Acta logistica - International Scientific Journal about Logistics
Volume: 9 2022 Issue: 4 Pages: 361-368 ISSN 1339-5629

doi:10.22306/al.v9i4.326 *Received: 12 July 2022; Revised: 12 Sep. 2022; Accepted: 07 Dec. 2022*

METHODOLOGY FOR CALCULATING THE COST PRICE OF THE BENDING PROCESS FOR THE NEEDS OF MANUFACTURING LOGISTICS

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Keywords: press brake, logistic process, bending, bid calculation, cost price.
Abstract: The research of this paper aims to characterize and describe the methodological sequence of operations necessary for the correct calculation of the cost price when performing a bid calculation in the bending process step on a bending machine. The research focuses on determining the methodology and its application exclusively to sheet metal parts in the engineering industry in the processing of steel and stainless-steel sheets. To research this issue, we used empirical and quantitative research in a real work environment. The methodology for calculating the cost price of bending sheet metal parts yields the relationships between component inputs, the result of which is a time parameter that is expressed by the actual production costs. The results can be used in the real working environment of manufacturing companies for comparison with already established practices and a verification of their outputs. At the same time, it is possible to use the determined methodological procedure as a basis for implementation in the Aurendi web application.

1 Introduction

Market trends are leading to the digitization, the use of technology and the transformation of businesses in the era called Industry 4.0. The most important aspect of any company's success is a satisfied customer. The business environment is changing year by year and marketing and business practices are witnessing an ever-increasing tendency to focus on the customer and their needs [1,2]. Global competition makes it necessary for industrial companies to accurately monitor production costs throughout the design process. However, it is difficult for a company to determine the best technology to ensure its profitability [3,4].

Cost management is a major section of business management in the manufacturing industry. The level of implementation of the cost management is a comprehensive index for measuring the level of enterprise management [5]. The ability to predict the cost of manufacturing parts is therefore considered a key factor for the commercial success of products [6]. Since tenders for inquiries usually take place with very limited availability of information and within short time frames, estimates of the costs on which these tenders are based are highly inaccurate and pose a significant risk to suppliers. In particular, the actual consumption of production capacity cannot be predicted with sufficient accuracy [7]. For a product to succeed in the manufacturer's competitive business, there should be an accurate estimate of its design, development, and manufacturing costs [8]. In this respect, calculations of the production costs of finished products need to be made quickly and reliably [9]. There are two concepts for calculating the price of a product, namely absorption calculations and direct calculations [10]. Absorption calculations are also called full calculations, meaning a calculation concept in which all production costs are absorbed into a product. Direct calculations, meanwhile, are commonly known as marginal calculations or variable calculations, and involve only assigning variable production costs to products [11]. The paper uses the full calculation methodology.

The methodology described herein for a specific bending process step is one of many inputs on a comprehensive scale to determine the target price. We understand the target price here as the cost of the product without compromising its quality [12].

The bending process is herein defined for the processing and production of sheet metal parts in the engineering industry, whereas individual processors must map their own given industry in detail, as they would any other industry. Manufacturers of sheet metal parts must take different measures to compete on the market to differentiate themselves from their competitors. Offering customized products of the highest quality at the lowest possible price is the ultimate goal for the long-term operation of any company. For the price to be as competitive as possible, the costs must be known. Once the product manufacturing process is complete, detailed information can be collected and used to determine the cost of the final product using additional costing. Regardless, an estimate of production costs is often required before the actual production of a given part. Therefore, the costs must be estimated within the specified accuracy range, even if not all the necessary details are known yet. To overcome these missing technical details, cost estimation techniques are used to approximate costs within a certain range of accuracy [13,14]. However, the basis of the calculation is the automation of the calculation based on structural and technological parameterization. This enables automatic transfer of initial design and technology data to the costing module [15].

The paper's research is based on the need to specify the individual process steps within the methodology of the Aurendi online web application. In this specific case, it is the issue of bending. The Aurendi web application is a calculation tool for the automated calculation of the offer price of sheet metal parts and welded structures in the engineering industry. The application mainly focuses on performing bid calculations by the calculation of cost prices and sales margin. The primary function of this tool is to achieve an accurate calculation of the bid price while increasing the efficiency of the bid creation process. At the same time, the application simplifies the manufacturing companies' contact with suppliers in the engineering industry through a regularly updated database system. The principle on which the system functions is its ability to extract data from the input production documentation in .dxf and .step file formats. Files in the aforementioned formats can be opened in the application environment and the system automatically loads all the key information for the calculation. By combining the ability to obtain the required data from the tender documentation, a unique methodological approach to the calculation of tender bids and a database system, the calculation of tender bids can be performed in a fraction of the time compared to the conventional method of calculation. The accuracy of the calculation of bid prices is also significantly better. The application is built on a cloud solution and can be used from anywhere, requiring only an Internet connection.

The paper describes a methodical approach to cost price calculations of a specific technical issue, focusing on the technology of bending sheet metal parts on press brakes. This is a key step in bid calculations, which has a significant share in the final price of the product and is also complicated for a qualified estimate. The paper's results can be used as a basis for the implementation of this methodology in the Aurendi web application. This implementation makes it possible to monitor the process and evaluate the outputs of individual calculations, and retrospectively verify the correctness of the determined methodology.

2 Methodology

The methodology is divided into three main branches that must be projected – preparation time, bending time and the resulting conversion to the price for the preceding sections. In the case of time per bend, it is necessary to state the time calculation for the setting of one bend, while the resulting time will be this calculation multiplied by the number of bends on a specific job. In the price calculations, it will then be necessary to take into account the possible need for the participation of auxiliary workers, whose time must be taken into account in the cost price.

The methodology is limited to the use of press brakes up to a maximum bend length of 5 meters. These relationships can also be used in setting up the methodology for larger press brakes, however, it would be necessary to make your own plans and adjust the relationships for the given machinery. Therefore, the following descriptions will only use a maximum bend length in the range of 5 meters. Longer bends are relatively more demanding in terms of the expected higher weight of the parts, in which it is necessary to take into account the additional costs associated with the use of transport equipment.

The method of statement of monitored outputs is described in two ways:

- General values,
- Precise values.

General values are stated in the research wherever a given value is subject to individual setting by each manufacturing company depending on the company's internal settings and pricing policy. Tables containing exact values are created using in-process surveys and are recommended for use in your own calculations.

2.1 Procedure for determining preparation time

Determining the amount of preparation time is generally considered to be the most important and at the same time the most complex quantity in the calculation of time parameters within the calculation of cost prices for bid calculations. This parameter is the most important mainly due to the very high costs associated with the operation of the machinery, whose acquisition value is on the order of millions of crowns. It is the most complicated due to the need to estimate when using the conventional method of calculation, and where the responsibility lies with the budgeter, who must be familiar with the production process. The hourly rate is calculated from the acquisition cost of the machine and the overhead costs associated with the operation of the machine, which must be reflected in the machine preparation time. Preparation time is understood here as a non-production cost of the machine, when certain operations must be performed within the machine settings and preparation of the machine workplace. This is unproductive time, but it must be taken into account in the calculation of the cost price of the product. It can therefore be stated that costs are already incurred in the pre-production phase of the processing process. The stated costs are calculated in the bid calculation and distributed proportionally to the quantities of the required parts. Here, a quantity discount based not on the business strategy but on the pre-production phase of the production cycle is evident. In the case of high series production on the order of hundreds of pieces, the preparation time is practically negligible, however, when dealing with small series production, this parameter is key and significantly affects the cost price.

As part of the calculation, all parameters must be considered and defined. The definition of input parameters is shown in Table 1. Also included is the information regarding selected inputs, especially information about the nature of the value, its source and the possibility of a user setting of the quantity. The latter information is required for Aurendi users. The value of the quantities is left in the general form.

Table 1 Chart of input parameters in the preparation process

Composition of overall preparation time	**Nature of value**	**Source of value**	**User setting of quantity**	**Quantity value**	**Unit**
Bend programming	Constant	Database	YES	a	minutes / bend
Number of bends	Variable	STEP	NO	b	pieces
Workplace preparation	Constant	Database	YES	c	minutes
Adjusting the press brake bars	Variable	Database	YES	d	minutes

2.1.1 Bend programming

This is a fundamental parameter for working on a press brake. The parameter has the nature of a constant, which we understand will be set only once within the work with respect to the measurements in the work process. The first value of the parameter describes the time required for programming individual bends on the machine.

2.1.2 Number of bends

This parameter must be read from the drawing documentation. When using the Aurendi application, this parameter is automatically loaded by the application from the input documentation in the .STEP file format. This is a variable depending on the specific production assignment.

2.1.3 Preparation of workplace

A constant whose value is adjustable by each manufacturing company depending on its own determinations and the layout of the working environment of the press brake. For the purposes of presenting the article, the plans were made in a specific manufacturing company. When using the Aurendi application, this parameter can be set by the user.

2.1.4 Setting up the press brake dies

This parameter is characterized by the relationship between the time requirements for the installation of dies in the machine when processing different lengths of bends. This is a variable depending on the input documentation. The specified relationship corresponds to the time it takes for the production worker to install the dies on the press brake. The specific type of die is selected based on the strength of the sheet, which is given by the input documentation. However, the sheet metal force parameter is irrelevant for this calculation. The production worker chooses the appropriate set of bending dies according to the individual properties of the machine. Since it is very probable that the bends will be of different lengths on different parts depending on their dimensions, to set the preparation time correctly it is necessary to work only with the longest detected bend on the part. The reason is the manual laborious installation of the dies in the press brake, and if we take into account the longest bend, there will be no risk of additional installation of dies being necessary, because there will no longer be a need to increase the length. In the case of choosing one of the shorter bends, or the shortest, there would be additional costs associated with the additional installation of dies in the machine. The given relationship is shown in table no. 2.

Table 2 Dependence of the length of bends on the time of setting the dies

	Minimum length of bend [mm]	**Maximum length of bend [mm]**	**Time required for die setting (d) [min]**
Span of bend lengths	1	1000	2
	1001	2000	4
	2001	3000	6
	3001	4000	8
	4001	5000	10
	5001	6000	20
	6001	7000	30
	7001	8000	40

Acta logistica - International Scientific Journal about Logistics
Volume: 9 2022 Issue: 4 Pages: 361-368 ISSN 1339-5629

2.1.5 Defining relationships of inputs to the preparation process

The actual calculation of the preparation time t_p is a simple task when we know all the input parameters and their values (1). The parameters correspond to the description in table no.1. The units of preparation time t_p are expressed as minutes [min].

$$t_p = \{(a * b) + c + d\} \quad (1)$$

2.2 Procedure for setting the bend time

To determine the time required in what is already the production phase of bending, the time for one bend was taken and subsequently multiplied by the number of bends detected on the part. This process step can be determined in this way, because the decisive parameter that could cause differences between bending times of different lengths is the thickness of the sheet, which, however, is constant with respect to the input of one part. Therefore, we always work with the part that is being bent and which is separated from a single sheet of metal of the same thickness in the previous step. 2 To solve the time per bend, we must proceed analogous to the determination of the preparation time. When using the Aurendi calculation application, setting the time for bending must be approached in such a way that the calculation methodology will be applied to each detected bend separately and then the bending times will be summed depending on the detected bends. If the conventional method of calculation is used, the process will be the same, with the difference that the detection of bends is up to the budgeter.

The approach of calculating the time for each bend has, compared to the preparation time, a certain specificity associated with the checking of the machine settings, which must be taken into account in the calculation. By checking, we mean by measuring every first different bend performed on the machine. 3 This is an inspection of the first piece, where we consider the constant time determined for inspection measurements of each bend during the initial setup of the machine.

An important criterion for calculating the bending time is understanding the bending process on the press brake. For a correct calculation, it is necessary to detect all the bends on the specified part. However, it is also necessary to consider the fact that if several bends are detected on a part that are in the same axis, they are considered to be a single bend. The reason is to adjust the press brake so that both bends are bent at the same time. With this type of bending, it is possible to prepare bending on the machine at what are called multiple workstations within the working space of the machine. At a given machine setting, bends are performed simultaneously. Figure 1 shows a typical example of several such bends (marked in green) on a part shown spread out, which are on a single axis.

All parameters required for the calculation of the bending time are shown in Table 3. This table provides information on all necessary inputs for the calculation. As in the previous table, it describes the nature of the value, its source and information on user settings with respect to functionality within the application. The values are again left on a general level.

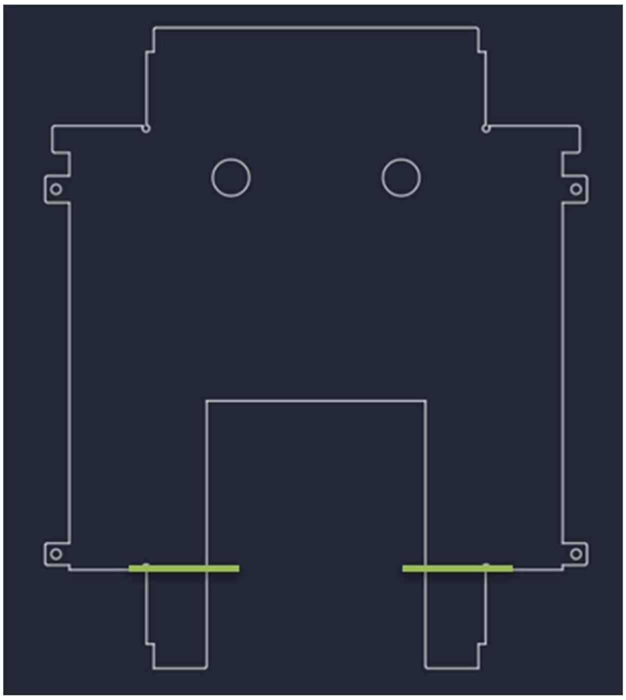

Figure 1 Expanded shape of the bent part, own drawing

Table 3 List of input parameters for the bend time calculation

Composition of total rate per bend	Nature of value	Source of value	User setting of quantity	Quantity value	Unit
Number of bends	Variable	STEP	NO	e	Pieces
Thickness of sheet metal	Variable	STEP	NO	f	mm
Insertion of part in press brake	Constant	Database	YES	g	Seconds
Unloading of part from press brake	Constant	Database	YES	h	Seconds
Net time for one bend on press brake	Variable	Database	YES	i	Seconds
Checking of executed bend	Variable	Database	YES	j	Seconds

2.2.1 Number of bends

The given parameter is a variable, which is the basic input of the tender documentation. In the conventional methodology of determining the cost price, this parameter is read by the budgeter directly from the tender drawing documentation. In the event of the use of an automated calculation process via the Aurendi web application, the parameter is loaded automatically.

2.2.2 Sheet metal thickness

As with the previous parameter, the sheet metal thickness is a parameter derived from the production documentation. When using the Aurendi application, this parameter is loaded automatically; in the case of a non-automated method, it must be read from the production documentation. The parameter enters the process in relation to the time required for bending on the press brake. Table 4 illustrates this dependence, but it should be noted that the dependence varies with the specific type of machinery. The limitation of this table is the technical assumptions of the press brake, which can handle bends up to a maximum sheet thickness of 6 mm.

Table 4 Sheet metal thickness dependency on bend time

Net time for 1 bend on press			
Sheet metal thickness [mm]	Bending time [s]	Sheet metal thickness [mm]	Bending time [s]
0.5	2	2.5	6
1	2	3	7
1.3	3	4	9
1.5	3.5	5	11
2	5	6	15

2.2.3 Insertion of part into press brake

This parameter is based on component surveys that should be performed by each company in order to specify the output cost price. This is the exclusive part of the process, which maps only the time needed for the operator to lift the part from position A, which is reserved for the part entering this process step and its insertion into the press brake. The process step ends by precisely placing the part on the preset stops of the machine.

2.2.4 Unloading of part from the press brake

The parameter for unloading a part from the machine is defined similarly to the previous, insertion, parameter. Here, part of the process maps the time required to unload the already finished part to location B, which is reserved for the already finished parts, and thus is based on the bending step in the process. The beginning of the step is the release of the press brake and shifting of the part by the operator to a predetermined place.

2.2.5 Net time for 1 bend on the press

This is based on the relationship given in Table 4. Based on the detected sheet metal thickness, an appropriate time parameter is assigned, the value of which corresponds to the technical parameters of the press brake. This is a process step that begins with the insertion of the part into the working space of the press brake. Immediately afterwards, the bending process itself takes place at the operator's signal. The signal is made by depressing the foot pedal. This step ends when the bend has been performed and the jaws are returned to the initial position.

2.2.6 Checking of the bend

This involves checking every first different bend that has been performed on a given part. The step maps the time required to check all bends. The inspection is usually performed with a protractor and a measure, or with a caliper – all measuring implements should be calibrated and certified. The result of the performed measurement is a possible correction on the machine, if required by the measurement result. The value itself is also the subject of a decision by the quality control department in each company. This value was left as general in the methodology.

2.2.7 Definition of relationships of inputs to the bending process

The calculation is performed including the parameter for checking the performed bending. First, the calculation for one bend (2) is determined, and then the calculation for all bends on the part (3). We check the performed bend j only for each different first bend. For a calculation in a series, this parameter is taken into account only for the first piece. Units of both equations are expressed as a seconds [s].

$$y = g + h + i + j \quad (2)$$

$$z = (g + h + i + j) * e \quad (3)$$

2.3 Determination of the cost per task depending on the preparation time and time per bend

The preceding sections map the process steps to ensure the time needed to fulfill them. In this section, all these times will need to be evaluated in terms of setting the cost prices for these procedural steps. To reliably meet this goal, it is necessary to define additional input parameters that are part of the given calculation. This mainly concerns company rates – specifically the hourly rate of the press brake and the hourly rate of the auxiliary worker.

Table 5 shows the inputs for calculating the cost price. It is not necessary to set specific values of rates within the methodology; general values will be used for the correctness of the calculation procedure.

Table 5 Hourly rates

Description of input	**Nature of value**	**Source of value**	**User setting of quantity**	**Quantity value**	**Unit**
Hourly machine rate	Constant	Database	NO	k	EUR / hour
Hourly rate for auxiliary worker	Constant	Database	NO	l	EUR / hour
Number of auxiliary workers	Variable	Database	NO	m	worker

2.3.1 Hourly machine rate

This varies depending on the purchase price of the machine and operating costs. The hourly rate must be set by the company so that it is competitive on the market with respect to the required profitability of the machine.

2.3.2 Hourly rate for auxiliary worker

The setting of the hourly rate of the auxiliary worker is fully under the control of each manufacturing company, again with regard to competitiveness.

2.3.3 Number of auxiliary workers

In calculating the cost price, the determination of the number of auxiliary workers with respect to the assignment must also be taken into account. Tables 6 and 7 show the criteria for determining the number of auxiliary workers. The priority criterion is the evaluation in Table No. 6, when it is necessary to first assess the part by weight. The secondary criterion is the distinction according to the dimensions of the part.

Table 6 Dependence of number of auxiliary workers on part weight

Number of auxiliary workers depending on the weight of the part		
Minimum weight [kg]	Maximum weight [kg]	Number of workers
0	20	1
21	40	2
41	60	3

Table 7 Dependence of number of auxiliary workers on part dimensions

Number of auxiliary workers depending on part dimensions				
Minimum length of side A [mm]	Maximum length of side A [mm]	Minimum width of side B [mm]	Maximum width of side B [mm]	Number of workers
0	1500	0	1500	1
1501	2500	1501	2500	2
2501	5000	2501	5000	3

2.3.4 Calculation of price for preparation time

The following calculation consists of two parameters – the net time spent preparing the machine and the working environment (4) and the proportional calculation of the price for the auxiliary worker (5), which is based on the specified preparation time. The relationship is defined between the preparation time t_p and the hourly rate of the machine k. Units of the equations (4), (5) and (6) are expressed in actual cost [EUR].

$$X_1 = \left(\frac{t_p}{60}\right) * k \tag{4}$$

When working on different parts, an auxiliary worker will not always be needed, but it is crucial to state the calculation, including the element of additional labor, and if no auxiliary worker is needed for the component assignment, the parameter m will be zero. The definition of the calculation of the price per auxiliary worker is defined by the relationship between the preparation time t_p, the hourly rate of the auxiliary worker l and the number of auxiliary workers m.

$$X_2 = \left\{\left(\frac{l}{60}\right) * t_p\right\} * m \tag{5}$$

The calculation of the complete price for the preparation time is expressed by the sum of the calculations of the price for the preparation time X_1 and the relative rate for the auxiliary worker X_2.

$$X = X_1 + X_2 \tag{6}$$

2.3.5 Calculation of price for bending

The calculation is performed first by determining the price for one bend (7) and then the calculation for all bends on the part (8). Both calculations are shown including the incorporation of the auxiliary worker parameter. Units of both equations are expressed in cost [EUR].

$$Y = \left(\frac{k}{360}\right) * y + \left\{\left(\frac{l}{360}\right) * m\right\} * y \tag{7}$$

$$Z = \left(\frac{k}{360}\right) * z + \left\{\left(\frac{l}{360}\right) * m\right\} * z \tag{8}$$

With the final sum of partial outputs when calculating the prices for the final preparation time X and calculating the price for all detected bends on the part Z, we achieve the determination of the price for the whole workshop bending operation on the press brake.

3 Result and discussion

The paper provides a definition of all component parts of the production process of bending sheet metal parts in the engineering industry on bending machines. The developed methodology describes the complete logistical sequence of all tasks within this operation to determine the time intensity of the process. Time data that can be effectively calculated through formulas and the connections of individual inputs are key elements in calculating the cost price for this technological operation.

The three main branches that make up the methodology describe the relationships between the individual inputs. When calculating the time required for bending, the factors of technical complexity when performing the bending operation were taken into account. The key parameter here is to define the relationship between the sheet metal thickness and the time required for the bending itself. This relationship was determined by measurements made directly in the work process. It should be noted that this relationship, although properly measured, can vary depending on the machine and the manufacturer. At the same time, it can be argued that the dependency will need to be updated over time due to the development of increasingly powerful machines. However, dependency is a legitimate and solid part of the methodology.

A similar result can be stated even when determining the preparation time for programming the bending parameters. Here, it can also be stated that the given time will depend on each machine and will need to be monitored and updated, depending on the development of the given technology on the market.

The final part of the methodological procedure then only determines the relationship between individual time determinations and the hourly rates of machines and the manufacturing companies themselves. Here, it is appropriate to conduct further research focused on this issue and to subject the input parameters under consideration to a more comprehensive analysis.

4 Conclusions

The presented methodology has two levels of practical use. The first is the application to a functional work process to accurately calculate rates in a specific area by each manufacturing company individually. In this phase, the methodology is fully usable without the necessary prerequisites in terms of system equipment of companies. If it is necessary to streamline the actual process of calculating bids at the same time as calculating cost prices, it is appropriate to use the given procedure. Though component values of individual inputs may differ, this fact does not have a negative impact on the specified process.

The methodology has a major impact when implemented in the already functional model of the Aurendi web application. Implementation of the process into the application results in a fully automated model for calculating the bending step in the process of calculating cost prices for sheet metal parts and welded structures. By using the model in the application, a further increase in the efficiency and accuracy of automated calculations will be achieved. Here, too, however, further research is recommended, which will monitor the corrective setting of all technical and economic inputs in the process of calculating the time and price. As part of more comprehensive research, with the participation of various engineering companies, it is recommended to regularly collect and evaluate feedback from already specific bid calculations and to compare the results with real production time. The methodological procedure research performed can serve as a basis for further research focused on the calculation of the deviation between the predicted calculation and the actual costs of production of sheet metal parts and welded structures.

Acknowledgement

The work was supported by the specific university research of Ministry of Education, Youth and Sports of the Czech Republic at VSB - Technical University of Ostrava, projects no. SP2021/43 and no. SP2022/78.

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Review process

Single-blind peer review process.