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A NOVEL FEATURE-BASED BENDING SEQUENCE PLANNING FOR SHEET METAL COMPONENTS FOR RAIL PARTS

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ABSTRACT
With the rise of mass customisation, smart manufacturing techniques are being employed. Because bending parts are complex, it is necessary to establish a bending sequence that is compatible with advanced manufacturing technology. A novel bending sequence was devised with the aim of enhancing sheet metal production efficiency and to lower the cost of bending the sheet metal part by minimising the number of tools, flips, rotations, sequence distance, and collisions involved in the process of bending. In contrast to other bending sequence methodologies, the bending sequence was generated by considering the number of flips, rotations, the shortest sequence distance, and collision detection methods. The bending subsequence was completed in a standalone system that was not integrated with any other CAD software. Two rail sheet metal components were utilised to demonstrate that the sequence with the highest fitness is automatically picked as the feasible sequence. The best sequence contains a sequence with the least number of flips, rotations, tools and the shortest distance.

Index Terms - Bending Sequence; Sheet metal; Bending, Bending press machine, Rotating, Flip, feature-based)

INTRODUCTION
The SMB industry must focus on using state-of-the-art technologies for the betterment of the environment in which the operations are conducted. Contemporary manufacturing techniques are marked by large volume, high diversity, and the production of tailored items of exceedingly high quality. For millennia, an assortment of manufacturing industries have utilised sheet metal forming to produce a broad range of products with several applications [1]. The forming of sheet metal (SMF) is an extensively used technology in various industries, including aerospace, automotive, food, and household appliances [2]. The bending of Sheet metals and stamping are among the most significant processes in the forming industry among the various forming procedures. Bending processes are commonly used in most sheet metal component production processes for deforming the sheet metals into the appropriate shape [3].

The bending of sheet metal components is the most intricate process of manufacturing in sheet metal production. The most complex manufacturing method used in the production of sheet metal is sheet metal bending. Even though it is the final operation in sheet metal forming. Due to the surge in mass customisation, there is a need to design a system that can generate bending sequences for batches of diverse products in the same production line. Mass customization focusing on the needs of the customer is one of the numerous competitive strategies closely associated with the idea of industrial sustainability [4].

Sheet metal bending CAPP entails performing complex tasks such as the recognition of features, the selection of available bend tools, and calculating the total production time. [5]. Thus, it becomes essential to incorporate customization in the setting up of CAPP systems. The rising need for high-quality custom products at a relatively inexpensive manufacturing cost and short production time has necessitated the development of better sheet metal bending sequence solutions. Because process planning is the backbone of manufacturing, it must adjust to rapid market change, increased mass customization, and globalization shifts. Process planning connects product design with manufacturing systems as a result it outlines the vital steps needed in the entire manufacturing process. As so, it will deal with the competitiveness issues faced by manufacturing systems.

Because of the complexity of bends, planning of sheet metal bending operations is required before the bending of sheet metal components can begin. Emerging process planning techniques, methods, and strategies need to be developed to satisfy the demands of the expanding systems. The fundamental function of the process plan is to generate the steps needed to create a product. Sheet metal bending process planning analyses features finds applicable tools and develops feasible bending operation sequences for the final sheet metal product. The bending sequence is an essential component of the sheet metal manufacturing plan. It can only be done after recognizing the features and selecting the available bending tools.

To accomplish a sheet metal bending process, the key step is to devise the most feasible bending sequence [6]. Bend sequencing is the process of developing the pattern that is used to produce a sheet metal product. It has proven difficult for the machine operator to determine the bending sequence during the bending operation. The bending sequence is a critical element in process design, thus smart techniques must be integrated to improve the system's accessibility. Generating a suitable sequence is a complex and efficient activity in sheet metal bending that has the potential to reduce rework and scrap. It also allows the machine operator to avoid deciding on the sequence while bending.

This article focuses standalone bending sequence subsystem and this means the system has not been integrated with any other CAD software. The rest of the article is arranged as follows: Section 2 describes the method of bending sheet metal. In Section 3, the bending sequence subsystem is explained. The research findings are presented in Section 4, and Section 5 concludes with recommendations for further study.

Various approaches, algorithms, and systems have been employed to generate viable sequences. These include constraint-solving and branch-and-bound methods, genetic algorithms, and fuzzy theories. The recent trend in sheet metal bending sequencing has focused on collision bending and direction; however, no research has addressed the number of rotations, flipping, calculating the total distance for each feasible sequence, and establishing the rules for bending collision on a single solution. As identified [7], an optimized bending sequence was proposed, the system reduces the no of tool stages, the length and distance between tool stages, and handling and tool setup to enhance a collision-free sequence. A modified branch and bound TSP algorithm were employed to generate the most feasible sequence and, in this case, also the number of flips, rotations and the sequence distance has not been considered. The paper focuses more on the material and process variations [8]. A two-stage approach was proposed for the rapid determination of the feasible bending sequence [9]. The first stage involves the use Bend Feasible Matrix to identify the near-optimum sequence and the second stage involves the best search approach.

An algorithm that allows a rapid exploration procedure for locating effective sequences without having to analyse potential bending sequences was developed. The part is divided into channels and spirals with bends in one direction [10]. A graphical programming system for sheet-metal bending that focuses on parameter identification to optimize bending quality as well as productivity was developed [11]. This research did not focus on the bending sequence distance, the rotation, flipping and collision detection rules. In [12] the study presents a method that uses tree-based bending sequence and wire representation as a robotic manipulator to automatically determine the proper bending sequence for a 3D wire CAD model. A variety of collision detection techniques are examined by taking information extracted from the SLT format to integrate the module with the sheet metal sequence system [13]. A modification of the V- Die bending formula was developed and validated using the finite element analyses [14]. In [15] two methods were compared the precedence constraint-based method and the travelling salesperson (TSP) method were compared and it was proven that the TSP was an additional consistent method as it detects the near problem sequence earlier compared to the other method. Yang & Hinduja [16] utilized a heuristic approach to automatically create operations sequences for sheet metal parts fabricated using a progressive die and reiterated that the heuristic sequence approach is less effective than near-optimal solutions. A sheet metal connectivity graph was employed to address limitations in a sequence of bends for a robot-operated sheet metal bending machine [17]. A modular framework for a CAPP system, specifically designed for sheet metal production in small batch parts environments was presented. This generic framework method describes how the manufacturing cycle is operated using the management information [18]. In this paper, the CAPP system for any sheet metal forming processes was not fully outlined. A constrained multiple-tool bending strategy was developed for incremental bending and it can be performed by one punch where the same strips can be processed at the same time. For incremental bending, a limited multiple-tool bending method was created. It may be used with several bending tools and bend numerous strips one at a time[19]. Rico et al [20] developed a method to recognize feasible sequences with parts divided into channels and spirals but this approach only works on sheet metal parts with bends of the same direction.

The rise in mass customization has necessitated the development of a system capable of generating bending sequences for batches of diverse items on a single line at a cheap cost and with minimal imperfections.

Related Work

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Sheet Metal Processing

The proposed bending sequence is suitable for all the bending processes conducted on a bending press machine. Sheet metal bending is flexible using a press brake [1], it involves a sheet metal blank using a punch and a die [2] as shown in Figure 1.

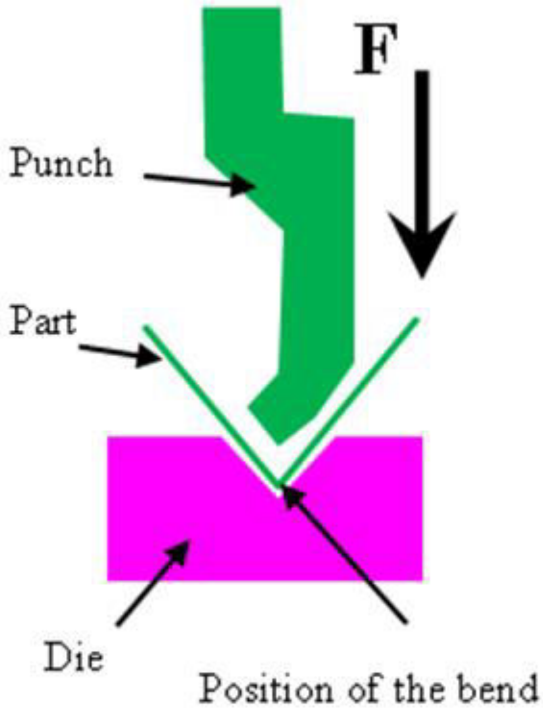


Figure 1: Sheet Metal Bending on a Press Brake

Due to the varying customer requirements, there has been an increase in the manufacture of sheet metal parts because of their capability to be converted into any complex shape. Hence sheet metal processing produces minimum waste but the can only be created if a correct sequence has not been generated. This has brought attention to the need to include novel methods and technologies in sheet metal bending process development. In this work, a new bending sequence methodology was explored by analysing the novel bending sequence subsystem. The major goal was to reduce cost by reducing the bend tools, the flips, the rotations and the sequence distance.

I. Process Planning for Sheet Metal Bending

In the bending of sheet metal, process planning entails identifying the ideal sequence of bends for a particular sheet metal particular sheet metal part [9]. In this article, the bending sequence subsystem works along with the feature recognition system and the tool selection system. Like all other process plans for sheet metal bending it includes a system that recognizes features, selects matching tools, generates feasible sequences and remote planning as illustrated in Figure 3. The only difference with other process plans is the independence of carrying out the process plan with minimal human involvement. The software has not been integrated with another CAD software. The process plan is conducted independently and there is no need for user input. The user only uploads the STEP file and then clicks the buttons in each phase of the process plan. No drawing with dimensions is required. Since this process is still working progress, this paper will focus on the novel bending sequence that was developed for the cloud-based process plan.

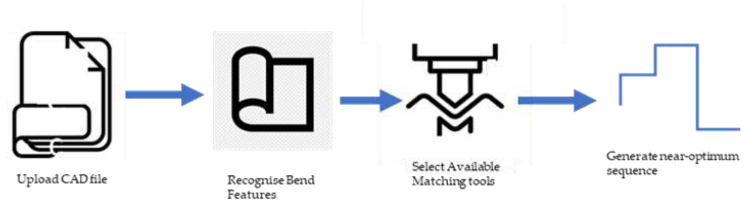


Figure 3: Sheet Metal Bending Computer Aided Process Planning

The process of recognising of bend features has been developed uniquely such that when the user uploads a CAD file to the cloud-based software and a table with the following details; bend ID, face ID, the angle of bends, the length of the bends, the radius of the bends, and the direction of bends will be displayed [21]. This information from the feature recognition is then used to select the tools that match the displayed bend features. After the matching tools have been selected then the next stage will be to generate the bending sequence.

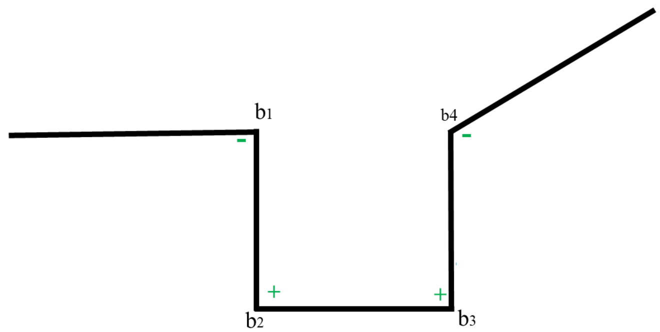
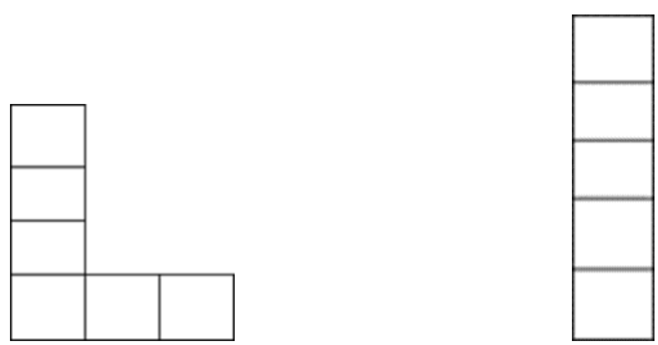


Figure 3: U Bends

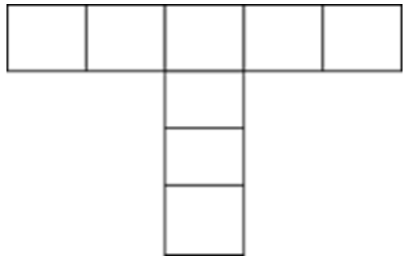
The tools selected are the ones matching the bends but during the bending sequence, the tools can be changed in the case of sheet metal parts with two parallel inside beds that have larger bend height. This applies to U-bends. When four bends form a rectangle, this shows the formation of U bends. In Figure 3, the sequence b1, b2, b3 and b4 forms a U shape thus it is a U shape bend. In this case, the bend height is the distance is the distance between two parallel bends. For example the distance between b1 and b2, or b2 and b3 or b4 and b3 respectively.

II. Bend Shape Families

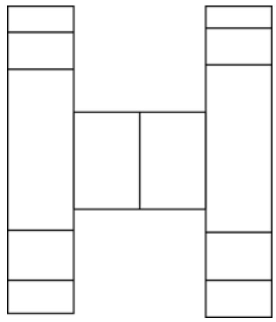
To determine the number of rotations and flips from every component, sheet metal bends components are classified into the following groups: bends that are parallel, bends that are perpendicular and collinear to each other.



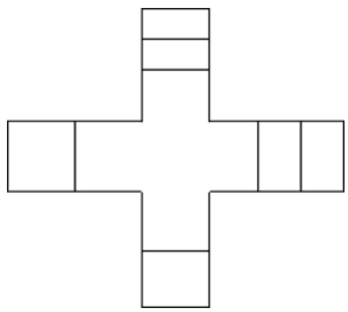
(A) .(B)



(C)



(D_



(E)

Figure 4: U Bends Sheet Metal Part Bend Shape Families. (A) L Type (B) I Type (C) T Type (D) H Type (E) STAR Type.

All sheet metal parts with bends that fall into these categories are classified into shape families. These families are obtained from the unfolded part as shown in Figure. There is the I type, H type, L type, T type and the star type. From the provided Figure the I type contains parallel bends only, the H type has one bend perpendicular to other bends and collinear bends, and the L, T and star types have perpendicular and parallel bends

III. Sheet Metal Bend Orientation Bend Shape Families

During sheet metal bending, a part is rotated if it contains bends which are perpendicular to each other. The sheet metal parts shaped as L, T, H and STAR types require rotation during bending. In this case, rotation means moving the unfolded part in a clockwise or anti-clockwise direction. The L type of bend consists of parallel and perpendicular bends. The L-type part will be rotated. The I-type part consists of parallel bends so there is no need to rotate the sheet metal part but flipping may occur in case the part has outside and inside bends. The T type has parallel and perpendicular bends and as for the Star type, the sheet metal part will be rotated almost 360 degrees. The H type usually consists of collinear bends. Thus, if a sheet metal bending part has collinear bends the bends can be processed simultaneously. Figure 4 shows the Star type and how it will be rotated during the bending process. After bending b1 and b2, to bend b3 and b4 the part will be rotated at 90 degrees. The rotation can be clockwise or anti-clockwise.

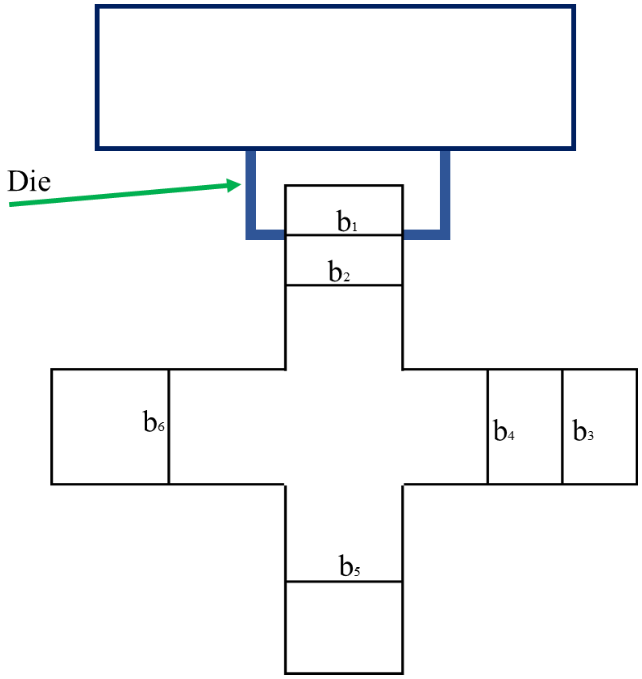


Figure 5: Rotating of the STAR Type

At this far several papers have neglected the rotation of sheet metal components during the generation of the bending sequence, the focus is only on flipping on some articles. The amount of time required to flip and rotate a part is equal. In most cases, the number of rotations is more than the number of flips. This shows that rotation should also be included when generating a feasible sequence. It helps in the optimisation of the sheet metal process and when formulating the overall total production time required to bend the part.

Iii. The Bend Direction

In this paper, the direction of bends is indicated as outside and inside bends as presented by [21]. All the bends processed at the top surface of the sheet metal part are named outside bends. All the bends that required flipping for the bends to be processed are named inside bends.

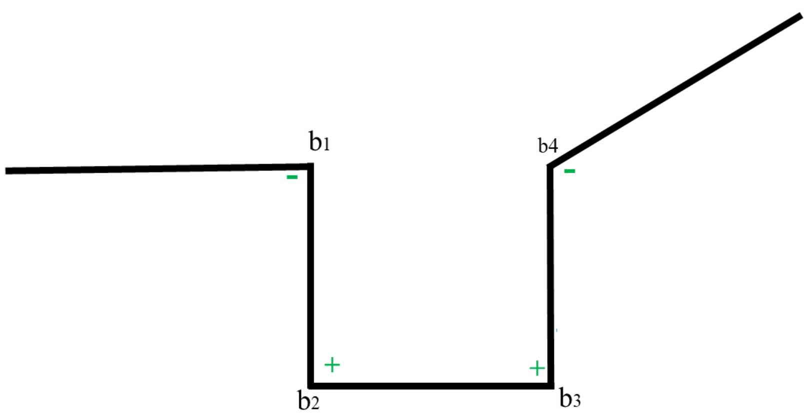


Figure 5: Bend Direction

Figure 5 shows the inside and outside bends. The positive sign represents the outside bends whilst the negative sign represents the inside bends. In Table 1, the bend, the direction and the symbol representing the direction.

Table I: The Bends and Direction

Bends	Direction		Symbol
Bend 1 b1	Inside		-
Bend 2 b2	Outside		+
Bend 3 b4	Outside		+
Bend 4 b4	Inside		-

THE BENDING SEQUENCE SUBSYSTEM

The most important step in the planning of the sheet metal bending process is the bending sequence. The bending sequence subsystem proposed in this paper works along with the feature recognition and tool selection subsystem as displayed in Figure 6.

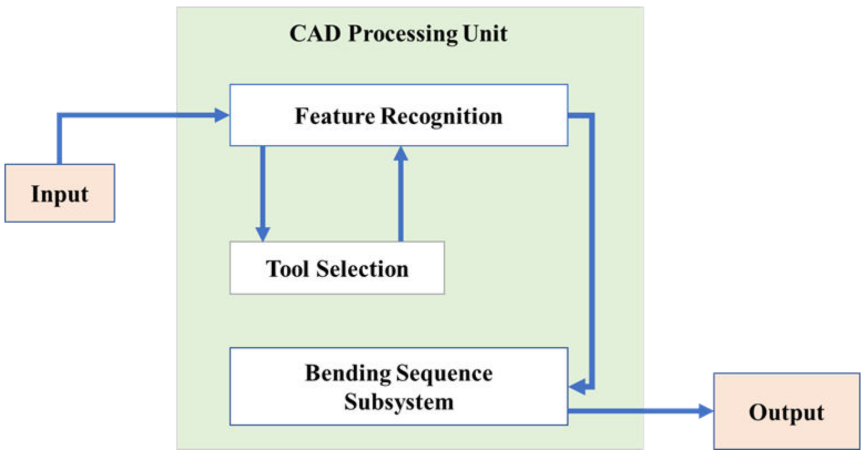


Figure 6: The Bending Sequence Subsystem

The feature extraction and recognition subsystems were designed for processing CAD files. Upon uploading the CAD files a 3D model is presented. For every feature, the tool selection subsystem is called to identify which tool is most suited for bending the sheet metal feature. As part of the processing plan system, the bending sequence subsystem is in charge of taking the ideal bending sequence and a few of its characteristics like the tools, flips, and rotations and displaying the results to the user in an understandable and accessible way.

Having the feasible sequence reduces the number of scraps created due to errors, and the time to bend the part thus increasing production. The availability of the feasible sequence also helps the machine operator not to decide on the bending sequence during the bending process. The process for generating a bending sequence involves placing bends in a precise order that the operator understands to produce a sheet metal bending component. If a component the sheet metal bending part consists of four bends each bend is recognized by b1, b2, b3, and b4. The layout of the pattern is displayed as (2, 3, 4, 1), (1, 2, 3, 4), (3, 1, 4, 2) which is the possible sequence.

I. Bending Tools

Since the proposed system is still a work in progress, At the moment the tool database system consists of 3 sheet metal bending tools namely: the acute tool, the standard V tool and the gooseneck tool. The standard V tool has the angle ranging from 15, 20, 30, 35, 45, 60, 88, 90. The gooseneck has angles ranging from 88 -90. The acute tool has angles 15, 20, 26, 35, 45, 60. The tool radius for all three tools ranges from 0.2 mm to 50mm.

II. Collision Detection

When there is a greater bend height in a U curve, collisions are more likely to happen. Figure 4 illustrates the formation of a U bend between b1, b2, b3, b4.

The following rules are followed to avoid collisions:

- In U-shaped bends with more than two bends, the outer bends are bent first; longer bends are bent later.
- When dealing with a sheet metal component that has varying bend levels. First, bends having smaller angles are processed then the other bends are processed later. In the event that a part has three distinct angles 30°, 60°, and 15°the rule is applied as follows. The first bend to be processed is with 15°, then 30°, then 60°.

In case of a collision the system does not change the sequence, it changes the tool. if the bending height is very long the collision is mostly to happen, a new sequence is generated, and a new tool is also selected. The gooseneck is selected when the bend height is large. The matching tools are selected just after the feature recognition. During the bending sequence if the system detects a large distance between bend lines it picks the gooseneck tool.

III. The Sequence Distance

During the bending process, the tool moves from one bend to another following the given sequence. The bending distance is the total distance travelled by the tool in each sequence. The required distance is the shortest distance with a feasible sequence. In this paper, the best sequence contains the least number of flips and rotations and the shortest distance.

IV. The Generation of the Bending Sequence

Most potential sequences are either feasible or unfeasible. In the event of a collision, the sequence is not viable. When no collisions are observed, the sequence is considered viable. As seen in Figure 7, the primary goal of this bending sequence, in contrast to previous ones, was to shorten the time required for bending by minimizing the number of rotations, flips, total tool distance travelled, and tools used. In most research, the number of flips and rotations is not included in the bending sequence. In Table 2 the set of rules were set.

Table 2: The Set Rules for the Bending Sequence

	Rules	Weight
R1 R2 R3 R4	If the bend angle of bi in the sequence and bi+1 are identical (minimise bend tools), The bend direction of bi and bi+1 is identical (minimise flipping). bi is parallel to bi+1, (minimise rotation) The sequences distance The total distance in a specific sequence between two succeeding bends	If true +10 +30 +20

To obtain the optimum or near-optimum bending sequence the following design features were considered the bend direction R1, bend orientation R2, toolset R3 and sequence distance R4. The toolset shows the number of tools displayed in an optimum sequence. Bend orientation is defined as a bend's parallelism or perpendicular to the reigning bend in the sequence. An ideal bending sequence has no collisions, uses the fewest number of tools, travels a short distance between bends, and has fewer flips and rotations overall.

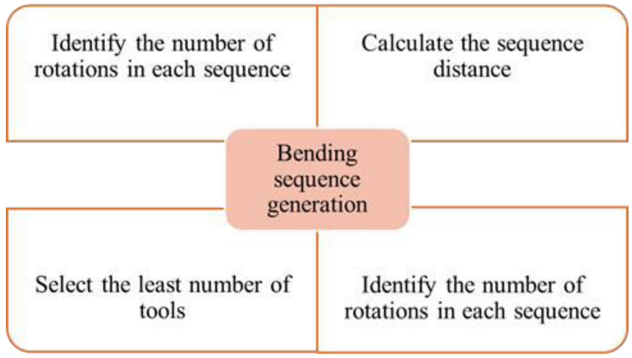


Figure 7: Bending Sequence Generation

V. The Genetic Algorithm

The genetic algorithm (GA) is an optimization and searching strategy that is based on natural selection and genetics concepts. With the use of a genetic algorithm (GA), a population composed of several individuals can develop under predetermined decision rules to a condition that increases "fitness" (i.e., reduces the cost function).

$$f(S_k) = \sum_{j=1}^{n} \frac{w_{ij} \times x_{ij} \times y_{ij}}{D_{sk} \times f_p \times r_{ij}} \quad [1]$$

Where

j = the bend identifier in Si

***w is** the bend weights assigned upon fulfilment of a rule R1*

***x is** the bend weight assigned upon fulfilment of a rule R2*

***y** is the bend weight assigned upon fulfilment of a rule R#*

$\boldsymbol{fp}$ = *number of flips in a particular sequence*

r = number of rotations in a particular sequence.

Dsk = The overall sequence distance for Sk in R4

The extracted bend features are transferred to the bending sequence subsystem, and to generate the ideal sequence. In contrast to previous bending sequence-generating research, the tool's overall travel distance as well as the number of flips and rotations were taken into account for full optimisation. It was determined that the sequence comprising just a few flips and rotations was the most optimal hence it shortens the time needed to produce each part. To ensure that the ideal sequence includes a few tool steps or die, and punch changes another rule was developed. This rule aims toward ensuring that, before a tool changes, bends with the same angle are processed sequentially. The bending sequence subsystem in Figure 8 makes use of the fitness function and genetic algorithm covered in this section.

VI. The Bending Sequence Subsystem Implementation

A huge population of bends (equivalent to n! (n factorial), where n is the number of bends) were processed separately from one another during the production of a bending sequence. The genetic algorithm has concurrent computation capabilities and can handle both discontinuous and perpetual functions. The system proved its independence in executing the process plan with the least amount of human intervention.

The uniqueness of this system is that it can perform the bending sequence without the need for any CAD software. It performs the bending sequence operations independently without the need for the use of inputting any data. Due to the computational complexity the maximum number of bends the bending sequence system can process is eight.

The system generates a population of N! randomly generated bend sequences, creates a mating pool, and assesses fitness. It selects two high-fitness parents and combines them to form a child. The system uses a cross-over approach, mutating the offspring according to a specified rate.

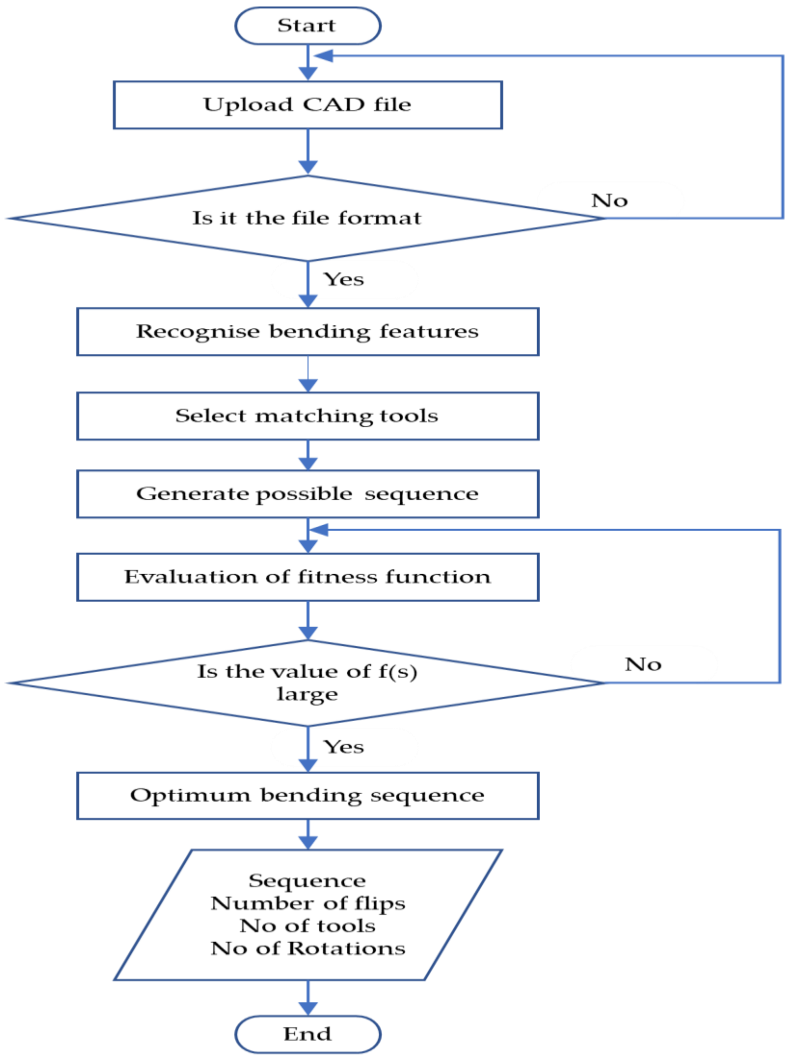


Figure 8: The Bending Sequence Subsystem

DISCUSSION AND THE RESULTS

To test the functionality of the developed bending sequence system, a typical component shown in Figure 8 was been uploaded to the system. The system was running on a Intel Core i5 laptop with 8 GB RAM and each core had a clock speed of 2.60GHz. Due to the computational complexity, the system could only generate sequences with not more than six bends.

A sheet metal rail component displayed in Figure 9 has four bends labelled as b1, b2 b3 and b4. The bend angle for b1 is 150 degrees, b2 is 45 degrees, b3 is 90 degrees b4 and is 90 degrees. Using the bending classifications mentioned in Section 2 the sheet metal part falls under the I type families. All bends are parallel to each other.

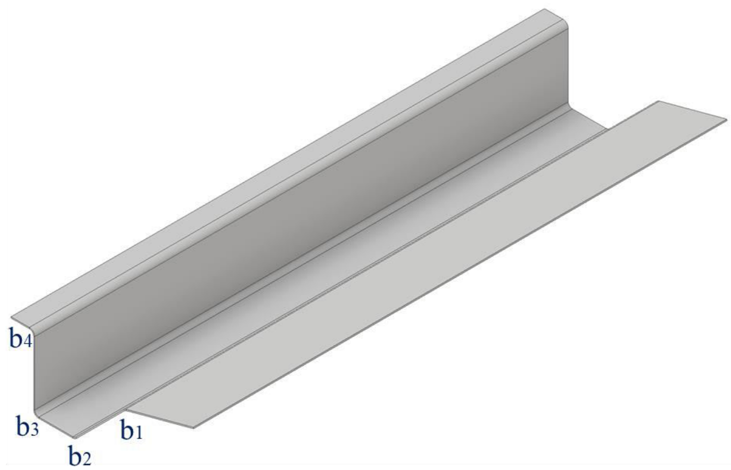


Figure 9: Sheet Metal part

The component has two bends in the same direction and the other two bends in a different direction. Figure 10 shows the bend direction thus the inside and outside bends. It is determined that the positive sign represents the outside bends whilst the negative sign represents the inside bends.

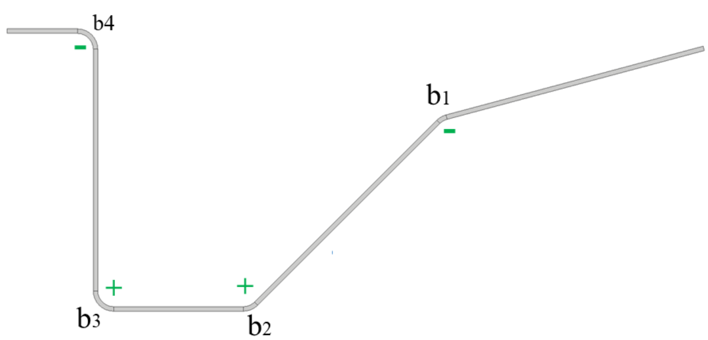


Figure 10: The bend direction

Using the face relationship model developed in [21]. A flat pattern or unfolded part has been developed for the component in Figure 9. The unfolded part in Figure 11 shows the relationship between bends and faces where F1 and F2 form b1, b2 is formed by F1 and F3, b3 links F3 and F$ and b4 links F4 and F5.

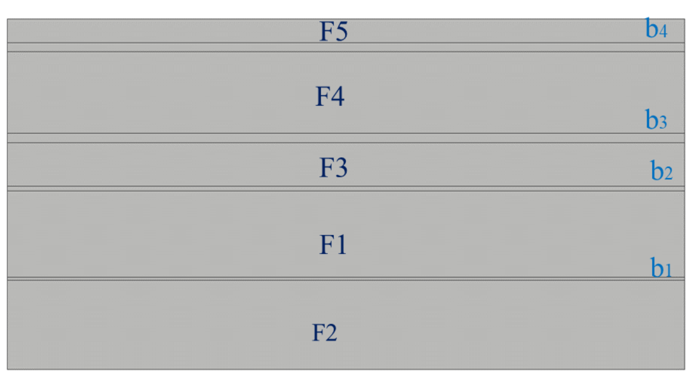


Figure 10: The Bend Direction

The results of the feature recognition show the ID of bends the face relationship and the bend direction In Table 3 the bends, the direction and the symbol represent the direction as shown. It has been noted that bends b1 and b4 have the same direction and, b1 and b4 have the same direction.

Table 3: The bend ID and direction

Bend ID	Face ID	Face ID	Direction	Symbol
b1	1	2	OUTSIDE	+
b2	1	3	INSIDE	-
b3	3	4	INSIDE	-
b4	4	5	OUTSIDE	+

Considering the bends, the number of bends shown requires different tools which are 45 degrees, 90 degrees and 60 degrees. The system was able to detect that the bends have different bend angles. Table 4 shows the feasible sequence obtained from the generation.

Table 4: The Bending Sequence Generation back-end console log

Best Sequence:	1 4 3 2					
No of tools:	3					
No of rotations:	0					
No of flips:	1					
Generations	**String**	**Fitness**	**Flip**	**Tools**	**Rotation**	**Distance**
0	1432	1401	1	3	3	342,499
1	2341	1401	1	3	3	342,499
2	4123	1221	1	4	4	345,961
3	3241	1221	1	4	4	366.046
4	3214	1221	1	4	4	345,961
5	4132	1221	1	4	4	397,135
6	2314	1221	1	4	4	397,135
7	1423	1221	1	4	4	366,043
8	2143	821	2	4	4	396,211
9	4321	821	2	3	3	299,106
10	1234	821	2	3	3	299,106
11	3412	821	2	3	3	396,043
12	2413	641	2	3	3	470,989
13	4231	641	2	4	4	373,884
14	3142	641	2	4	4	404,053
15	1324	641	2	4	4	470,989
16	4312	241	3	3	3	373,884
17	1243	241	3	3	3	404,053
18	3421	241	3	3	3	372,96
19	2431	241	3	3	3	372,96
20	2134	241	3	3	3	424,134
21	1342	241	3	3	3	404,053
22	3124	61	3	4	4	427,657
23	4213	61	3	4	4	427,657

Table 3 shows the console log of the feasible sequences obtained from the 24 generations. The console log will be displayed for the part in Figure 5. The results for the next parts will only display the number of tools, the flips, the rotation and the sequence. Table 3 has been displayed to show how the system calculates the fitness function and selects the best bending sequence.

It can be seen in Table 4 that the system was able to generate feasible sequences. For each sequence, the system was able to calculate the total distance, generate the number of flips and rotations and also pick possible sequences

Table 5: The Feasible Sequence

No of tools		3
No of flips		0
No of rotations		0
Bend ID	Bend Angle	Direction
b1	45°	Inside
b4	90°	Inside
b3	90°	Outside
b2	150°	Outside

It can be seen in Table 4 that the system was able to generate feasible sequences. For each sequence, the system was able to calculate the total distance, generate the number of flips and rotations and also pick possible sequences.

The bending sequence generator uses the fitness functions of each bending sequence that the genetic algorithm generates to determine which sequence is the best. 24 possible sequences were generated and the one with the highest fitness function was the one selected as the best feasible sequence. Two sequences have the same fitness, number of tools, flips, rotations and distance. The best sequence is the one that follows the collision sequence rules set.

Sequence 2341 is not feasible; it starts with outside bends instead of the inside bends. The sequence did not follow the collision detection rule set. Generation 0 with sequence 1432 is the best sequence hence it contains the least number of tools, flips and rotations as well as the shortest possible sequence distance. The same sequence follows the collision detection rules. For example, b1 has a small angle and is an inside bend and also b4 is an inside bend. To avoid tool change and to reduce the distance travelled by the tool and the time taken for tool change b3 was the next in the sequence. Since b4 and b3 have the same bend angle the same tool used to bend b4 will be used to bend b3. The last bend in the sequence was b2 which has a large angle.

From this, it can be noted after a CAD file was uploaded to the bending subsystem the system managed to automatically generate the possible sequences and then select feasible the bending sequence. Figure 12 represents a part with 6 bends.

From the part families, the part falls under the STAR type.

The unfolded part is displayed in Figure 13. The results for the feature recognition in Table 6 show the bend ID the face relationship and the bend direction.

As shown in Table 3, the system relies on the sequence with highest fitness, shortest distance, few numbers of tools, rotations and flips. In this case, for the part shown in Figure 8 only shows the results selected by the system the console results will not be shown. The results from the system are shown in Table 7.

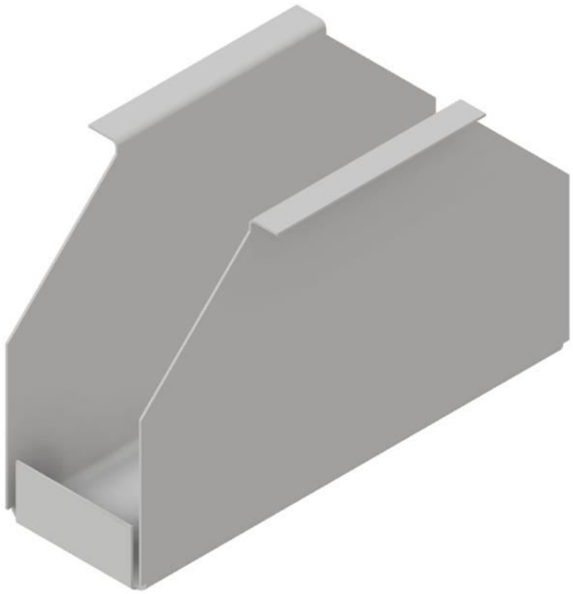


Figure 12: Sheet Metal Part 2

From the part families, the part falls under the STAR type

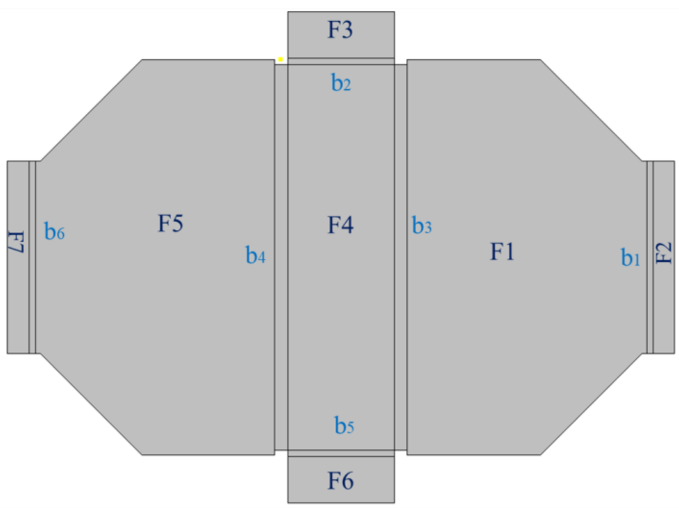


Figure 13: Sheet The unfolded part for Sheet Metal Part 2

Table 6: The bend ID and direction (Figure 11)

Bend ID	Face ID	Face ID	Direction	Symbol
b1	1	2	INSIDE	-
b2	3	4	OUTSIDE	+
b3	4	1	OUTSIDE	+
b4	5	4	OUTSIDE	+
b5	6	4	OUTSIDE	+
b6	5	7	INSIDE	-

For this part sheet metal part, the results are shown in Table 7. From Table 7, it can be seen that the system managed to pick the sequence with the least number of rotations, flips tools and the short. Referring to Table 3 the same sequence also has the shortest distance.

Table 5: The feasible sequence

No of tools		3
No of flips		0
No of rotations		0
Bend ID	Bend Angle	Direction
b6	90°	Inside
b1	90°	Inside
b4	90°	Outside
b3	90°	Outside
b2	90°	Outside
b5	90°	Outside

Only 1 tool is required since all the bends have the same bend angle. The best sequence only requires one flip thus the inside bends will be bent first then later the later. About rotation, from the sequence shown in Table 7, to reduce the number of rotations the system managed to pick the parallel bends first and then the perpendicular bends were the last in the sequence. Only 1 rotation is required.

CONCLUSIONS

Over the last decade, there has been a spike in demand for sheet metal parts. The need for personalized, high-quality products has resulted in fierce global rivalry. In this study, the following research contributions were made: This article presented a novel feature-based bending sequence approach for sheet metal bend processes on a bending press machine. In contrast to prior studies on sheet metal bending sequences reducing the number of tools, the number of flips and rotations and the sequence were taken into account. In this present study the following research contributions were made:

- The sheet metal parts were grouped according to bend shape orientation thus the L type, I type, H type, Star type and the T type. This was used to identify whether bends are parallel or perpendicular to each other.
- The layout of the bending sequence subsystem was shown and it consists of a system that recognises the bend feature and then selects the available tools that match the bending features. With the combination of feature recognition and tool selection, the system generates the best sequence.
- Four rules were formulated and three rules were assigned weights. The first rule aims at reducing the number of tools whilst the second rule aims at minimising the number of flips in case of bends in different directions. The third rules reduce the number of rotations in case of perpendicular bends. The fourth rules calculate the total distance in a sequence.
- The genetic algorithm was used to formulate the fitness function. Using the rules given the system can calculate the fitness function and the total distance for each bend. The sequence with the highest fitness was found to be the minimum number of flips and rotations, fewer tools, and the shortest distance.
- The console has been displayed to show the results from the fitness function.
- A bending sequence subsystem that can automatically generate a feasible sequence with a smaller number of flips and rotations, and the shortest distance to increase efficiency and reduce cost was developed.
- The system can detect different bend angles in a component and pick the number of tools that are required to bend each part.
- The collision detection rules were also incorporated in the system and the system generates the best sequence with no possible collision. The system managed to start with outside bends and then the inside bends later.
- The developed sheet metal bending sequence system is a stand-alone system the bending sequence is performed without the need for integrating other CAD software and systems.

- Upon uploading the STEP file, the system generates the sequence without the need for user input.

As mentioned in the article the system was developed on a laptop with on an Intel Core i5 laptop with 8 GB RAM. From the previous work done by the researcher, the same system can automatically extract and recognize features with more than 20 bends. As for the bending sequence, due to the higher computational complexity of the bending sequence generator, the system can only generate bending sequences for parts with not more than 6 bends. The number of people using the Internet is increasing significantly these days due to the rapid advancements in information science and technology, and the era of enormous data is silently emerging [22]. There is a need to host the system on the cloud to cater for the memory and computation challenges. As for further work, a bending sequence cloud-based subsystem will be developed to solve the higher computational issues. the formulation of the collision detection will be included in the system such that the system can simulate each possible sequence to check for collision. The bending tool selection also needs to automatically detect the radius of the tool that matches each bend in case the component has a different radius for each bend.

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DECLARATION
The authors declare that all works are original and this manuscript has not been published in any other journal.

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