

Units : Degrees, mm, kN, sec — MODULES : 0

ENGINEER : guest — CHECKED BY : click to enter moderator name — DATE CREATED : 10/01/2025

PART No : click to enter the part number — PART NAME : S-sharp part.stp — MATERIAL : Stainless Steel — QUANTITY : 1

MACHINE PARAMETERS : No.of tools : 1, Thickness : 2, Bending Force : 11.3625 — NO.OF ROTATIONS : 0, NO.OF FLIPS : 1 — PROCESS PLANNING TIME : 5.91232 — ESTIMATED PRODUCTION TIME : 0 d : 0 h : 4 min : 48 s

OPERATION NO.	BEND ID	BEND ANGLE	BEND RADIUS	BEND DIRECTION	BEND LENGTH	TOOLS
1	B6	90	2	Outside	200	AC90
2	B1	90	2	Outside	200	AC90
3	B5	90	2	Outside	200	AC90
4	B2	90	2	Outside	200	AC90
5	B7	90	2	Outside	200	AC90
6	B3	90	2	Outside	200	AC90
7	B4	90	4	Inside	200	AC90
8	B8	90	4	Inside	200	AC90

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Fig. 13 Process Plan for a 3D model in Fig. 12

6. Discussions and Further Work

The newly developed framework seamlessly integrates the decoupled systems to collaboratively generate the process plan. The implementation of the CBPP addresses the need for a high-performance computational system for generating the bending sequence. The cloud platform enables the processing of multiple files simultaneously and provides storage for CAD files and data. The CBPP is compatible with any operating system and reduces the need for continuous computer hardware upgrades. The feature recognition and extraction (FRE) system was created to efficiently process the STEP file. It was built on the OpenCascade boundary representation (B-Rep) model library and categorizes the geometric and topological features of a CAD model. The CBPP demonstrates exceptional precision in extracting geometric features. The FRE system consistently produces results that align with the dimensions of the sheet metal model.

The tool selection subsystem determines the best tool that matches with each bend feature. The bending sequence subsystem processes bend features extracted from a STEP file to generate the most feasible sequence. The bending sequence subsystem is a component of the process plan that identifies the optimal sequence and presents it in an easily interpretable format.

The design of the CBPP focuses exclusively on the sheet metal bending process performed on a reconfigurable bending press machine. It does not include bending of material other than sheet metal. The FRE system can only recognize STEP files containing only bend features. This limitation prevents the CBPP from processing other features from sheet metal parts processed by other sheet metal operations. The generation of the feasible sequence relies on the minimum number of tools, rotations, and flips. However, the issue of collision detection to generate a more optimal sequence has not been addressed.

In the sheet metal forming process, sheet metal bending is the last process. For further work, the CBPP could be expanded to include other sheet metal operations like punching, notching, cutting, blanking, slotting, piercing, perforating, and shearing.

Different approaches, such as visual inspection systems, could be employed for feature recognition and extrac which converts the CAD models to ReCo files, enabling the system to recognize all part features [4]. To create a 3D annotation environment for 3D visualization, it is important to integrate product and manufacturing information (PMI) with the CBPP for 3D visualization and graphical simulation of the bending sequence with collision detection. The PMI can also allow the automatic labeling and dimensioning of the sheet metal bends.

The integration of sheet metal operations including punching, notching, cutting, blanking, slotting, piercing, perforating, and shearing, would require additional data processing and storage capacity. For a fully autonomous system, it is necessary to integrate internet of things (IoT), big data, and generative artificial intelligence (AI) into the CBPP.

7. Conclusion

This research presents the first time an independent cloud-based process plan for a reconfigurable bending press machine was developed as CAD software. In this research, all the stages of the sheet metal CAPP system have been fully integrated and operate on the cloud. These stages are interconnected together to generate a process plan. The CBPP is a standalone CAD software that can perform all the activities without being integrated with any CAD software. The CBPP eliminates the need for user data input; to execute the process plan, the user uploads a STEP file. The system then displays a 3D model, a bend summary, and the process plan consisting of the bend angle, bend length, bend ID, bend radius, bend direction, bend length, and matching tool.

For the reconfiguration, the cloud-based system allocated the required modules per sheet metal component based on the longest bend length. The system demonstrated autonomy in executing the process plan with minimal human assistance during the implementation. A new method for calculating the total production time was formulated, incorporating the tool change time, tool setup time, and machine setup time. Unlike existing methods, which only focus on the bending time and neglect other activities required prior to the bending process. It assists operators in determining how long it will take to machine a part. The system calculates the total time required to bend the part and intelligently selects an optimal sequence with fewer flips and rotations. Because the system is compatible with any operating system, manufacturers do not need to update their computer hardware to accommodate increased processing capacity.

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Conflicts of Interest

The authors declare no conflict of interest.

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