FINAL PROJECT REPORT

DEVELOPMENT OF FRAMEWORK USING GROUP TECHNOLOGY APPROACH IN ESTIMATING FABRICATION TIME OF SUBSEA MANIFOLD

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Development of Framework

Using Group Technology Approach

for Estimating Fabrication Time

of Subsea Manifold

BY

Naqib Hakim Bin Kamarudin

FINAL PROJECT REPORT

Submitted to Department of Mechanical Engineering Department in Partial Fulfilment of the Requirements for the Degree Bachelor of Engineering (Hons) (Mechanical Engineering)

Universiti Teknologi Petronas

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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Approved:

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(IR. DR. MOHD. AMIN BIN ABDUL MAJID)

Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2013

CERTIFICATION OF ORGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Naqib Hakim Bin Kamarudin

ABSTRACT

The purpose of this study is to adopt Group Technology approach to establish a framework for estimating fabrication time of Subsea Manifold. The framework was developed using EXCEL spreadsheet consisting of two main components which were database and fabrication estimation model. The development of the database applied Group Technology principles which were to classify parts and components in the fabrication process of similar attributes. Apart from that, the calculation was also added into the template for production time estimation applications. The project is related to Greater Western Flank (GWF) project which is one of subsea development project by Woodside Petroleum Company. In this project, Sapura Kencana is one of the sub-contractors tasked for manufacturing the structure of the Subsea Manifolds. The GWF project was used as benchmark to test the model framework. The database contains 189 parts that have been classified. The assessment method was done by comparing the estimated time generated by the theoretical mathematical framework with actual manufacturing time. Fabrication process that depends largely in manual skills gave larger percentage differences in fabrication time as compared to mechanized or CNC machining fabrication process. The database framework has successfully reduces work effort as systematic classification through Group Technology enables ease of access for information.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The project is a final year project which was done in the field of Mechanical Engineering at the Universiti Teknologi Petronas (UTP). The aim of this project is to establish a systematic framework to estimate fabrication time by using a Group Technology (GT) approach of Subsea Manifold fabrication. Group technology is a manufacturing technique of which parts in similar attributes are identified and grouped together to take benefits of their similarities in design features (Dowlatshahi & Nagaraj, 1998). Similarly, the project applied the same principle and applied it to fabrication time estimating model. The tool to estimate the fabrication time was adopted from existing model manufacturing time and cost estimation for large mechanical engineering assemblies from Design for Manufacture (De Sward). Group Technology was used to further refine the model by sorting the design information into a database. A framework was developed to reduce redundant work of estimating fabrication time. The project was related to the Greater Western Flank (GWF) project where Sapura Kencana is one of its contractors entrust to manufacture the Subsea Manifolds. The assessment of the framework was done by comparing the estimated production time results with the GWF project actual fabrication time.

1.2 Problem Statement

Estimation of time in a fabrication project is a factor that is critical in a project planning. Normally engineers use their experiences or heuristic approaches to estimate the fabrication time. This involves the estimation of fabrication activities such as cutting, welding and assembly. This approach does not provide consistency and accuracy. In some situation, the deviation from actual time is rather big. This will lead to loss of time and contributing to higher cost. This project addressed the problem by adopting group technology approach. It is a concept of standardizing objects of similar design. An EXCEL model was developed to estimate fabrication time. The model was tested using the actual data from a fabrication company.

1.3. Objectives

The main objective of the study is to develop a framework to estimate fabrication time for Subsea Manifold using Group Technology approach. Specifically this study aims to;

- Investigate application of Group Technology as tool to further refine production time estimation model.
- Use of spreadsheet for database to classify parts and components in the fabrication process to similar geometrical and technological features as well as adding calculation for production estimation time applications.
- To assess the time estimation from the model framework with an existing subsea manifold fabrication project.

The significance of the study is that valuable time and effort can be saved for estimating production time through a single framework instead of going through sets of production estimation model. The framework is also design to be robust enough at least for large fabrication assemblies in the industry.

1.4 Scope of Study

The scope of study is as follows;

- Estimated the product fabrication time in the fabrication of the GWF subsea manifold.
- Involved in metal fabrication processes in large fabrication assemblies.
- The time estimation model was adopted from an already existing product fabrication model from Manufacturing Engineering and Technology (Kalpakjian & Schmid, 2004),Design for Manufacture (De Sward) and Simplified Time Estimation Booklet (Polgar, 1996).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Over the past two decades, Malaysia has been seen to have rapid technological development and shown successes in the manufacturing sector (Lai & Yap, 2004; Noori, 1997). The technological process design for manufacturing has been sought as one of the most complex and knowledge intensive process (Bailey, Roy, Harris, & Tanner, 2001; Newman & Nassehi, 2009; Opetuk & Ćosić, 2012). As what as it seems, the manufacturing sector are industries that requires for strategic risk management for continuing success (Pons, 2010). As in manufacturing project context, project success in simplest terms can be considered successful if it can implement four criteria where two of them are time criterion and monetary criterion (Pinto & Slevin, 1988). The two criteria are inter-related as an accurate estimation of the manufacturing time can give advantage for more competitive prices, higher profits, and also increase the client portfolio. The estimation of the processing times of each one of the operations involved in the manufacturing of a product is an important task in any manufacturing industry (Giordana & Neri, 1995; Mucientes, Vidal, Bugarin, & Lama, 2008). The purpose of this literature review is to understand the background of production time estimation model and form a relation with Group Technology approach to further refine it with its principles.

2.2 Group Technology

During World war II, Group Technology have already been applied by the Russians which is where it was originated (Rajput, 2007). The benefit it has on mass production layout and techniques into smaller batches have made it very popular in manufacturing industry. The technique is usually used in product manufacturing where similar parts or products are grouped together to form families so that all members of a family are processed in a miniature factory called cell. Group Technology comes into role where the processing section in a small batch manufacturing factory is traditionally arranged according to their function, for example, in a manufacturing company there have a machining section where they have many type and sizes of machines such as milling machine, lathe machine, etc.

Parts and components need to visit to these sections and the common results are machines have to be reset and adjusted to comply with the dissimilarities of the object. This result in loss of time and delay in activities because of high built up concentrated in an area. Group Technology help facilitates this problem by introducing group of families where each family's processes parts and products are assigned to processing operations that process according to their similar features. The main characteristic of a group technology system is to group components into families.

There are many studies that uses Group Technology approach to improves their working environment (Andres, Albarracín, Tormo, Vicens, & García-Sabater, 2005; Burbidge, 1996). Group Technology is also popular as a refining tool for parametric modelling. This is demonstrated by Djassemi (2000) to improve efficiency of a CNC programming by featuring group technology in parametric modelling where there are some similarities among parts in CNC machining operations (Djassemi, 2000). Estimating fabrication time by using Group Technology approach is not a new activity. This is demonstrated by Opetuk & Ćosić, (2012) to estimate fabrication time of machining shafts. Group technologies are used to classify different parts as shown in Figure 2.1 (Opetuk & Ćosić, 2012). The different types of shafts are classified into two parts which is symmetrical and non-symmetrical. The parts are digit coded so that the technological process for new parts can be found according to their similarities. EXCEL spreadsheet are used as the database and working model to calculate the production time.

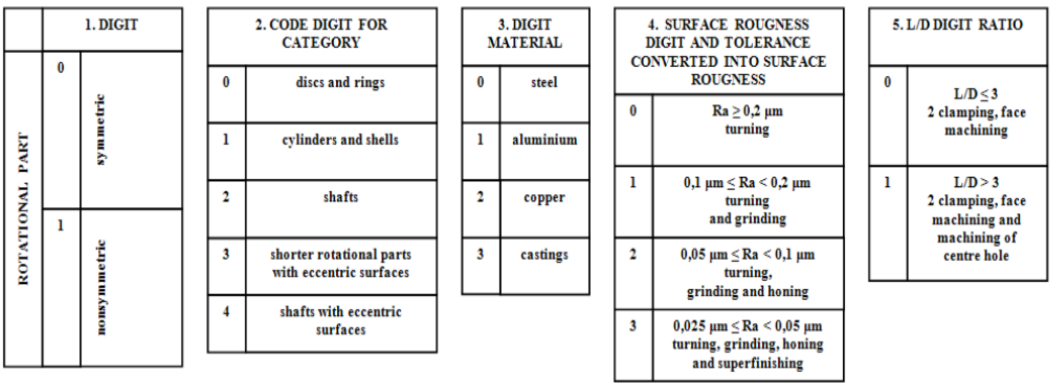


Figure 2.1 Parts Classifier for rotational parts (Opetuk & Ćosić, 2012)

The author first classifies the basic shapes of rotational parts as shown in Figure 2.2 (Opetuk & Ćosić, 2012). This was done to easily retrieve the calculation as well as calculate the production time.

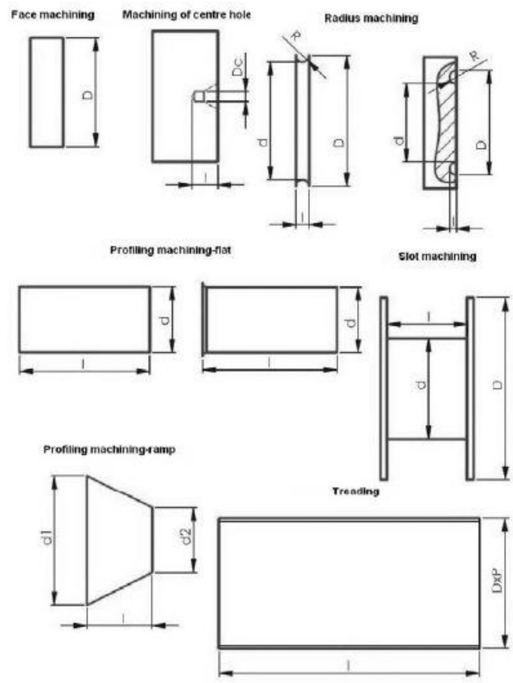


Figure 2.2 Types of basic shapes (Opetuk & Ćosić, 2012)

A more comprehensive and larger expansion of Group Technology database development is demonstrated by Dowlatshahi & Nagaraj (1998). The author outlined five steps of developing group technology database which first start with

i. data collection,
ii. data classification,
iii. data analysis,
iv. data coding
v. and finally data querying.

Instead of applying the database into EXCEL, the research designed a new system called the Interactive Design Retrieval System (IDRS) to cope with the large array of data and facilitation of data retrieval. The study only extended to data query.

2.3 Production Time Estimation Model

The usual practice to estimating fabrication time are likely to be using heuristic approach where in most cases, manufacturers give an approximate estimation with an assumed product price and production times based on their experience and on what they can see in the drawing (Opetuk & Ćosić, 2012). This approach does not have a mathematical modelling basis thus provide inconsistency and inaccuracy. In some situation, the deviation from actual time is rather big. Other practice in estimation is by using the Product Cost Estimation approach which can be categorized to qualitative and quantitative (Dai, Balabani, & Seneviratne, 2006). Qualitative approach is usually used in production line where it is based upon the similarity found through the manufacturing processes of the last similar production features. Whereas for the quantitative approach are based on detailed analysis of the part such as the geometrical and technological features. In Figure 2.3 shows the classification of PCE of Qualitative techniques and Quantitative techniques to Intuitive or Analogical Techniques and Parametric and Analytical Techniques respectively.

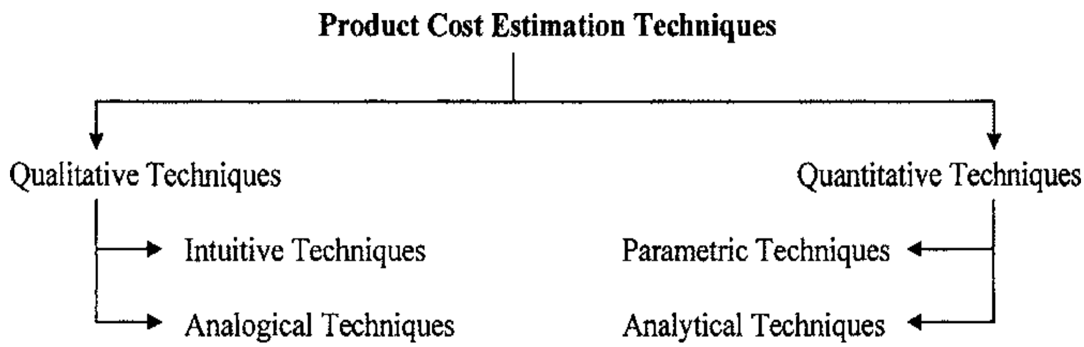


Figure 2.3 Initial classification of the PCE techniques (Dai et al., 2006)

The PCE techniques that are classified in Product Cost Estimation are mainly for estimating cost instead of estimating production time. However, Parametric techniques are also mentioned as a product time estimation model along with Predetermined Motion Studies (PMTS) and Process Models (Neo, 1995). The PMTS model requires two input approach which is individual elemental motion to do a task and design variable as shown in Figure 2.4 (Neo, 1995). The individual elemental motion works by defining the motion involved from the beginning until the end of the process. Design variables are the geometric measurement required for each of the motion such as length, diameters and width.

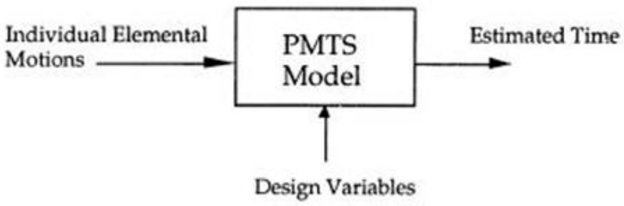


Figure 2.4 Predetermined motion time study model (Neo, 1995)

For the case of process model as illustrated in Figure 2.5, the model first start with outlining the steps of the manufacturing process and then input the design variables. The same model are applied in Design for manufacture (De Sward).

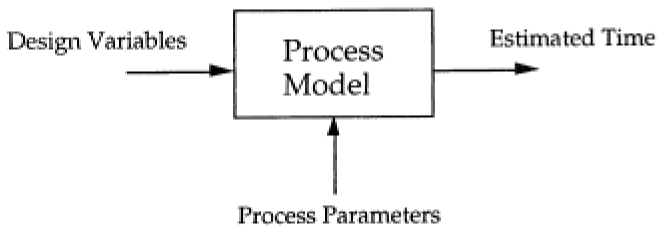


Figure 2.5 Process models (Neo, 1995)

In Figure 2.6, parametric models are shown in which provide relatively rough estimates. The design variable used weight to correlate fabrication time thus weight are the fundamental input variable (Neo, 1995). A brief description in Cost Implication of composite materials of Military Airplanes (Harmon & Arnold, 1991) where the first unit cost as a function of weight for composite airframe parts are categorized into;

- primary or secondary structure
- a fuselage, wing or an appendage component
- part associated with military
- part associated with commercial aircraft

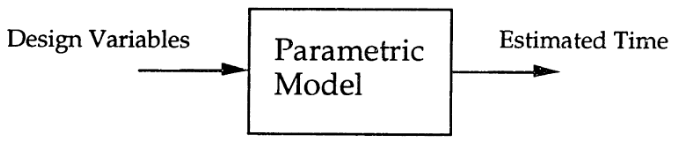


Figure 2.6 Parametric modelling (Neo, 1995)

Other production time estimation practices are by using simplified time estimation booklet that have been already derived (Polgar, 1996). Studies adopting this idea have been demonstrated earlier by Opetuk & Ćosić (2012) to estimate fabrication time of rotational shaft by using applications of EXCEL spreadsheet to calculate production time estimations.

Figure 2.7 shows the working model of the applications using EXCEL spreadsheet. Calculations are applied into the spreadsheet and the user just need to input on the variables wanted. The output is shown as the production time per piece. (Opetuk & Ćosić, 2012).

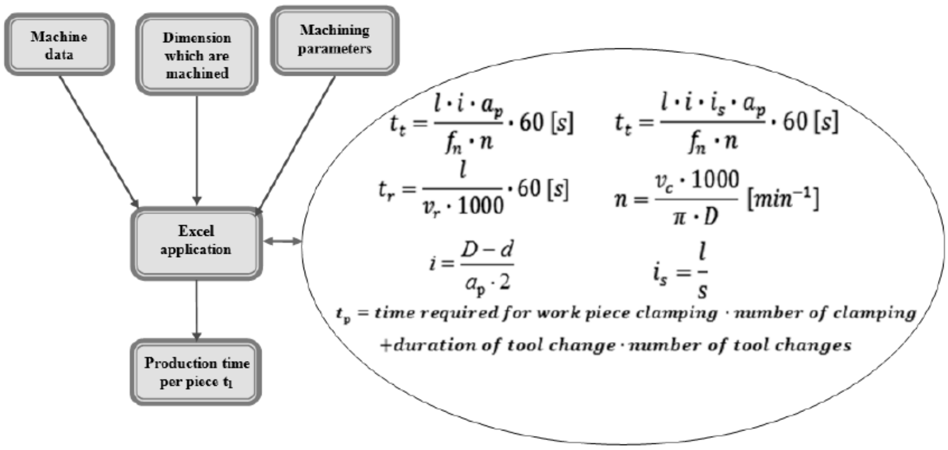


Figure 2.7 Working model of the application (Opetuk,& Ćosić, 2012)

2.4 Manufacturing process

A study shows that for Large Mechanical Engineering Assembly consist of manufacturing processes shown in Figure 2.8 (Boothroyd & Dewhurst, 1988; De Sward). This type of manufacturing process is quite common for parts fabrication that is plate based. Most Subsea manifold fabrication including Greater Western Flank project is composed of plate based material (Naqib, 2013) .

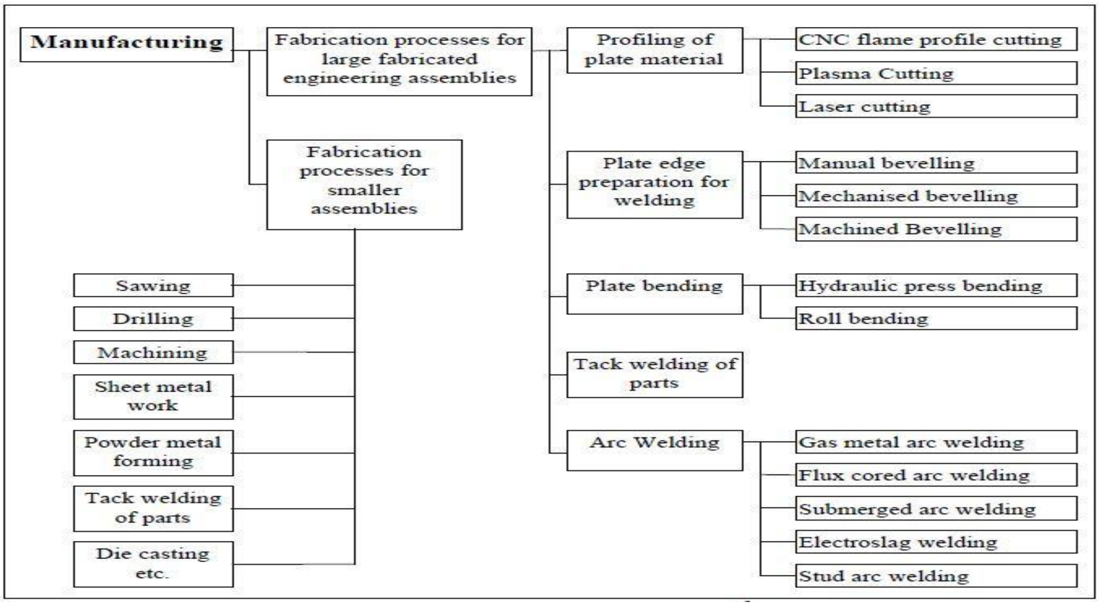


Figure 2.8 Manufacturing Processes (De Sward)

2.5 Summary of Literature Review

The followings are the summary of the literature review

- Group Technology is not a new tool to be used to refine estimation techniques as stated by Dai et Al (2006). This are demonstrated by Opetuk & Ćosić (2012) through their development of database for rotational parts.
- A more comprehensive database design adopting the same approach are shown by Dowlatshahi & Nagaraj (1998) to develop data retrieval system out of a huge array of manufacturing process data. However, the study just extended to data query and modelling of own system compared to Opetuk & Ćosić (2012) which uses EXCEL as database.
- The project decided to adopt by Dowlatshahi & Nagaraj (1998) database development steps and use the estimation model by Opetuk & Ćosić (2012).
- Due to a broader scope of manufacturing process of Subsea Manifold fabrication, the production time estimation formula are to be based on Large Mechanical Engineering Assembly as presented in Design For Manufacture (De Sward). The formulas can be obtained from Manufacturing Engineering and Technology (Kalpakjian & Schmid, 2004),Design for Manufacture (De Sward) and Simplified Time Estimation Booklet (Polgar, 1996).

As a conclusion, the study adopted the production estimation model from Opetuk & Ćosić (2012) with added improvement of database development (Dowlatshahi & Nagaraj 1998) and additional production time estimation methods (De Sward; Kalpakjian & Schmid, 2004; Polgar, 1996).

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

The following research approach were adopted

- Developed a database of existing technological processes and then classified them according to the geometrical and technological features of parts by using Group Technology approach.
- Adopted methods of estimating fabrication time from Manufacturing Engineering and Technology (Kalpakjian & Schmid, 2004),Design for Manufacture (De Sward) and Simplified Time Estimation Booklet (Polgar, 1996) were used.
- The accuracy of the model was assessed by comparing the estimated production time with the actual production time of fabrication processes.

Figure 3.1 shows the flow chart for the activities involved in the research. The flow chart is explained in simple description provided in the balloon.

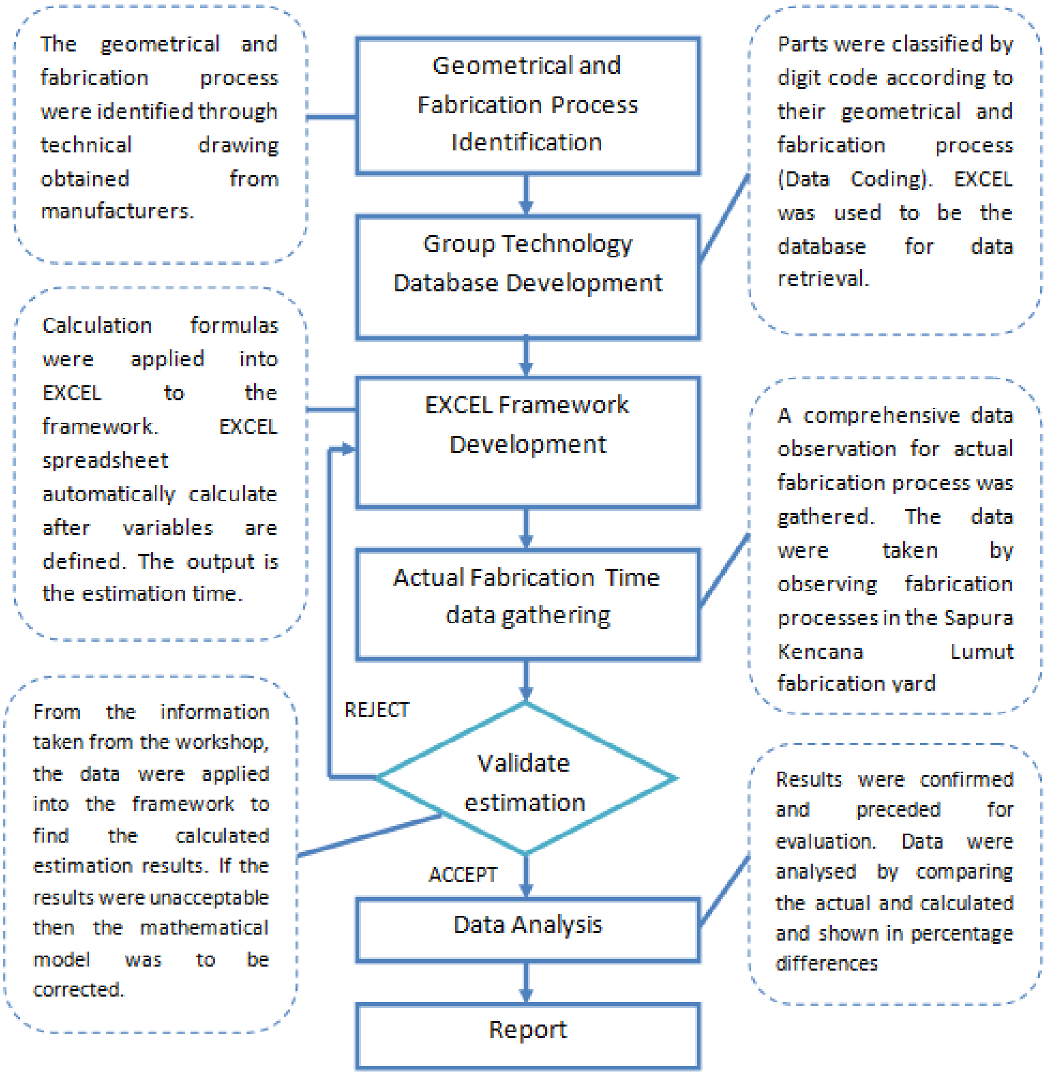


Figure 3.1 Methodology of research

3.2 Summary of Research Methodology

The followings are the activities in the research methodology

- Data for the geometrical and technological features of the GWF subsea manifold fabrication project were obtained. This was done through analysis of the technical drawings provided by the manufacturing company.
- Then, parts were grouped by geometrical and technological features and input it into the EXCEL spreadsheet. This is the database for the parts which were digit coded.

- After that, the calculations of the fabrication time were applied in the EXCEL spreadsheet.
- From there, a comprehensive estimation of the manufacturing process estimated through the framework prepared for assessment purposes.
- The assessment was done by comparing the estimated production time with the actual fabrication project of the GWF Subsea Manifold.
- Finally, the results was analysed based on percentage differences of time comparison.

3.3 Key Milestones

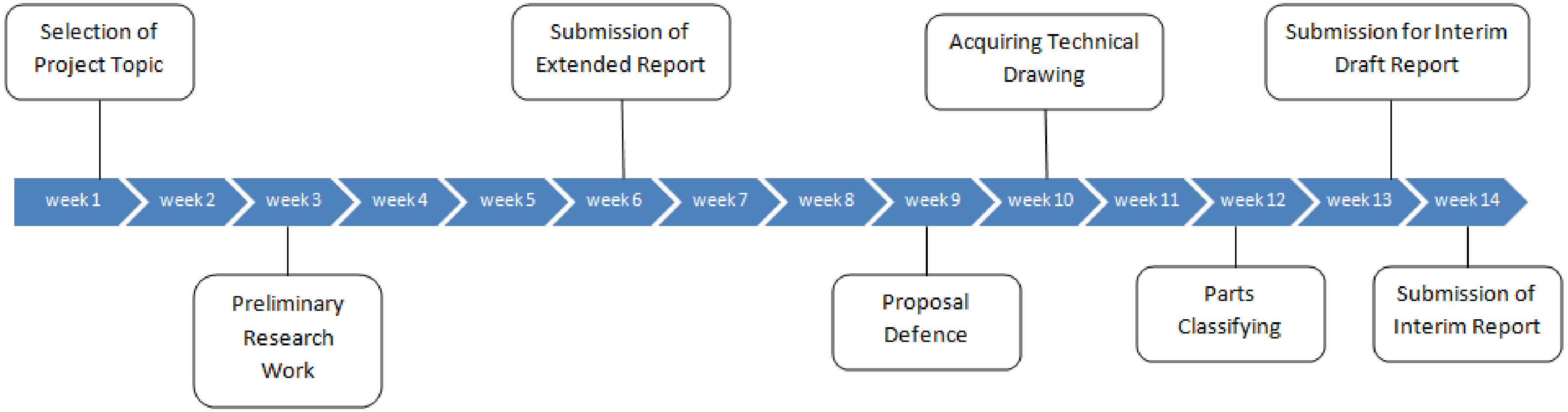


Figure 3.2 Key Milestones for FYP 1

For the key milestone in Final Year Project (FYP) 1, the first stage was to select the topic followed by a preliminary research work to support the chosen topic. In week 6 the extended report was submitted. Then, in week 9, proposal defence was held. A presentation was done to show the feasibility studies and defend whether the project is relevant for the 39 weeks course and standard of FYP. Next, technical drawings for the subsea manifold structure was obtained from the manufacturing company. In week 12, Parts classification was included in the database. This was a very demanding stage of the project where a lot of time and energy was spent as the huge array of data that are needed to be classified. Therefore, a large amount of time is given for the task. Finally, the semester ends with the submission of the interim report.

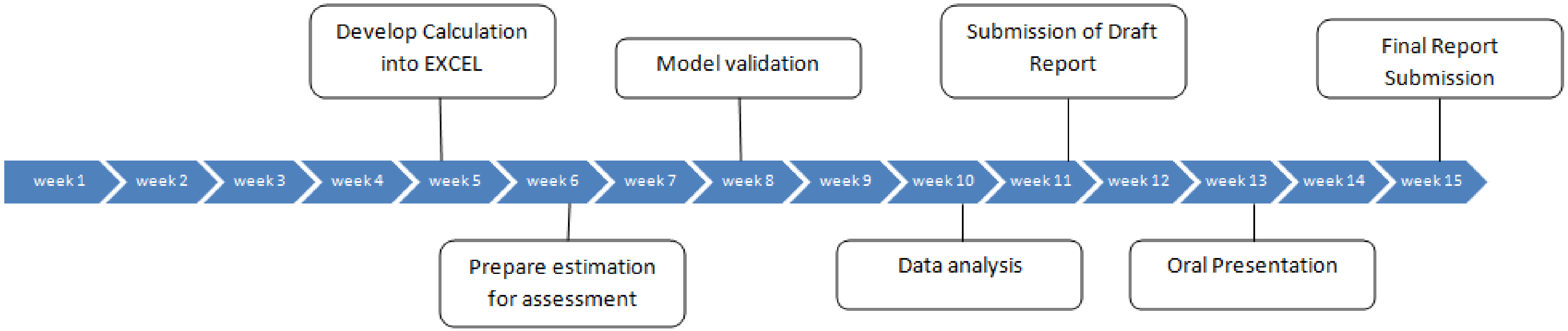


Figure 3.3 Key Milestones for FYP 2

In FYP 2, the work continued with the last task which is development of database. Then, the process continued with the time estimation calculation and was applied into EXCEL spreadsheet. A comprehensive data of the actual time involving basic fabrication processes of the subsea manifold was taken. The actual time was then compared with the calculated time by percentage differences. The data was then analysed.

3.4 Gantt Chart

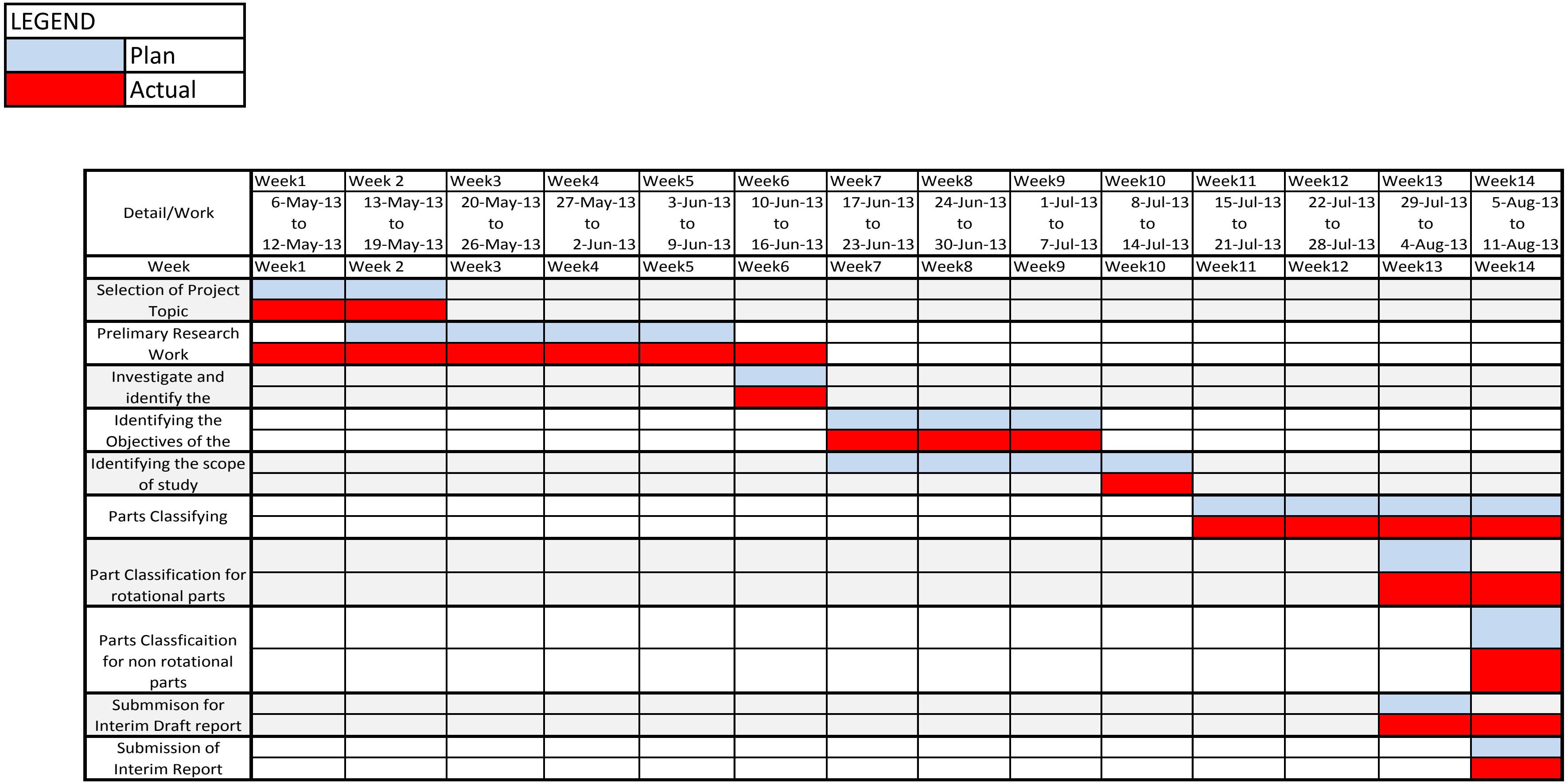


Figure 3.4 Gantt chart for FYP 1

During FYP 1, the progress shows the actual work is manageable and the work continues as progress. Most crucial works are data classifications of parts. All activities were completed according to the datelines without any major problems.

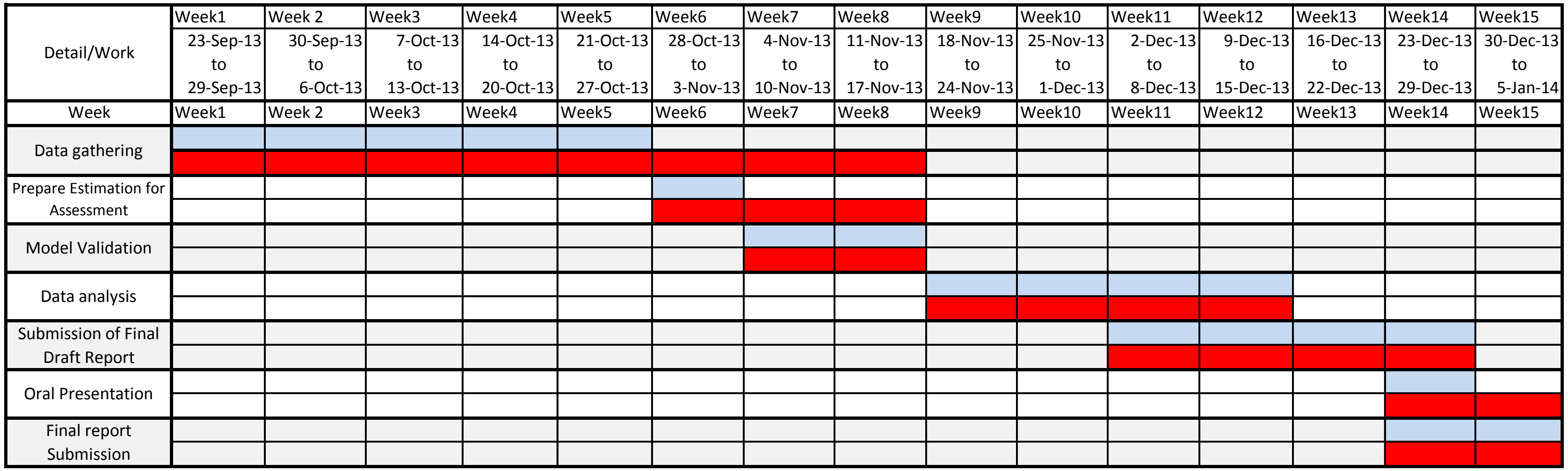


Figure 3.5 Gantt chart for FYP 2

For FYP 2, continuation of development of the EXCEL framework was focused on calculation application. During week 6 to week 7, the data gathering for actual time of fabrication process was set out. The actual time was taken through observation of basic fabrication processes. Then the mathematical model for assessment of the estimation time of the GWF manufacturing processes was prepared for assessment. From there, the analysis was conducted by comparing the time estimation with the actual fabrication time.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Parts Classification by shape

Generally the parts in the manufacture of the Subsea are mostly based on metal plates. Others are to be rotational in shape which consist only a few parts of the structure. Table 4.1 shows the descriptions of digit presented in Table 4.2

Table 4.1 Basic structure of the coding system for Table 4.2

Digit	Description
1	In the Part Digit Class, for rotational parts, the code is identified by length (L) to Diameter (D) Ratio. Whereas, for non-rotational parts the code is identified by the length, width and thickness
2	Shape features code, the variations of type of geometry is identified and distinguished
3	For this part, in case for rotational part the digit applies to internal shape such as holes and threads. Whereas for non-rotational parts features general non-rotational parts
4	This digit is to show plate machine surfaces features such as flats and slots
5	Shows features such as auxiliary holes and gear teeth
6	The overall size of the dimensions
7	The material used by the parts such as steel, aluminium or plastic
8	The original shape of the raw material
9	Accuracy requirements

Table 4.2 Parts Classification by Shape

Digit 1

Part Class		
0	Rotational Parts	L/D < 0.5
1		0.5 < L/D < 3
2		L/D > 3
3	Non Rotational Parts	
4		
5		
6		
7		
8		
9		

Digit 2

External shape, External shape elements			
0	Smooth, no shape elements		
1	Stepped to one end		No shape elements
2			Thread
3		Or smooth	Functional Groove
4	Stepped to both ends		No shape elements
5			Thread
6			Functional groove
7	Functional cone		
8	Operating thread		
9	All others		

Digit 3

Internal shape, Internal shape elements		
0	No hole, no breakthrough	
1	Smooth or stepped to one end	No shape elements
2		Thread
3		Functional Groove
4	Stepped to both ends	No shape elements
5		Thread
6		Functional groove
7	Functional cone	
8	Operating thread	
9	All others	

Digit 4

Plane Surface machining	
0	No surface machining
1	Surface plane and/or curved in one direction, external
2	External plane surface related by graduation around the circle
3	External groove and/or slot
4	External spline
5	External plane surface and/or slot, external spline
6	Internal plane surface and /or slot
7	Internal spline (polygon)
8	Internal and external, polygon, groove and/or slot
9	All others

Digit 5

Auxiliary holes and gear teeth		
0	No gear teeth	No auxiliary hole
1		Axial, not on pitch circle diameter
2		Axial on pitch circle diameter
3		Radial, not on pitch circle diameter
4		Axial and/or radial and/or other direction
5		Axial and/or radial on PCD and/or other directions
6	With Gear Teeth	Spur gear teeth
7		Bevel gear teeth
8		Other gear teeth
9		All others

Digit 6

Diameter D or length of edge A (mm)	
0	< 20
1	>20 < 50
2	> 50 < 100
3	>100 < 160
4	>160 < 250
5	>250 < 400
6	>400 < 600
7	>600 <1000
8	>1000 < 2000
9	>2000

Digit 7

Material	
0	API 5L X 52
1	API 2H GR 50
2	EH 35 – Z 35
3	API 2W 50 LS
4	A992 GR 50
5	Other Material
6	
7	
8	
9	

Digit 8

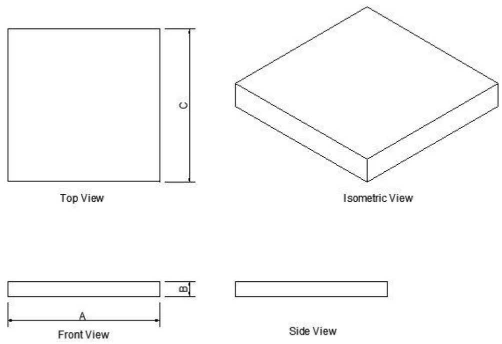
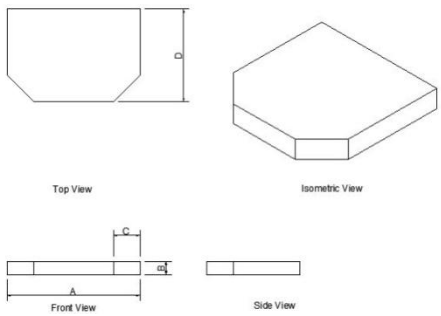
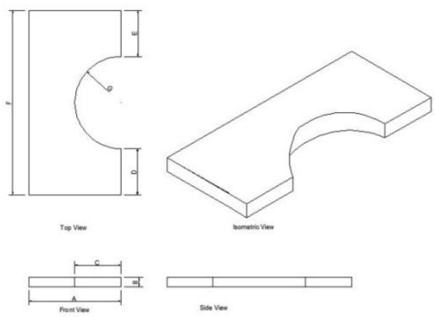
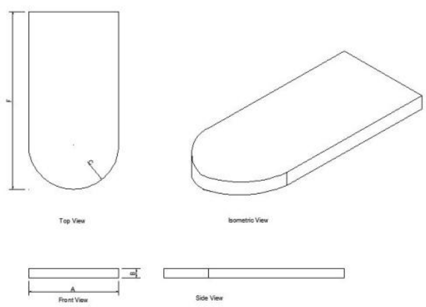
Basic shape elements	
0	Round bar
1	Bright Drawn round bar
2	Triangular, square, hexagonal and other bar
3	Tubing, pipe
4	Angle, U, T, H and similar sections
5	sheets
6	Plates and slabs
7	Cast or forged components
8	Welded Group
9	Pre- machined components

Digit 9

Accuracy encoding digit	
0	No accuracy specified
1	2
2	3
3	4
4	5
5	2 + 3
6	2 + 4
7	2 + 5
8	3 + 4
9	(2 + 3) + 4 + 5

Table 4.3 and Table 4.4 shows the basic parts for the rotational and non rotational parts. The tables shows the class of the parts and the description of the design.

Table 4.3 Classification for Non Rotational Parts

Class	Description
Basic sheet with no variation	
Basic Sheet with variations	
Basic Sheet with curve	
Basic sheet with curve	

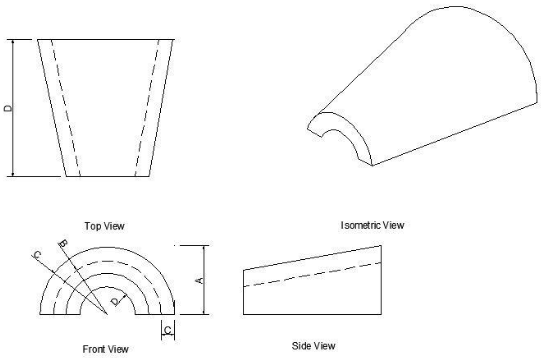
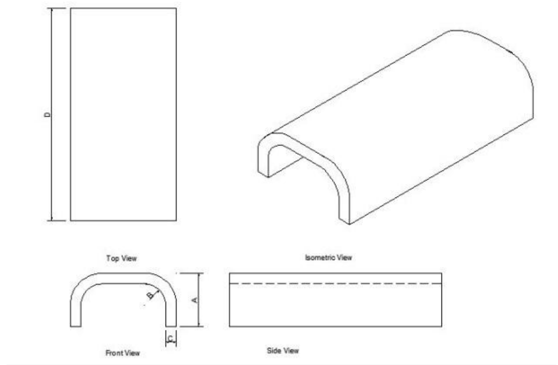
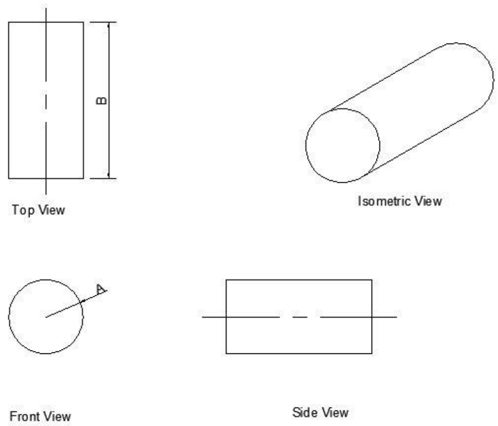
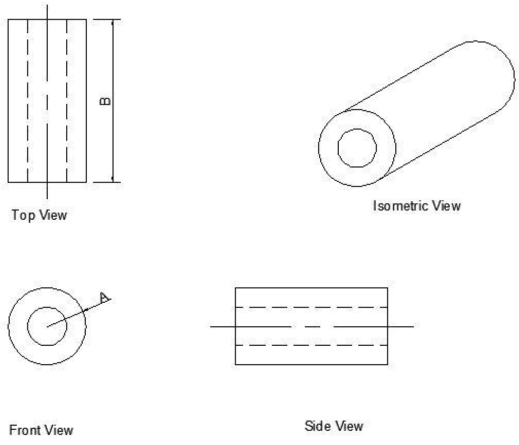
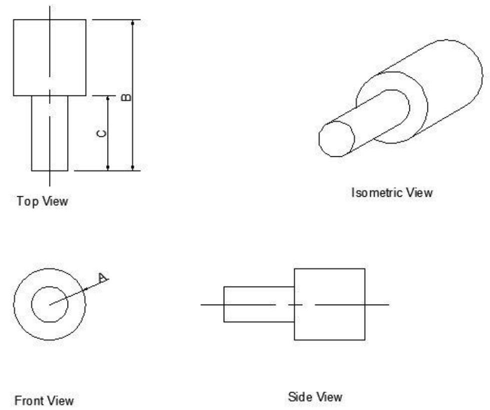
Basic Sheet with one bend	
Basic Sheet with more than one bends	

Table 4.4 Classification for Rotational Parts

Class	Descriptions
Basic Rotational Parts with no variation	

Basic Rotational Parts with holes	
Basic Rotational Parts with variations	

4.2 Parts Classification of Subsea Manifold

The parts classification are digit coded based on Table 4.2. There were 189 parts that have been digit coded and the database was attached in Table 4.6 in the appendices. The parts can be found according to the drawing numbers that are attached as appendices in this report. In Table 4.5 the drawing number and the part number is stated. This information shows technical drawing which is being referred. As for example part number 1 in table has a drawing number of TPA-DU400051177-05-SP1-01 which information can be found in the yellow highlighted area in the following figure.

Table 4.5 Guide for parts classification for part number 1

No	Drawing number	Part Number	Descriptions	Material	Digit								
					1	2	3	4	5	6	7	8	9
1	TPA-DU400051177-05-SP1-01	12a	Plate, thermal cut, bend	EH36	3	0	0	0	1	8	2	6	1

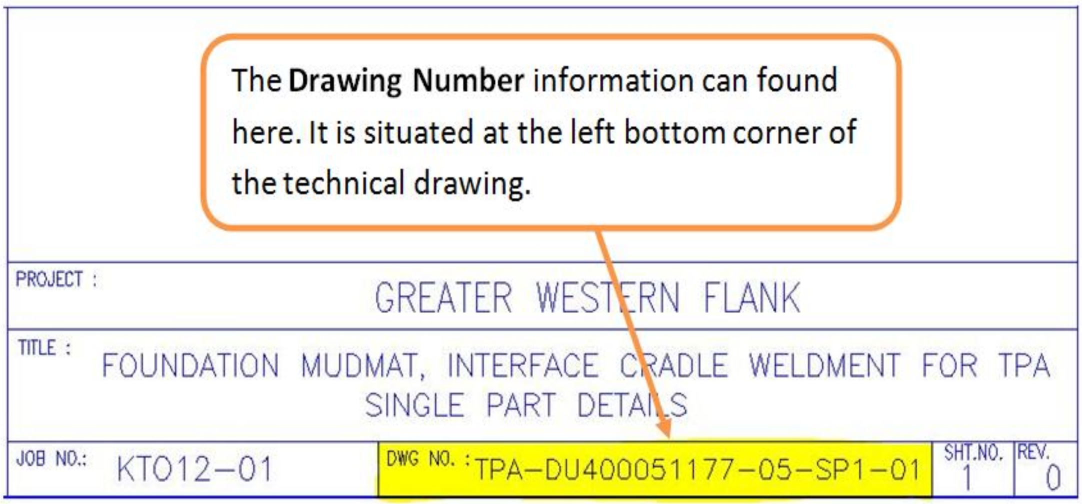


Figure 4.1 Guide for finding drawing number

In the following Figure 4.2, the information of the part number stated is shown which is item 12a. The details of the drawings can be seen. From here, the shape and the fabrication process on the item are figured as described in the table. The codes are then given based on the parts classification in table 4.2.

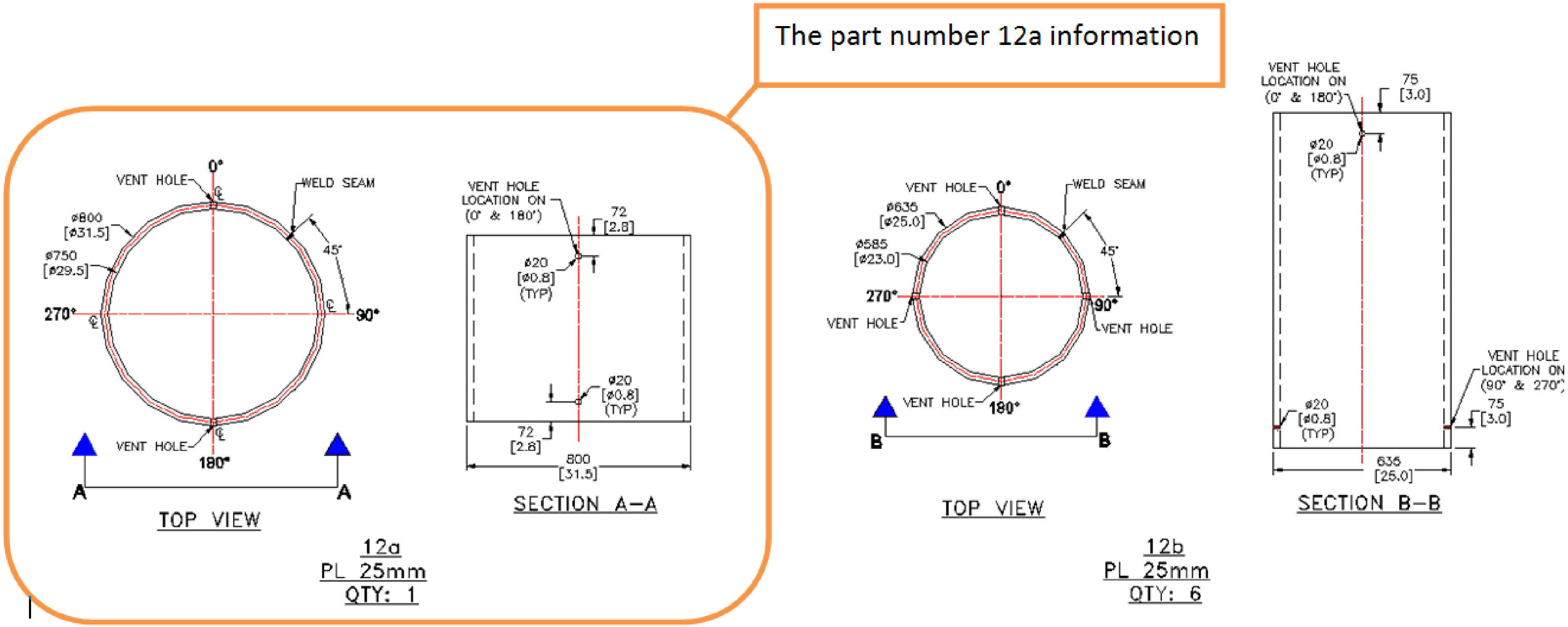


Figure 4.2 Guide for finding part number

Table 4.6 Parts Classification Database

Attached as Appendix A

4.3 Applications for the estimation of production times

The application for the calculation of basic data is used to calculate some general data which are needed to estimate the production time. To estimate the production time, it is necessary to calculate the time required for the production of each basic steps and the sum of all these times will give the production time per piece. The accuracy of the application was tested by comparing the results with the real application in the workshop. The actual production time per piece was then compared with the estimated production time per piece obtained by the Excel application.

In Figure 4.3 shows the working model of the application. The user needs to input the machining data, the machining dimensions and the machining parameters into the application. Depending on the type of machining operations the user needs to input the following dimensions:

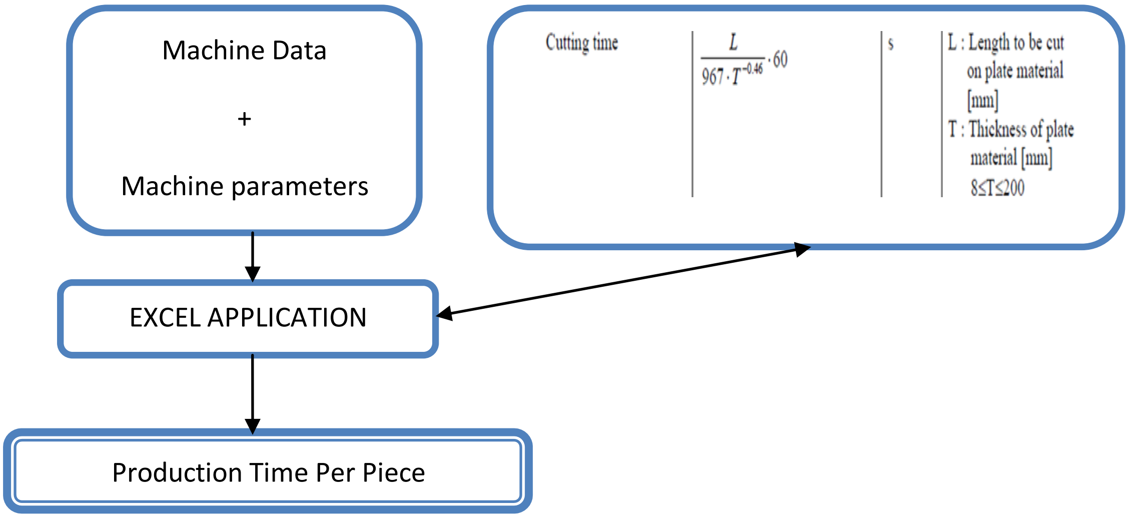


Figure 4.3 Working model of the application

Table 4.7 Flame profile cutting time estimation

L, Length (mm)		100
T, Thickness of the plate (mm)		50
N, Number of parts on plate		1
ITF, Number of internal features on plate		0
Tc, if plate is thicker than 30 mm		1

Variables Declaration which the basic data are required to be input. The formulas which is applied will automatically calculate the time estimation

Cutting time	1.026121	seconds
Piercing time	9764	seconds
Total Set up time	864	seconds
Total de- set up time	280	seconds
Total Completion time in seconds	10909.03	seconds
Total Completion time in minute	181.8171	minutes
Total Completion time in hours	3.030285	hours

After declaring the variables, the time estimation is then calculated.

Table 4.7 shows the Flame profile cutting time estimation. When entering this information, the application automatically puts it into all work sheets. If the length in other work sheets changes, the application will automatically change the value and input it in the work sheet. After the user inserts the machining dimensions and the machining data, the application will use the above mentioned formulae and will automatically calculate the production time for all operations and add it in the production time per piece work sheet.

Percentage differences concept was used to show the differences between the actual time and the calculated time. The equation for percentage differences is

$$Percentage\ Differences, \% = \frac{Average\ EXCEL\ calculation - Average\ Actual\ Time}{(Average\ EXCEL\ calculation - Average\ Actual\ Time)/2} \times 100\%$$

(Mathisfun.com, 2013)

If the average calculation is positive, it signifies that the average excel calculation is faster than the average actual time. Thus, negative value gives a faster processing time for the average actual time. Figure below shows the value of the percentage differences. This is shown in Figure 4.4.

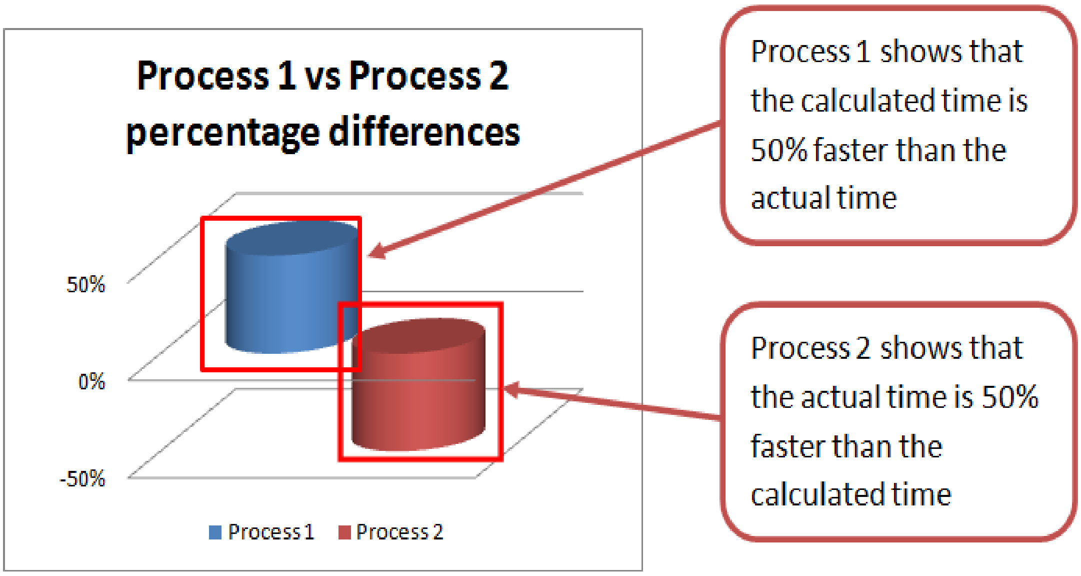


Figure 4.4 Percentage Differences between process 1 and process 2

4.4 CNC Flame Profile Cutting Time estimation

The total CNC flame profile cutting time, of a whole plate, is broken down into smaller time elements. These time elements are related to specific operator tasks and machine cycle times. Each element is calculated separately and combined in a predetermined manner with the other time elements to obtain the total CNC flame profile cutting time per piece.

This data comparison is done by observation, therefore the plate used to estimate the time depends on the current activity in the workshop. The plates used for the time are as below;

Table 4.8 Details on parts to be cut by CNC Flame Cutting

Material	Steel (EH36)
Thickness	80 mm
Length	1000 mm
Parts on plate to be cut	5
Code	3-0-0-0-0-8-2-6-1

The time taken is based on the flow chart in Figure 4.5. The figure shows the activity flow chart that the operator needed to follow. Through this, the completion time of part per piece can be obtained.

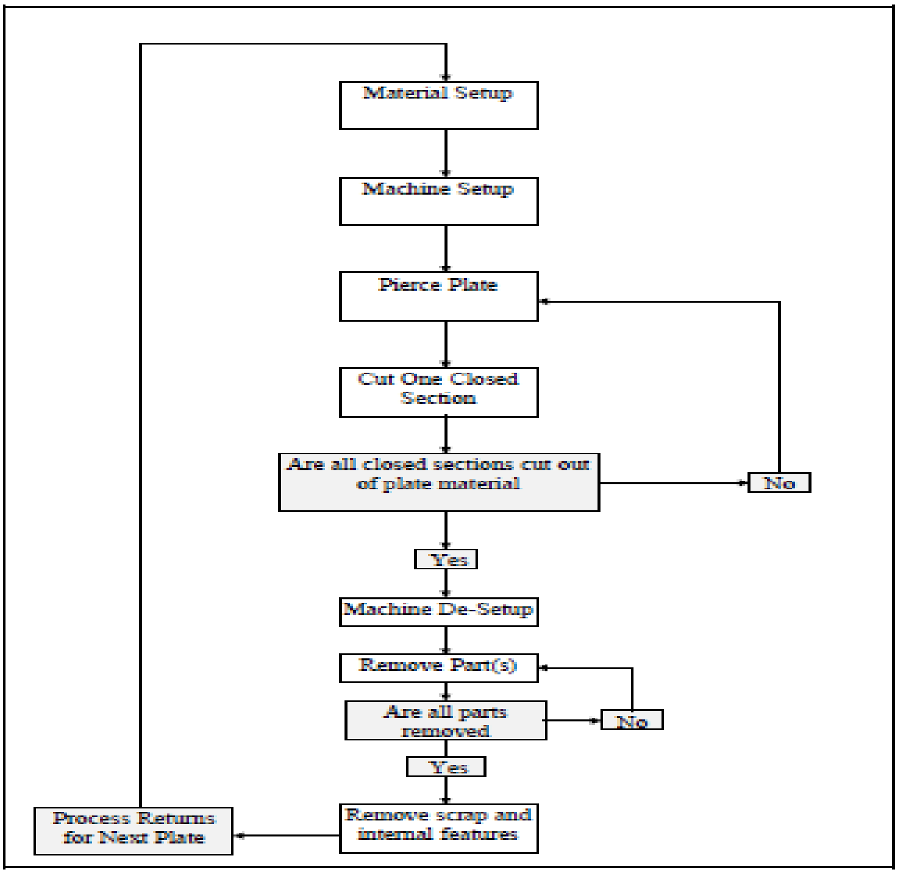


Figure 4.5 Process flow diagram for CNC Flame Profile Cutting (De Swardt)

Table 4.8 CNC flame profile cutting time estimation formulas (De Swardt)

CNC Process Times			
Description	**Formula**	**Unit**	**Variable Declaration**
Cutting time	$\frac{L}{967 \cdot T^{-0.46}} \cdot 60$	s	L : Length to be cut on plate material [mm] T : Thickness of plate material [mm] $8 \leq T \leq 200$
Piercing time	$(1.95 \cdot T + 14) \cdot (N + ITF)$	s	N : Number of parts on plate ITF : Number of internal features on plate T : Thickness of plate material [mm] $8 \leq T \leq 200$
Total set-up time	$600 + 253 + 11 \cdot (N + ITF) \cdot T_c$	s	T_c=1 if plate thicker than 30mm else T_c=0
Total de-set-up time	$188 + 92 \cdot N + 125 \cdot ITF$	s	

Table 4.8 shows the time estimation formulas for CNC flame profile cutting. The formulas are programmed in the EXCEL spreadsheet and the user just needed to input the variable declaration as shown in the table above.

Figure 4.6 shows the average differences between the production times per piece obtained by the Excel application and those obtained by the real application at the workshop.

Table 4.9 Flame profile cutting time estimation results

L, Length (mm)	1000
T, Thickness of the plate (mm)	80
N, Number of parts on plate	5
ITF, Number of internal features on plate	3
Tc, if plate is thicker than 30 mm	1

Table 4.9 (a) above are the variables input based on the parts design. The number of parts on plate (N) is the number of parts being fabricated from a single plate with the thickness of 80 mm.

Test Piece	1	2	3	4	5	Average
Cutting time (s)	7	8	7	8	7	7.4
Piercing time (s)	124919	111324	121921	123114	111556	118566.8
Total Set up time (s)	6712	8312	5231	6432	7721	6881.6
Total de- set up time (s)	1032	1213	1321	1211	1200	1195.4

Table 4.9 (b) There were 5 parts that were cut from the same plate. The data above are the actual time for each fabrication process. The average time for each process was then found.

Process Fabrication	Excel calculation (s)	Average actual time (s)	Percentage difference
Cutting time	8.266151912	7.400	11.058
Piercing time	124912	118566.800	5.212
Total Set up time	6912	6881.600	0.441
Total de- set up time	1023	1195.400	-15.543
Total completion time per piece	132855.2662	126651.200	4.781

Table 4.9 (c) The data above shows the comparison of the estimated fabrication time from EXCEL framework database and the average actual time obtained from table 4.9 (b).

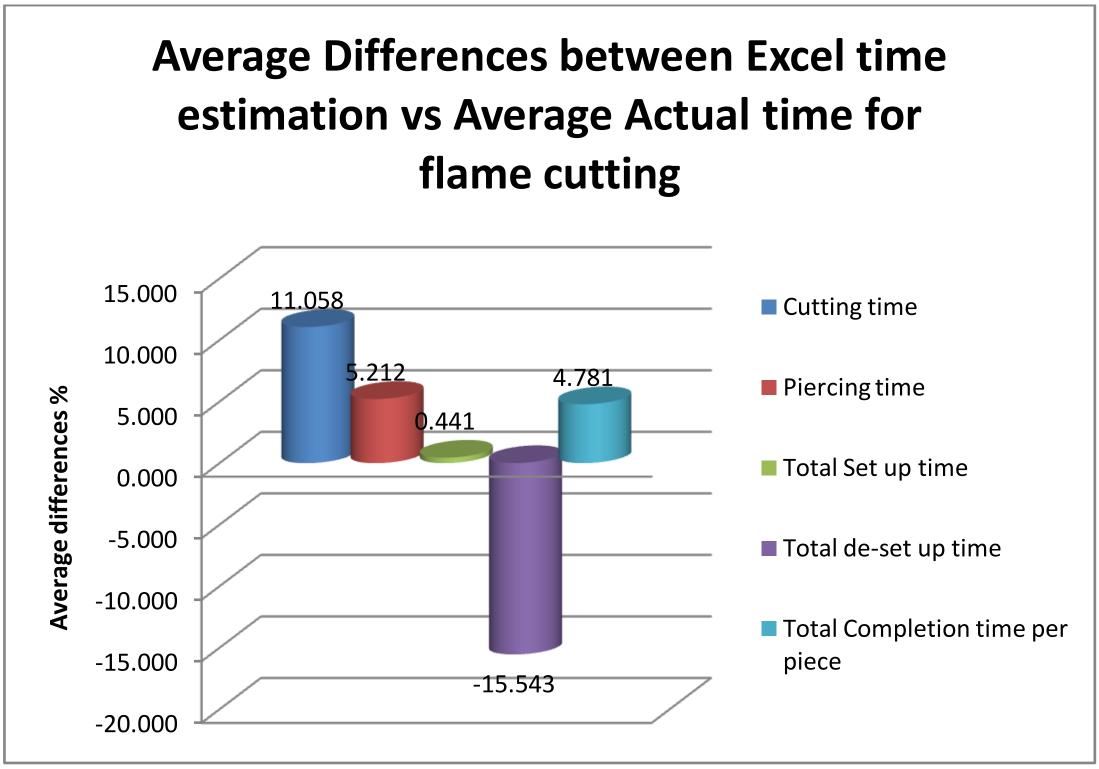


Figure 4.6 Average Differences between Excel time estimation vs Average Actual time for flame cutting

In Figure 4.6, it can be observed that the highest average difference is in Piercing time which is 1.628% and the lowest would be total setup time which is 0.004% which is very low. From here we can say that the application is very good in estimating CNC Flame profile cutting.

4.5 Burr Removal Time Estimation

After a flame cutting process, the burr are needed to be removed to avoid the plate material from crack or surface damage. This activity was needed to be done before the next fabrication activity can proceed. The activity were done by grinding away the irregularities and chips it away. The job are to be done by the grinder. Figure 4.7 shows the flow process of the burr removal process.

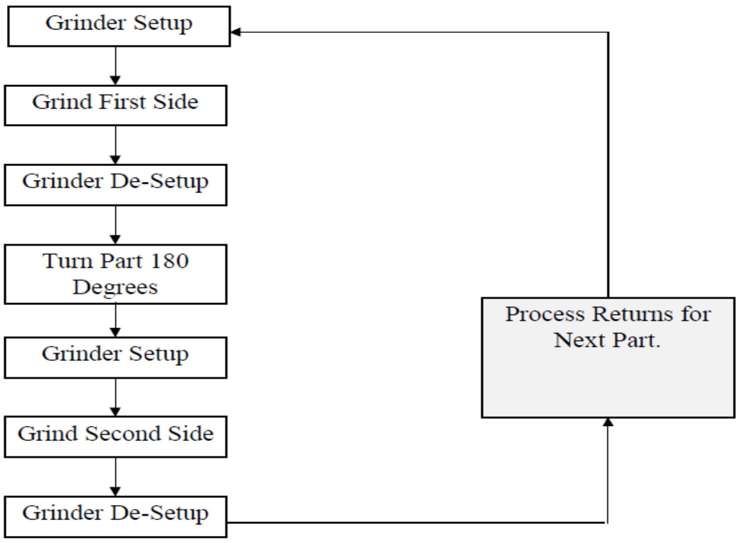


Figure 4.7 Process flow diagram for burr removal grinding (De Swardt)

Table 4.10 shows the time estimation formulas for the burr removal process using the grinder. The formulas are programmed in the EXCEL spreadsheet and the user just needed to input the variable declaration as shown in the table above.

Table 4.10 Burr removal time estimation formulas (De Swardt)

CNC Flame Profile Cutting Secondary Process Times			
Description	**Formula**	**Unit**	**Variable Declaration**
Grinding time	$\frac{2 \cdot L}{7041} \cdot 60$	s	L : Total profiled length on plate material [mm]
Set-up/De-set-up time	$104 \cdot N$	s	N : Number on parts on plate material
Handling time	$196 \cdot N$	s	N : Number on parts on plate material

Table 4.11 shows the part details that were observed to find the actual estimated time.

Table 4.11 Details on parts grinded (burr removal)

Material	Steel (EH36)
Thickness	80 mm
Length	100 mm
Parts needed to be grinded	5
Code	3-0-0-0-0-3-2-6-1

Table 4.12 Burr removal process time estimation results

L, Total Profile length on plate material (mm)	100
N, Number of parts on plate	5

Table 4.12 (a) The data above shows the variables that are needed to be input into the formula.

Test Piece	1	2	3	4	5	Average
Grinding time	5	5	6	7	9	6.4
Setup/ De-setup time	304	321	311	257	287	296
Handling time	230	199	256	231	234	230
Total completion time per piece	539	525	451	303	530	469.6

Table 4.12 (b) The data above shows the time for each process of the grinding activity. The average time for each process was then found.

Process Fabrication	Excel calculation (s)	Average actual time (s)	Percentage difference (%)
Grinding time	1.704303366	6.400	-115.882
Setup/ De-setup time	104	296.000	-96.000
Handling time	196	230.000	-15.962
Total completion time per piece	301.7043034	469.600	-43.536

Table 4.12 (c) Above shows the comparison for the estimated EXCEL calculation estimated time from the framework database with the average actual time obtained from Table 4.12 (b).

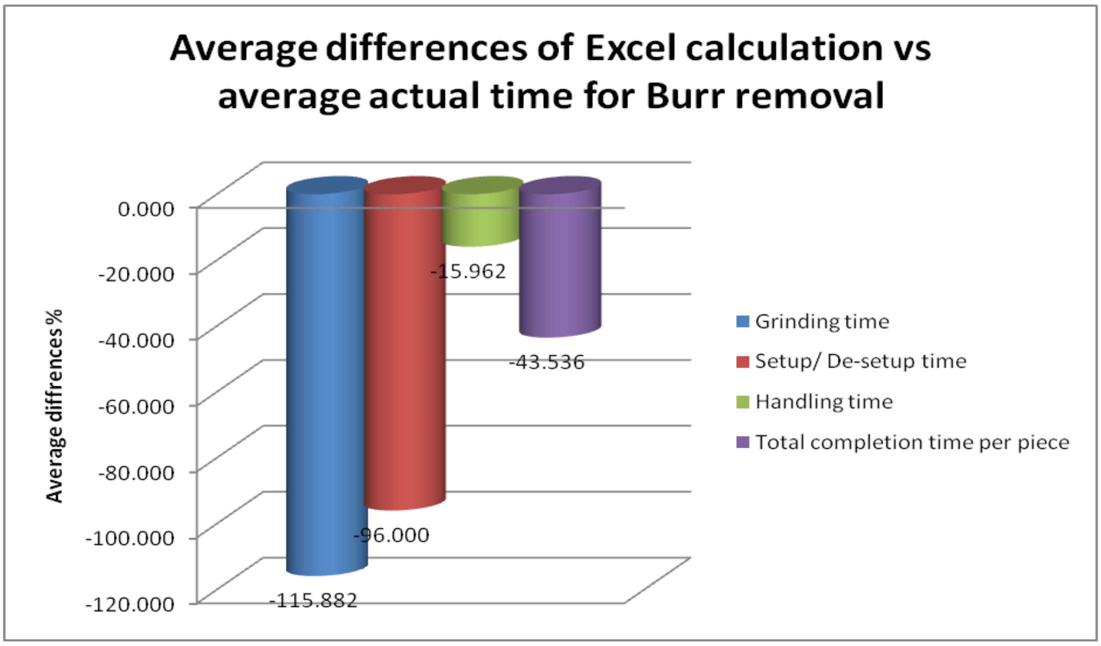


Figure 4.8 Average differences of Excel calculation vs average actual time for burr removal

In figure 4.8 it can be observed that the highest percentages are the grinding time and followed setup time and the handling time. The highest percentages are quite high which is 115%, however the difference in seconds (s) are 5 seconds. The reasons maybe probably grinding speed are depended on the grinder skills, techniques and diligence.

4.6. Time Estimation for Mechanised Bevelling Process

Bevelling process is a process fabrication to obtain a slant surface at the edge of a surface of a part. There are two bevelling process which are;

- Mechanised bevelling process
- Manual bevelling process

Figure 4.9 shows the flow chart process of a mechanised bevelling process which the operator need to follow.

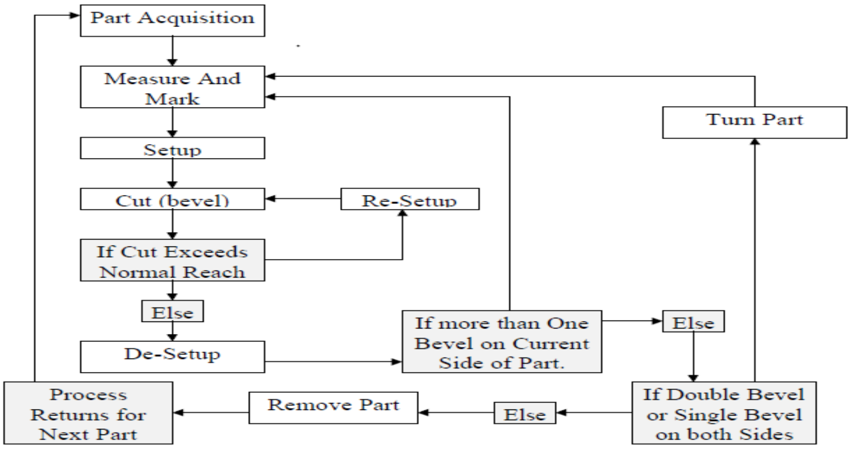


Figure 4.9 Process flow diagram for mechanised bevelling (De Swardt)

Table 4.12 shows the formulas for mechanised bevelling time estimation which were applied into the EXCEL framework database.

Table 4.13 Mechanised bevelling time estimation formulas (De Swardt)

Mechanised Bevelling Time			
Description	**Formula**	**Unit**	**Variable Declaration**
Cutting and burr cleaning time	$\sum_{i=1}^{N}\left[\left(0.223\cdot L_i+27+0.01\cdot L_i+18\right)\cdot Q_i\right]$	s	N : Number of bevels on part L_i : Length of bevel [mm] Q_i=2 if bevel is a double bevel else Q_i=1
Set-up and de-set-up time	$\sum_{i=1}^{N}92\cdot Q_i+\sum_{i=1}^{N}14\cdot Q_i+\sum_{i=1}^{N}round\left(\frac{L_i}{1270}\right)\cdot 63\cdot Q_i$	s	Rounding is to the lower integer
Handling time	$3.5\cdot D+114+196\cdot P$	s	D : Distance of storage from bevelling area [m] P=2 if part contains a double bevel else P=1
Marking time	$\sum_{i=1}^{N}\left(0.031\cdot L_i\cdot 2+16\cdot NL_i\right)\cdot Q_i$	s	NL_i = 2

Table 4.13 shows the details of the parts observed to find the estimated mechanised bevelling time.

Table 4.14 Details on parts bevelled by the Mechanised Bevelling Machine

Material	Steel (EH36)
Thickness	80 mm
Length	100 mm
Parts needed to be bevelled	5
Code	3-0-0-0-0-3-2-6-1

Table 4.15 Time estimation for the mechanised bevelling process results

N, number of bevels on part	4
L, Length on bevels (mm)	100
Qi = 2 if bevel is double bevel else Qi = 1	1
D, Distance of storage from bevelling area (m)	10
P=2 if part contains a double bevel else P=1	1
Nli=2	2

Table 4.15 (a) The data above shows the variables that were inputted into the formula.

Test Piece	1	2	3	4	5	Average
Cutting and burr cleaning time (s)	200	234	214	241	222	222.2
Setup and de setup time (s)	132	121	111	109	109	116.4
Handling time (s)	421	411	389	367	399	397.4
Marking time (s)	400	412	345	389	333	375.8
Total completion time per piece (s)	1153	1178	1059	1106	1063	1111.8

Table 4.15 (b) The data above shows the time for each process of the mechanised bevelling process. The average time for each process was then found.

Process Fabrication	Excel calculation (s)	Average actual time (s)	Percentage difference (%)
Cutting and burr cleaning time	273.200	222.200	20.589
Setup and de setup time	112.643	116.400	-3.281
Handling time	345.000	397.400	-14.116
Marking time	308.124	375.800	-19.791
Total completion time per piece	1038.967	1111.800	-6.773

Table 4.15 (c) Above shows the comparison for the estimated EXCEL calculation estimated time from the framework database with the average actual time obtained from Table 4.15 (b).

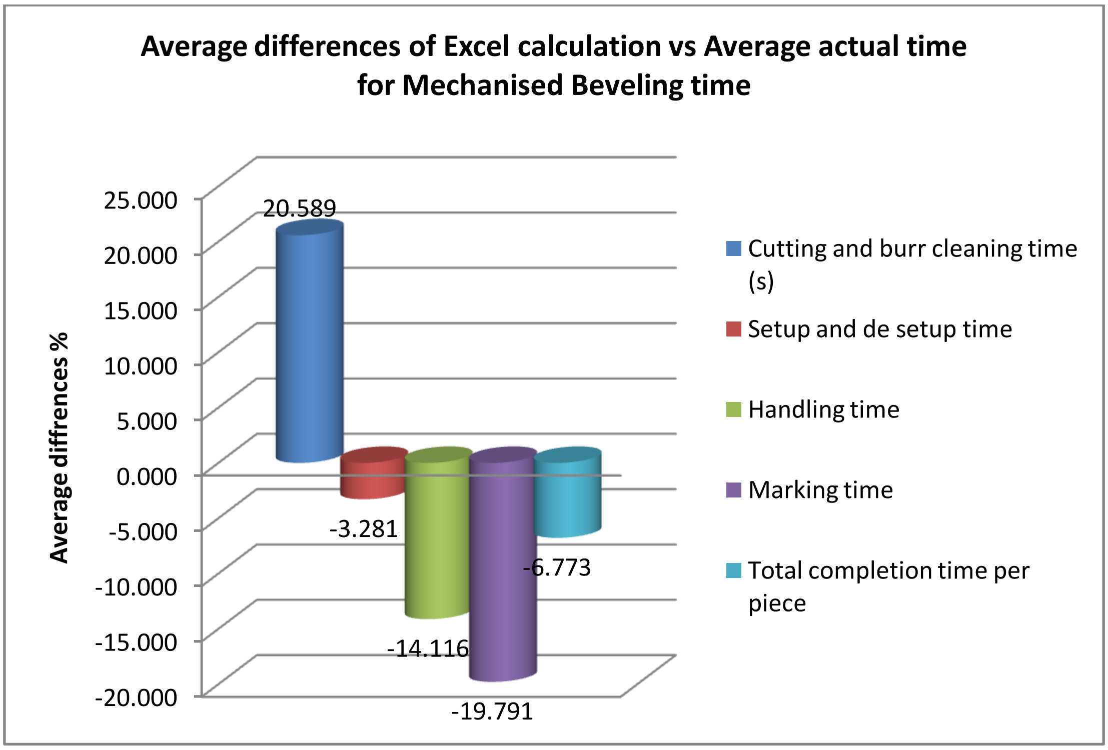


Figure 4.10 Average differences of Excel calculation vs. Average actual time for Mechanized Beveling time

In Figure 4.10 the highest data difference is the cutting and burr cleaning time which is 20.589% followed by marking time which is 19.791%, handling time, and finally the setup and de-setup time. Although the percentage is quite high, but on time differences it is only by 51 seconds which is quite tolerable. Therefore, the calculation can be used as good estimator.

4.7 Manual Bevelling Process Time Estimation

As mentioned before, there are two processes for bevelling. This part shows the manual bevelling process which uses a handheld thermal cutter to cut the edges of the parts to obtain the bevel. Figure 4.11 shows the flow chart process of a manual bevelling process.

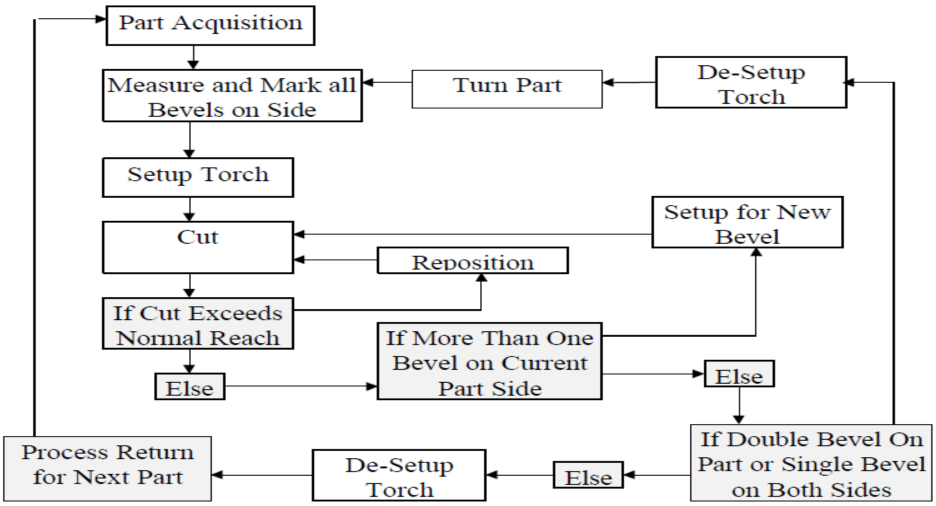


Figure 4.11 Process flow diagram for the manual bevelling process (De Swardt)

Table 4.15 shows the manual bevelling times calculation formulas that were applied in the framework database.

Table 4.16 Manual Bevelling times calculation formulas (De Swardt)

Manual Bevelling Times			
Description	**Formula**	**Unit**	**Variable Declaration**
Cutting and burr cleaning time	$\sum_{i=1}^{N}\left[\left(0.256\cdot L_i+2+\frac{L_i}{879}\cdot 60\right)\cdot Q_i\right]$	s	L_i : length of bevel section [mm] N : Number of bevels on part Q_i=2 if bevel is a double bevel section else Q_i=1
Set-up and de-set-up time	$82\cdot P+\sum_{i=1}^{N}\left[round\left(\frac{L_i}{260}\right)\cdot 21\cdot Q_i\right]$	s	P=2 if part contains a double bevel else P=1 Rounding is to the nearest integer
Repositioning time for new bevel section	$(N_s+N_d\cdot 2-1)\cdot 32$	s	N_s : Number of single bevels on part N_d :Number of double bevels on part
Handling time	$3.5\cdot D+114+196\cdot P$	s	D : Distance of bevelling area from storage [m]
Marking time	$\sum_{i=1}^{N}(0.031\cdot L_i\cdot 2+16\cdot NL_i)\cdot Q_i$	s	NL_i : Number of lines to be marked (2)

Table 4.17 shows the details of the part observed to estimate the actual time of the Manual Bevelling Process. The parts have the same characteristics with the pars fabricated with the Mechanised Bevelling Machine.

Table 4.17 Details on part to be bevelled by the Manual Bevelling Process

Material	Steel (EH36)
Thickness	80 mm
Length	100 mm
Parts needed to bevelled	5
Code	3-0-0-0-0-3-2-6-1

Table 4.18 Manual Bevelling time results

N, number of bevels on part	4
L, Length on bevels (mm)	100
Qi = 2 if bevel is double bevel else Qi = 1	1
D, Distance of storage from bevelling area (m)	10
P=2 if part contains a double bevel else P=1	1
Ns, Number of single bevel on parts	4
Nd, Number of double bevels on part	0
Nli, Number of lines to be marked	0

Table 4.18 (a) The data above shows the variables that were inputted into the formula.

Test Piece	1	2	3	4	5	Average
Cutting and burr cleaning time (s)	213	321	121	153	111	183.8
Setup and de setup time	123	142	132	155	165	143.4
Repositioning time for new bevel selection	109	101	153	141	101	121
Handling time	365	321	398	442	298	364.8
Marking time	432	321	211	243	254	292.2
Total Completion time in seconds	1242	1206	1015	1134	929	1105.2

Table 4.18 (b) The data above shows the time for each process of the manual bevelling process. The average time for each process was then found.

Fabrication Process	Excel calculation (s)	Average actual time (s)	Percentage difference (%)
Cutting and burr cleaning time	137.704	183.800	-28.675
Setup and de setup time	114.308	143.400	-22.578
Repositioning time for new bevel selection	128.000	121.000	5.622
Handling time	345.000	364.800	-5.579
Marking time	208.124	292.200	-33.609
Total Completion time in seconds	933.135	1105.200	-16.883

Table 4.18 (c) Above shows the comparison for the estimated EXCEL calculation estimated time from the framework database with the average actual time obtained from Table 4.18 (b).

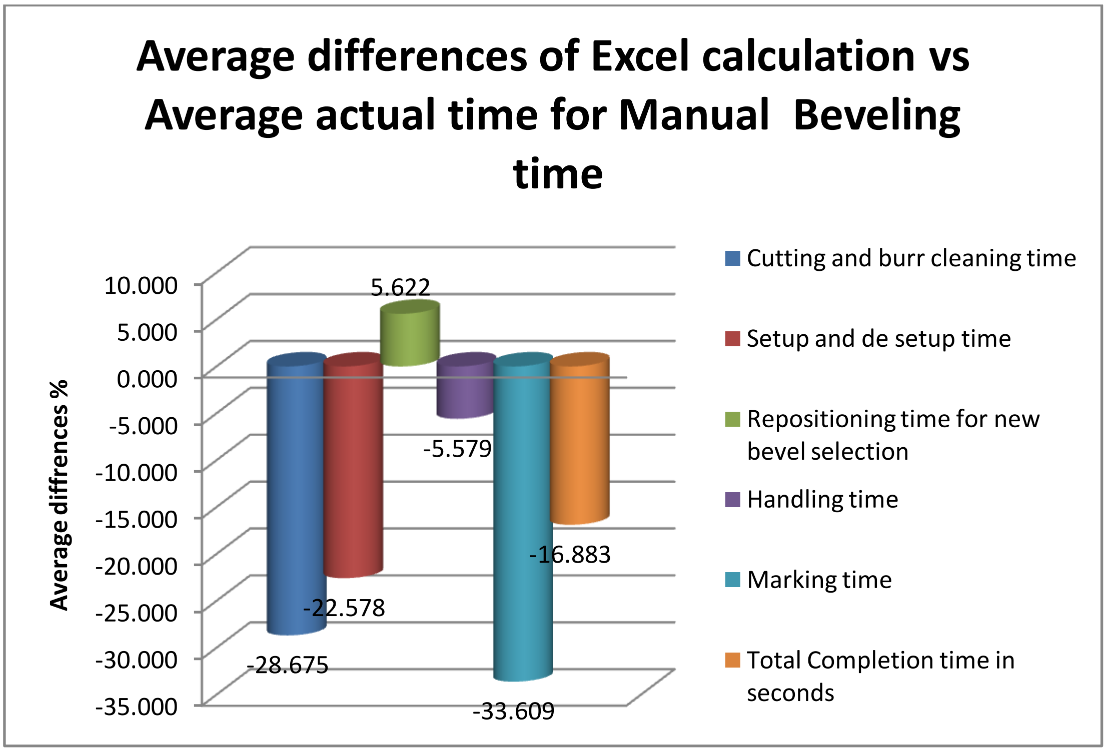


Figure 4.12 Average differences of Excel calculation vs. Average actual time for Manual Beveling time

Figure 4.12 shows the highest percentage to be the marking time which is 33.609% while the lowest is the handling time which is 5.56%. The sum average of the completion time is 16.8% which is quite tolerable to be used for time estimation. The differences again would probably depend on the skills and techniques of the cutter and grinder.

4.8 Grind Time Estimation Procedure for Bevelled Edges

Figure 4.13 shows the flow process of grinding the bevelled edges which is very important to maintain the quality of the work piece as well as the quality in the welding stages. This process uses a handheld material which is a grinder. Grinding disk is a rough disk that acts as a medium to remove metal from its original material. The grinding disk needed to be change when it exceeds its operating grinding time.

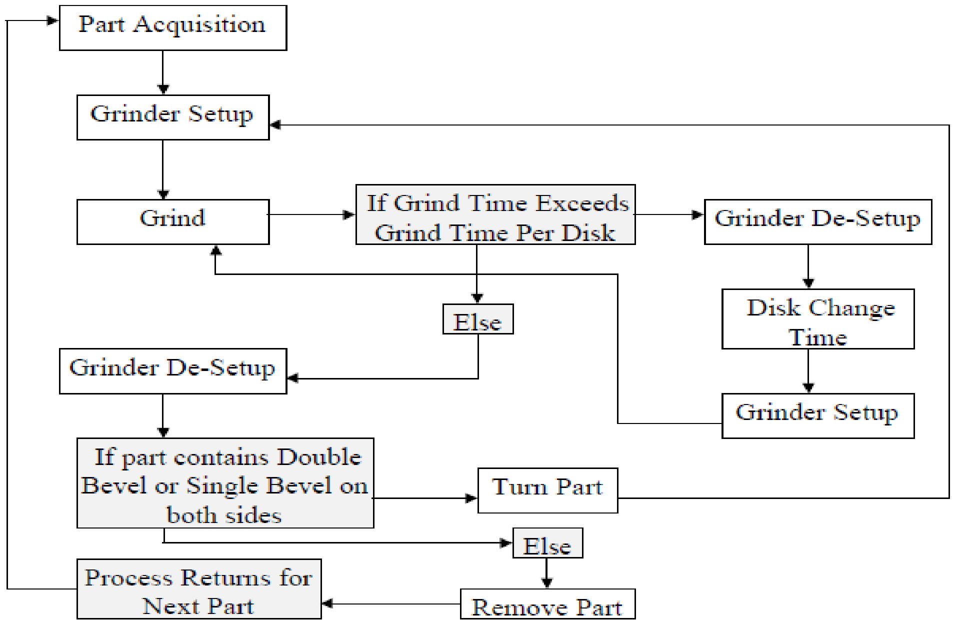


Figure 4.13 Process flow diagram for bevelled edge clean grinding (De Swardt)

Table 4.19 shows the formulas for each fabrication process in the grinding process.

Table 4.19 Clean grinding of bevelled edge time estimation formula (De Swardt)

Bevelling Sub Task Times			
Description	**Formula**	**Unit**	**Variable Declaration**
Grind time	$7.028 \cdot 10^{-4} \cdot A_1 + 52 + \frac{A_2}{3487} \cdot 60$	s	A_1 : Mechanised bevel area [mm^2] A_2 : Manual bevel area [mm^2]
Disks required	$round\left(\frac{T_{GrindingTime}}{900}\right)$		$T_{grindingTime}$:Total Grinding time on part [s] Rounding is to the higher integer
Set-up, de-set-up and disk change time	$159 \cdot Disks + 52 \cdot N_s + 104 \cdot N_d$	s	Disks = the number of grinding disks required
Handling time	$3.5 \cdot D + 114 + 196 \cdot P$	s	D : Distance of grinding area from storage. P=2 if part contains double bevel or single bevel on both sides, else P=1.

Table 4.20 shows the details of the parts to be grinded.

Table 4.20 Details on parts for grinding process

Material	Steel (EH36)
Grinded length	100
Bevel area	3 mm^2
Parts needed to be grind	5
Code	3-0-0-0-0-3-2-6-1

Table 4.21 Clean grinding of bevelled edge time estimation results

A_1, mechanized bevel area, mm^3	3
A_2, manual bevel area, mm^3	3
$T_{grinding\ time}$, Total grinding time on part (s)	1.8
Disks, the number of disks required	1
D, Distance of grinding area from storage (m)	10
P=2 if part contains a double bevel else P=1	1
Ns, Number of single bevel on parts	4
Nd, Number of double bevels on part	0

Table 4.21 (a) The data above shows the variables that are needed to be input into the formula.

Test Piece	1	2	3	4	5	Average
Grind time (s)	76	77	88	79	83	80.6
Disks required (s)	1	1	1	1	1	1
Setup De-setup time (s)	199	234	189	235	332	237.8
Handling time (s)	341	431	432	312	334	370
Total Completion time per piece (s)	617	743	710	627	750	689.4

Table 4.21 (b) The data above shows the time for each process of the grinding fabrication process. The average time for each process was then found.

Process fabrication	Excel calculation (s)	Average actual time (s)	Percentage difference (%)
Grind time	52.054	80.600	-43.039
Disks required	0.002	1.000	-199.202
Setup De-setup time	367.000	237.800	42.725
Handling time	346.000	370.000	-6.704
Total Completion time per piece	765.056	689.400	10.403

Table 4.21 (c) Above shows the comparison for the estimated EXCEL calculation estimated time from the framework database with the average actual time obtained from Table 4.20 (b).

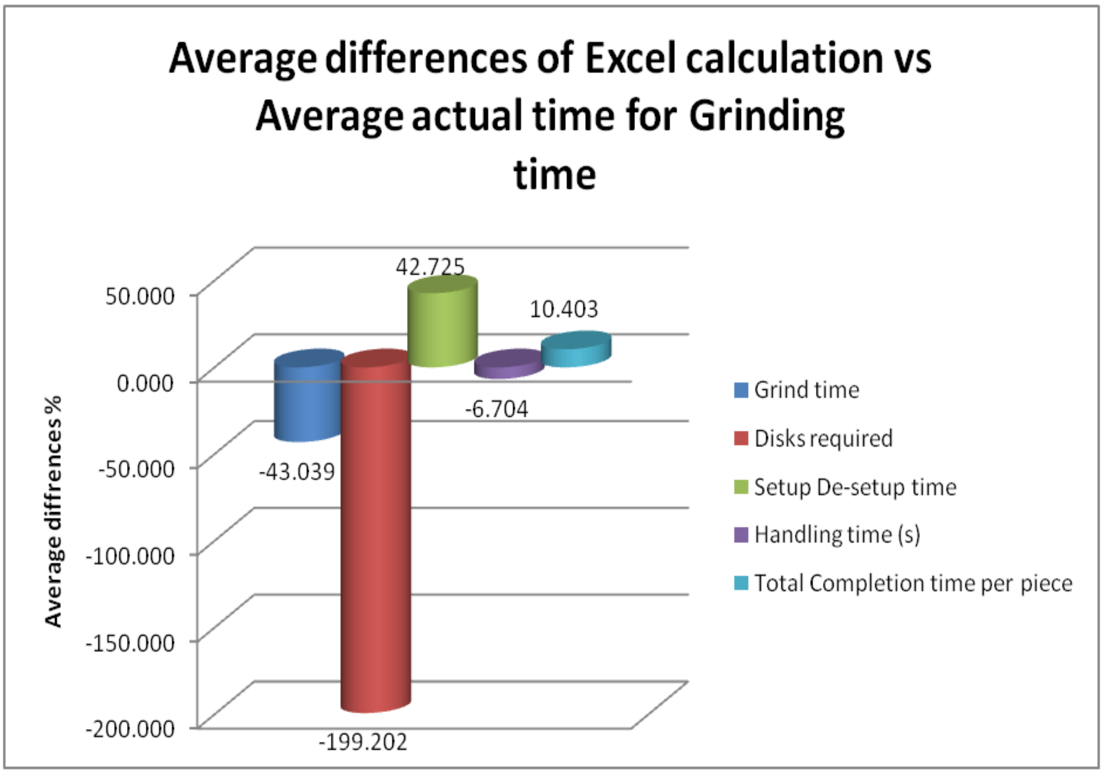


Figure 4.14 Average differences of Excel calculation vs Average actual time for grinding time

According to figure 4.14 the highest percentage would be the disks required to do the grinding which is 199.202%, followed by grind time 43.039%, Setup de set-up time 42.725%, and handling time 6.704%. The value is quite large as these shows that activities that require skills and technique by the user or handler is really hard to estimate. However the total completion time per piece percentage different is only 10.403% which is considerably quite good. Therefore the time estimation is tolerable.

4.9 Plate Bending Time Estimation

The Bending fabrication process is a fabrication process which is done by applying heat to the parts and then extorts or retorted to get the shape as designed. Back set is used as a guide to get the parts bend to as designed. Figure 4.15 shows the process flow diagram for the normal type of bending, channel type bending and curved type bending.

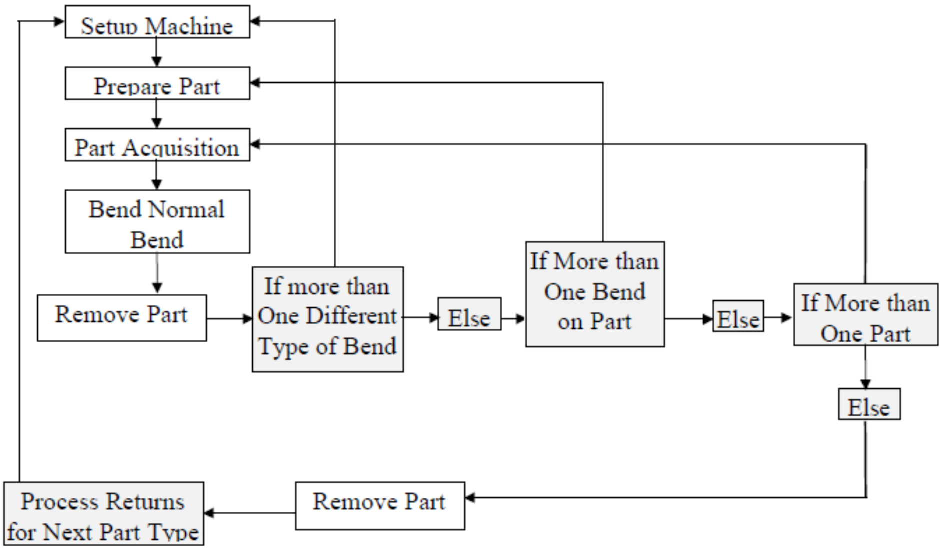


Figure 4.15 Process flow diagram for normal type bends (De Swardt)

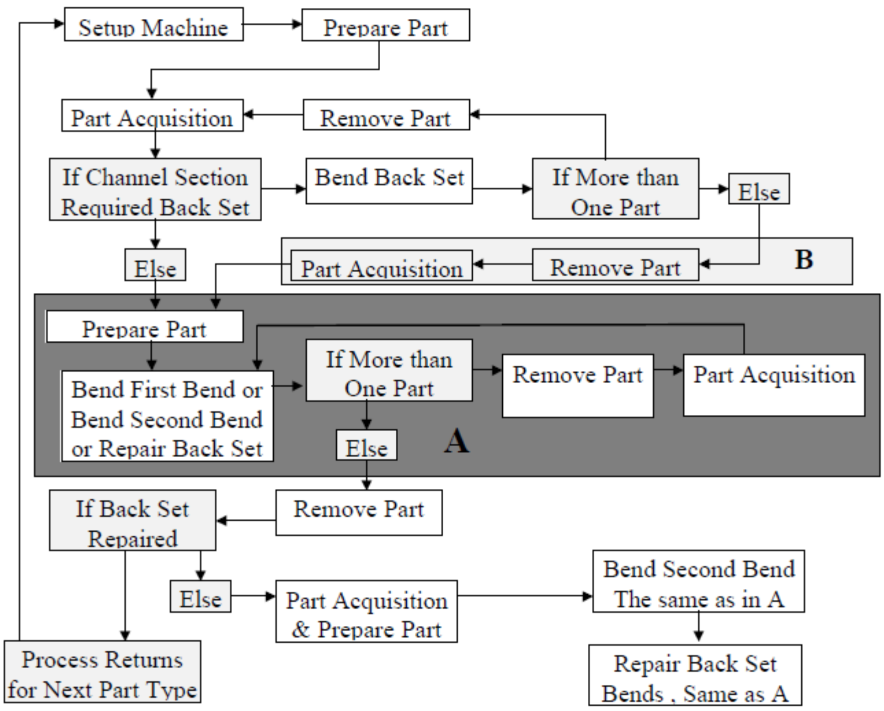


Figure 4.16 Process flow diagram for channel type bends (De Swardt)

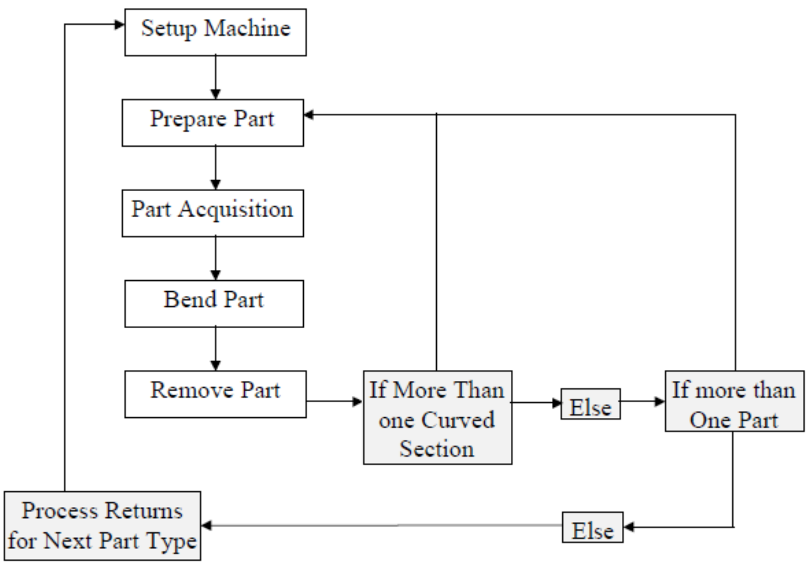


Figure 4.17 Process flow diagram for curved type bends (De Swardt)

Table 4.22 shows the formula for three different bending process.

Table 4.22 Plate Bending time estimation formulas (De Swardt)

Plate Bending Time			
Description	**Formula**	**Unit**	**Variable Declaration**
Normal bend time[4]	$N \cdot S \cdot 275 + 1465 \cdot Q + 509 \cdot S$	s	N : Number of same parts S : Number of normal bends in part Q : Number of different types of normal bends
Channel bend time[4] "Back Set" Condition	$1465 \cdot C + 1018 + 550 \cdot N + B_s \cdot (1018 + 454 \cdot N)$ $W_c - D_c > \frac{U_{dw} \cdot \sqrt{2}}{2}$	s	C : Number of Setups required for Channel section B_s=1 if back set is required else B_s=0 W_c : Width of channel [mm] D_c : Depth of Channel [mm] U_{dw} : Upper die width [mm]
Curve bend time[4]	$1465 + \sum_{i=1}^{B} N \cdot \left(661 + \frac{L_i}{31.37} \cdot 60\right)$	s	B : Number of curved sections on part L_i : Length of curved section [mm]

Table 4.23 shows details of the parts needed to be bent.

Table 4.23 Details on parts for bending fabrication process

Material	API 5L X 52
W_c: Width of channel	50mm
D_c: Depth of channel	30mm
U_{dw}: upper die width	50mm
Number of bends in part	1
Length of curvature	77.6
Parts needed to be bent	5
Code	3-0-0-0-0-1-2-5-1

Table 4.24 Plate Bending time estimation results

N, Number of same parts	1
S, Number of normal bends in part	1
Q, Number of different type of normal bends	0
C, Number of Setups required for Channel Section	1
B_s=1 if back set is required else B_s=0	1
W_c:Width of channel (mm)	50
D_c: Depth of Channel (mm)	30
U_{dw}: Upper die width (mm)	50
B, Number of curved sections on parts	1
L_i, Length of curved section	77.6

Table 4.24 (a) The data above shows the variables that are needed to be input into the formula.

Test Piece	1	2	3	4	5	Average
Normal Bend time (s)	799	834	943	743	723	808.4
Channel Bend time (s)	4431	4667	5642	4564	4111	4683
"Back set" Condition	12.5	12.5	12.5	12.5	12.5	12.5
Curve Bend time (s)	2190	2332	2011	2121	1891	2109
Total Completion time per piece (s)	7432.5	7845.5	8608.5	7440.5	6737.5	7612.9

Table 4.24 (b) The data above shows the time for each process of the bending process. The average time for each process was then found.

Fabrication Process	Excel calculation (s)	Average actual time (s)	Percentage difference (%)
Normal Bend time	784.000	808.400	-3.065
Channel Bend time	4505.000	4683.000	-3.875
"Back set" Condition	12.500	12.500	0.000
Curve Bend time	2274.422	2109.000	7.548
Total Completion time per piece	7575.922	7612.900	-0.487

Table 4.24 (c) Above shows the comparison for the estimated EXCEL calculation estimated time from the framework database with the average actual time obtained from Table 4.24 (b).

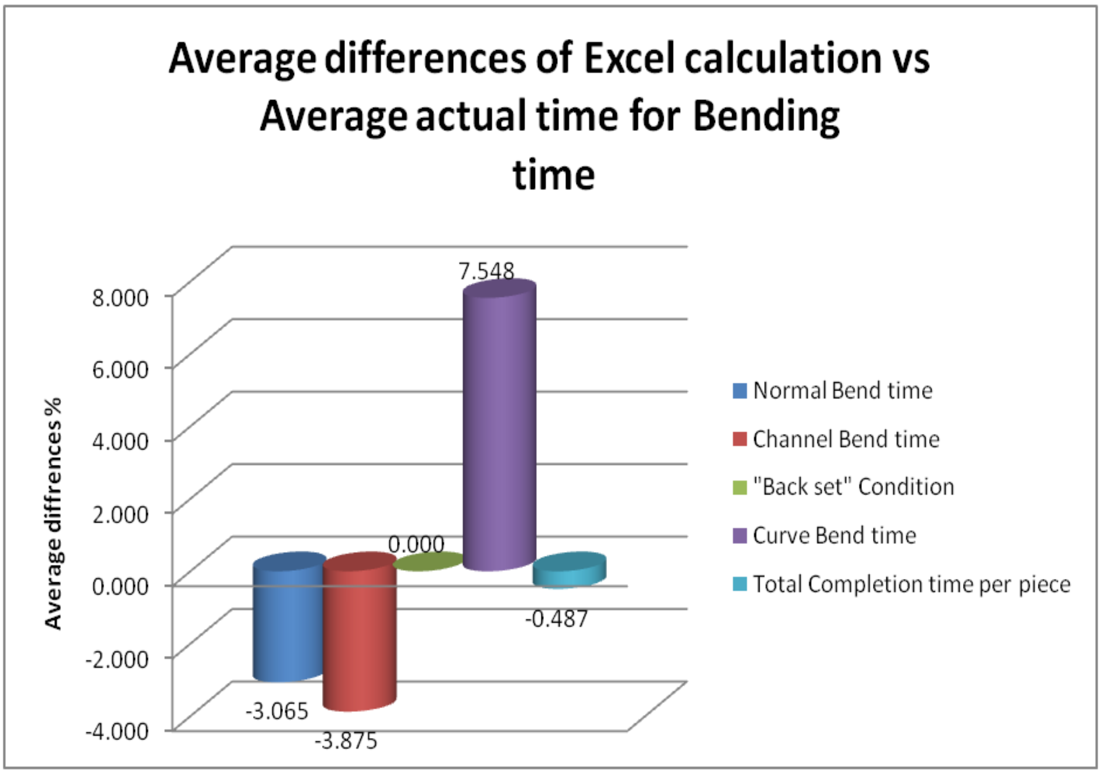


Figure 4.18 Average differences of Excel calculation vs. Average actual time for bending time

In figure 4.18, overall percentage is quite low; the highest 7.548% which is the curve bend time which is still tolerable. Therefore, the time estimation is applicable.

4.10 Fit Up Tack Welding Time Estimation

Tack welding activity is to temporarily hold the different parts for the purpose of later welding them together. It is important for the fitter to ensure that it is precise. Figure 4.19 shows the tack welding material acquisition activity flow process.

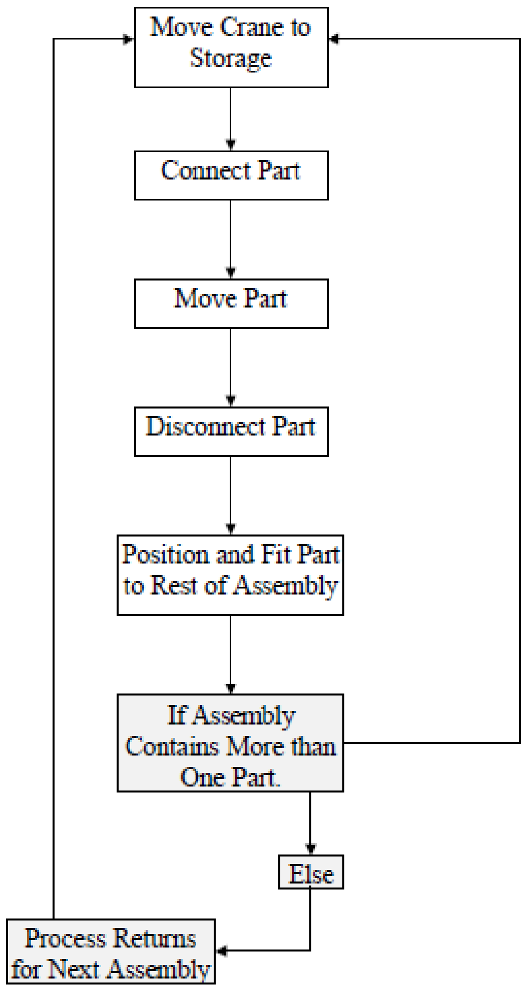


Figure 4.19 Process flow diagram for handling and tack welding (De Swardt)

Table 4.25 shows the formulas for the estimation of handling time while tack welding. Because tacking is very short duration activity, the variable only takes the duration of the time of the tack welder takes to take the equipment and welding stick from the storage to the assembly area.

Table 4.25 Tack welding material acquisition time estimation formula (De Swardt)

Material Acquisition Time			
Description	**Formula**	**Unit**	**Variable Declaration**
Handling Time	$3.5 \cdot D + 114$	s	D : Distance of assembly area from storage [m]

Table 4.26 Tack welding material acquisition time estimation results

D, Distance of assembly area from storage (m)	10

Table 4.26 (a) The data above shows the variables that are needed to be input into the formula.

Test Piece	1	2	3	4	5	Average
Handling time (s)	112	132	121	121	113	119.8
Total Completion time per piece	112	132	121	121	113	119.8

Table 4.26 (b) The data above shows the time for each process of the tacking process. The average time for each process was then found.

Process Fabrication	Excel calculation (s)	Average actual time (s)	Percentage difference (%)
Handling time	149.000	119.800	21.726
Total Completion time in seconds	149.000	119.800	21.726

Table 4.26 (c) Above shows the comparison for the estimated EXCEL calculation estimated time from the framework database with the average actual time obtained from Table 4.26 (b).

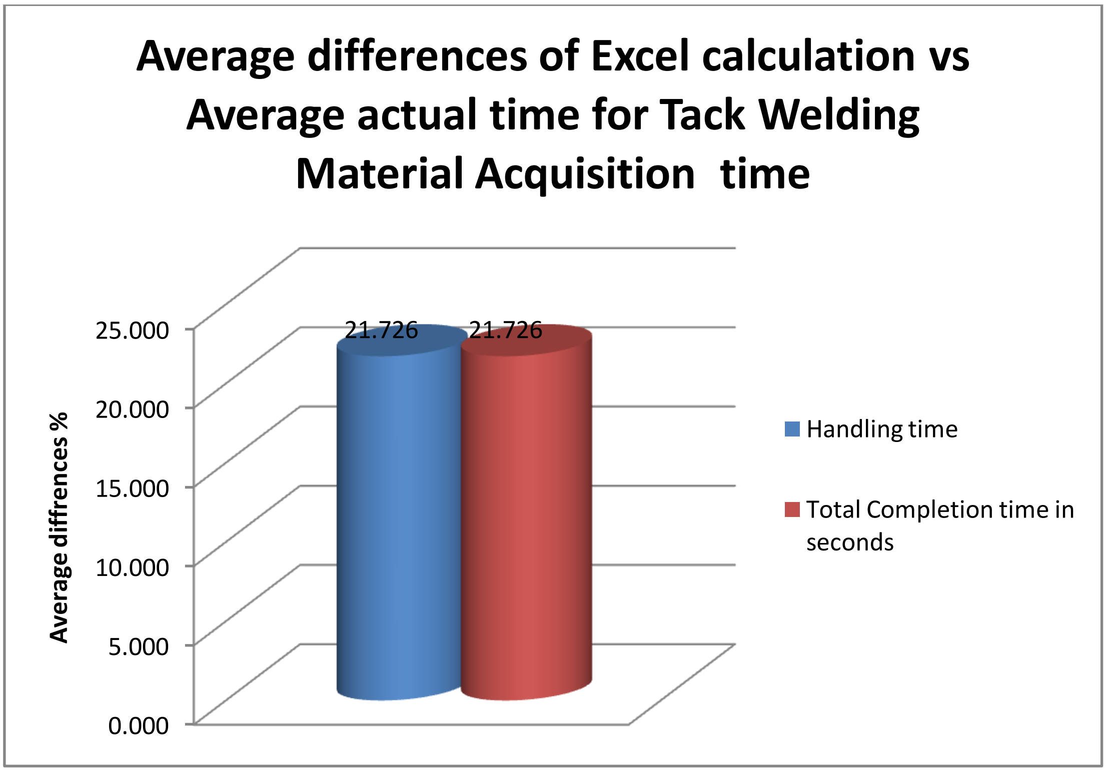


Figure 4.20 Average differences of Excel calculation vs. Average actual time for grinding time

In figure 4.20, the data shows an average difference which is 21.768%. The high difference is probably because this activity depends on the technique and skills of the fitter. The fitter's job also will become much slower when the item that is needed to be assembled are very challenging.

4.11 Basic Tack Welding Time Estimation

The fit up process were preceded by tack welding where the temporary parts were removed after the tack welding of the fixed parts was done.

4.27 Table Basic tack welding estimation time (De Swardt)

Tack Welding Time			
Description	**Formula**	**Unit**	**Variable Declaration**
Basic tack welding time	$O_p \cdot (0.325 \cdot w + 0.157 \cdot L + 567 \cdot C + 4.783 \cdot T)$	s	W : Weight of part [kg] $0.2 \leq w \leq 13190$ L : Length of joining line [mm] $127 \leq L \leq 11132$ T : Material Thickness [mm] C=1 if part has in plane curve else C=0 O_p=2 if only one operator[5] is working else O_p =1
Additional trimming time	$Tbasic \cdot 0.274$	s	Tbasic : Basic assembly time [s]

Table 4.28 shows the parts that were fit up by temporary supports. This process will ensure that the part is then fixed and the temporary supports were then removed

Table 4.28 Details on parts for tack welding fabrication process

Material	Steel (EH36)
Length	123.6
Material Thickness	30
Parts needed to be tack	5
Code	3-0-0-0-0-3-2-6-1

Table 4.29 Tack welding time estimation results

W, weight of part (kg) 0.2<L<11132	7.8
L, Length of joining line (mm)	123.6
T, Material Thickness (mm)	30
C, 1 if part has in plane curve else C = 0	0
O_p = 2 if only one operator is working else O_p=1	2
T_{basic}, basic assembly time (s)	300

Table 4.29 (a) The data above shows the variables that are needed to be input into the formula.

Test Piece	1	2	3	4	5	Average
Basic tack welding time (s)	321	333	343	323	354	334.8
Additional trimming time (s)	45	56	81	81	43	61.2
Total Completion time per piece (s)	366	389	424	404	397	396

Table 4.29 (b) The data above shows the time for each process of the tacking process. The average time for each process was then found.

Fabrication Process	Excel calculation (s)	Average actual time (s)	Percentage difference (%)
Basic tack welding time	330.860	334.800	-1.184
Additional trimming time	82.200	61.200	29.289
Total Completion time per piece	413.060	396.000	4.217

Table 4.29 (c) Above shows the comparison for the estimated EXCEL calculation estimated time from the framework database with the average actual time obtained from Table 4.29 (b).

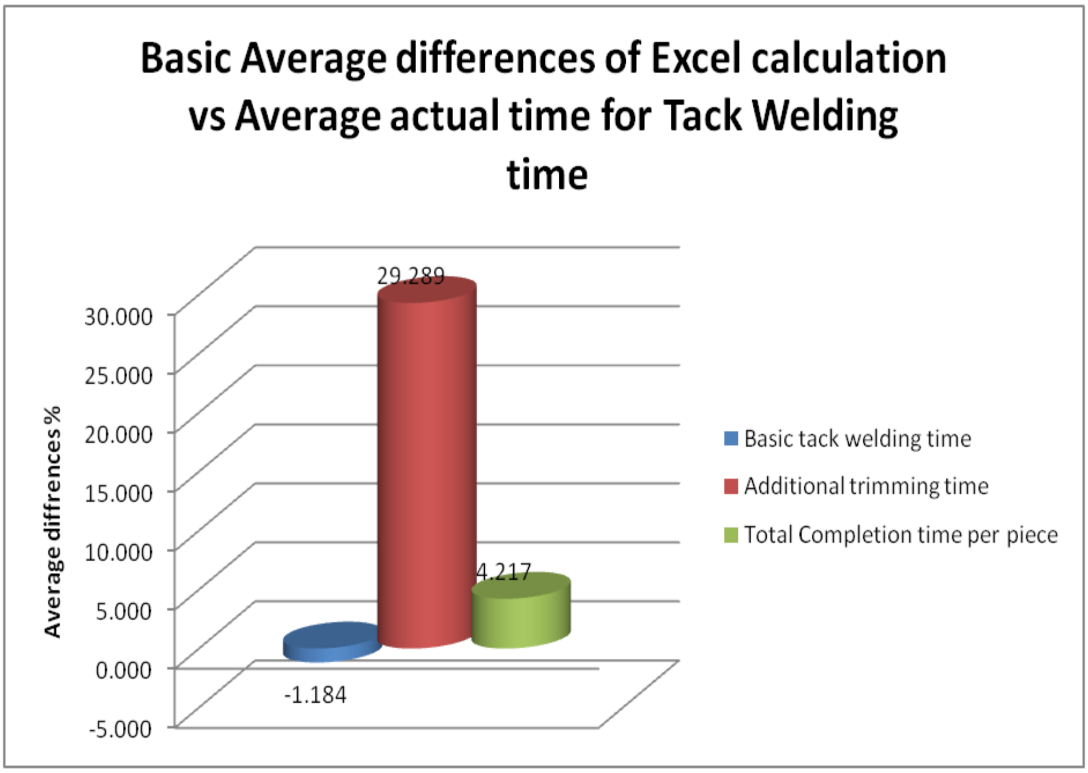


Figure 4.21 Basic Average differences of Excel calculation vs Average actual time for Tack welding time

Based on figure 4.21 the data shows an average difference which is 29.287% for additional trimming time. The high difference is probably because this activity which requires a considerate coordination between the welder and the grinder. The grinder job also will become much slower when the item that is needed to be assembled is very challenging.

4.12 Welding Time Estimation

Welding is the fabrication process after the fit up and tacking is completed. In this activity, only the Flux Cored Arc Wired (FCAW) is compared.

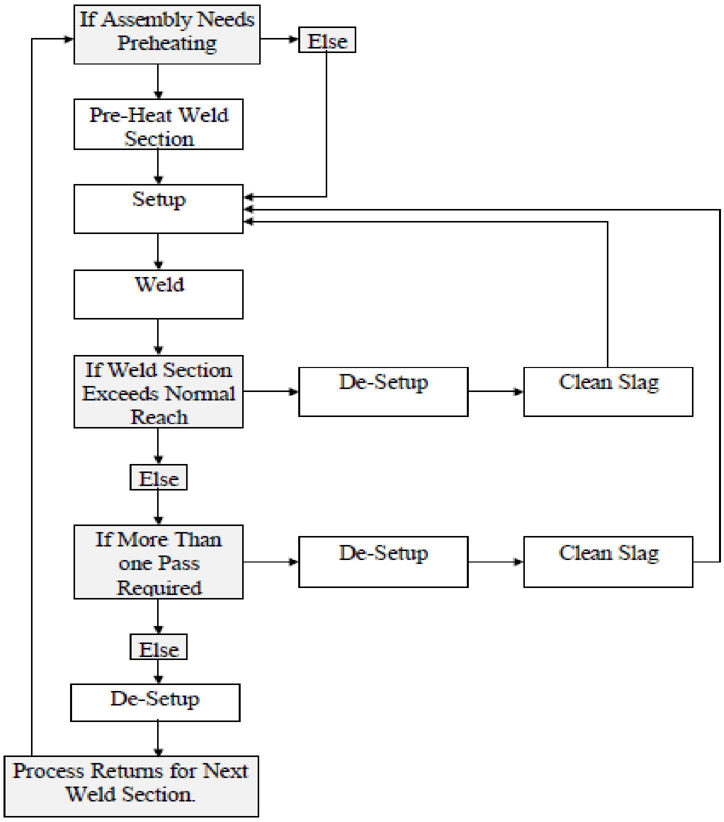


Figure 4.22 Process flow diagram for flux core arc welding (De Swardt)

Table 4.30 shows the Fettling time estimation formulas. Runs refer to the time that was covered to weld the specific length.

Table 4.30 Fettling time estimation formulas (De Swardt)

Description	Constant/Formula	Unit	Variable Declaration
Runs	$round\left(\frac{A}{AreaCoveredPerRun}\right)$		A : Cross sectional area of weld section [mm^2]
Fettling Time	$\frac{Runs \cdot L}{878} \cdot 60$	s	L : Length of weld section [mm]

Table 4.31 shows the details of the parts to be welded. There were three test pieces both consist of two parts that have already been fit up.

Table 4.31 Details on parts for welding fabrication process

Material	Steel (EH36)
Welding length	66
Weld section area	28 mm^2
Parts needed to be weld	3
Code	3-0-0-0-0-3-2-6-1

Table 4.32 Fettling Time estimation results

A, Cross sectional area of weld section (mm^2)	28
L, Length of weld section (mm)	65

Table 4.32 (a) The data above shows the variables that were inputted into the formula.

Test Piece	1	2	3	Average
Runs	1	2	1	1.333333
Fettling time	2	2	2	2
Total Completion time in seconds	3	4	3	3.333333

Table 4.32 (b) The data above shows the time for each process of the welding process. The average time for each process was then found.

Fabrication Process	Excel calculation (s)	Average actual time	Percentage
Runs	0.431	1.333	-102.326
Fettling time	1.913	2.000	-4.424
Total Completion time per piece	2.344	3.333	-34.843

Table 4.32 (c) Above shows the comparison in percentage differences for the estimated EXCEL calculation estimated time from the framework database with the average actual time obtained from Table 4.32 (b).

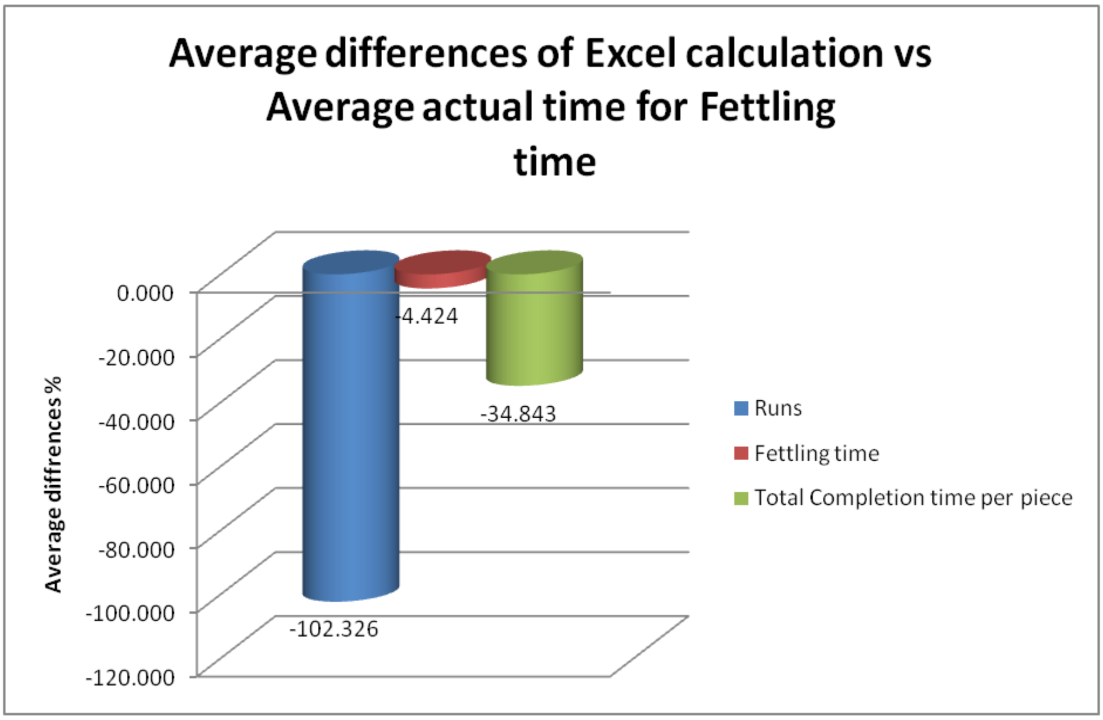


Figure 4.23 Average differences of Excel calculation vs Average actual time for Fettling time

Referring to figure 4.23 there is 102.326% differences for the runs in welding and 4.424% differences in fettling time. The high difference of the runs are again depends on the technique and skills of the welder which the welder needs to have steady hand in applying the weld.

4.13 Weld Set-up and De-Set-up Estimation Time

Weld Set-up and de set-up time refer to the time taken to prepare for the next fabrication process task and the time taken to finish the process.

Table 4.33 Setup and de-set-up time estimation formulas (De Swardt)

Description	Constant/Formula	Unit	Variable Declaration
Runs	$round\left(\frac{A}{AreaCoveredPerRun}\right)$		A : Cross sectional area of weld section[mm^2]
StartStop	$round\left(\frac{L}{833}\right)$		Rounding is to the higher integer
"Set-up" and "De-Set-up" Time	$Runs \cdot StartStop \cdot (11+5)$	s	

Table 4.34 shows the details of the parts to be welded. There were three test pieces both consist of two parts that have already been fit up.

Table 4.34 Details on parts for welding fabrication process

Material	Steel (EH36)
Welding length	66
Weld section area	28 mm^2
Parts needed to be weld	3
Code	3-0-0-0-0-3-2-6-1

Table 4.35 Setup and de-set-up time estimation results

A, Cross sectional area of weld section (mm^2)	28
L, Length of weld section (mm)	65

Table 4.35 (a) The data above shows the variables that are needed to be input into the formula.

Test Piece	1	2	3	Average
Runs	11	13	9	11
StartStop	4	3	4	3.666667
"Set-up" and "De-Set-up" Time	23	34	21	26
Total Completion time per piece	38	50	34	40.66667

Table 4.35 (b) The data above shows the time for each process of the welding setup and de-setup process. The average time for each process was then found.

Fabrication Process	Excel calculation (s)	Average actual time (s)	Percentage difference (%)
Runs	0.431	11.000	-184.926
StartStop	2.017	3.667	-58.058
"Set-up" and "De-Set-up" Time	13.900	26.000	-60.649
Total Completion time per piece	15.917	40.667	-87.479

Table 4.35 (c) Above shows the comparison in percentage differences for the estimated EXCEL calculation estimated time from the framework database with the average actual time obtained from Table 4.35 (b).

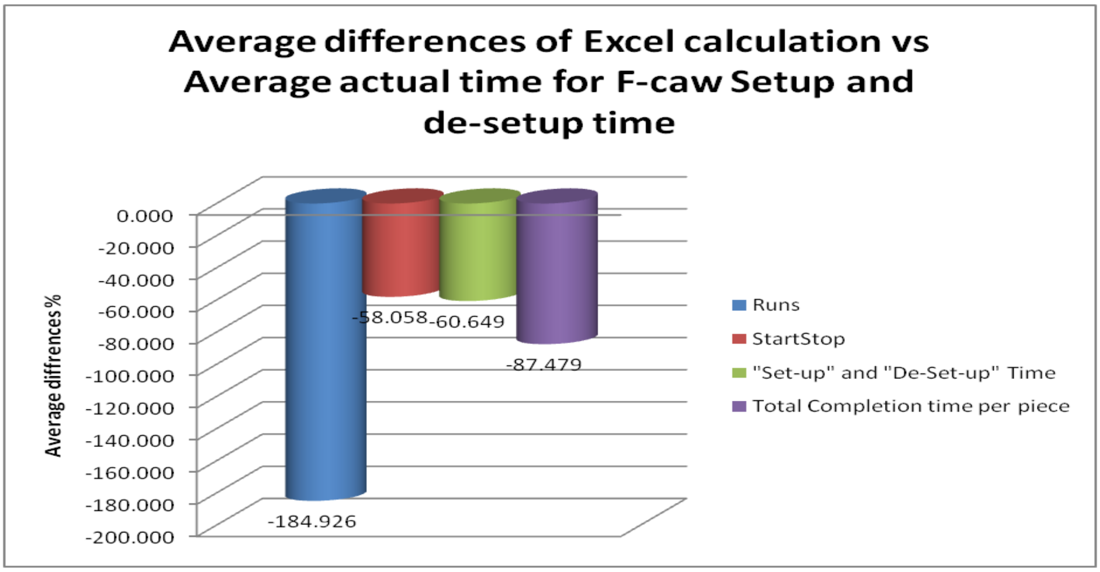


Figure 4.24 Average differences of Excel calculation vs. Average actual time for F-caw Setup and de-setup time

Referring to figure 4.24 there is 184.926% differences for the runs in welding. Followed by Set up and de set up time which is 60.6649%. The high difference of the runs are again depends on the technique and skills of the welder which the welder needs to have steady hand in applying the weld.

4.14 Back Gouge Time Estimation

Gouging is the fabrication process which a welded section needed to be removed. Figure 4.25 shows the procedure for the gouging process.

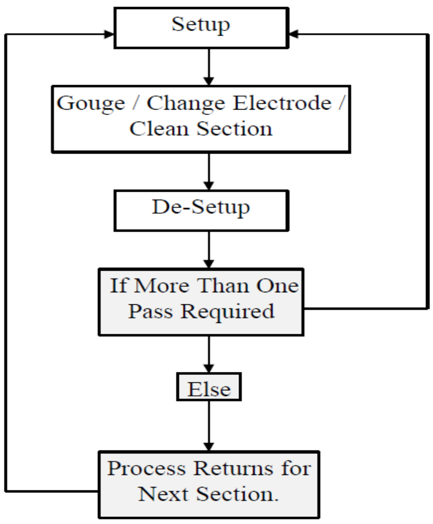


Figure 4.25 Process flow diagram for back gouging (De Swardt)

Table 4.36 shows the formulas for estimating the fabrication time of gouging fabrication process.

Table 4.36 Back gouging time estimation formulas (De Swardt)

Gouging Process Time			
Description	**Constant/Formula**	**Unit**	**Variable Declaration**
Gouging time	$67 + N \cdot (0.272 \cdot L + 135)$	s	N : Number of passes required to obtain required gouging depth L : Length of weld section to be back gouged [mm]
Additional Gouging Parameters			
Area Removed	$N \cdot 101.96$	mm^2	
Gouging Rods Required	$round\left(\frac{L \cdot N}{511}\right)$		Round to nearest integer

Table 4.37 shows the details of the parts to be welded. There were three test pieces both consist of two parts that have already been fit up

Table 4.37 Details on parts for gouging fabrication process

Material	Steel (EH36)
Weld section area	28 mm^2
Parts needed to be weld	3
Code	3-0-0-0-0-3-2-6-1

Table 4.38 Back gouging time estimation results

Process Details	Test piece 1	Test piece 2	Test piece 3
N, Number of passes required to obtain required gouging depth	1.000	1.000	1.000
L, Length of weld section to be back gouged (mm)	460.000	670.000	995.000

Table 4.38 (a) The data above shows the variables that were inputted into the formula. There were three set pieces with different lengths.

Excel Calculation based on 3 different set piece				
Test piece	1	2	3	Average
Gouging time	327.120	384.240	472.640	394.6667
Area removed	101.960	101.960	101.960	101.96
Gouging rods required	0.900	1.311	1.947	1.386171
Total Completion time in seconds	429.980	487.511	576.547	498.0128

Actual time				
Test piece	1.000	2.000	3.000	Average
Gouging time	321.000	431.000	301.000	351
Area removed	101.960	101.960	101.960	101.96
Gouging rods required	1.000	1.000	2.000	1.333333
Total Completion time in seconds	424.960	535.960	407.960	456.2933

Table 4.38 (b) The data above shows the estimated and actual time for each test pieces of the gouging process. The average time for each process was then found.

Process Fabrication	Average Excel calculation (s)	Average actual time (s)	Percentage difference (%)
Gouging time	394.667	351.000	11.712
Area removed	101.960	101.960	0.000
Gouging rods required	1.386	1.333	3.886
Total Completion time	498.013	456.293	8.743

Table 4.38 (c) Above shows the comparison in percentage differences for the estimated EXCEL calculation estimated time from the framework database with the average actual time obtained from Table 4.37 (b).

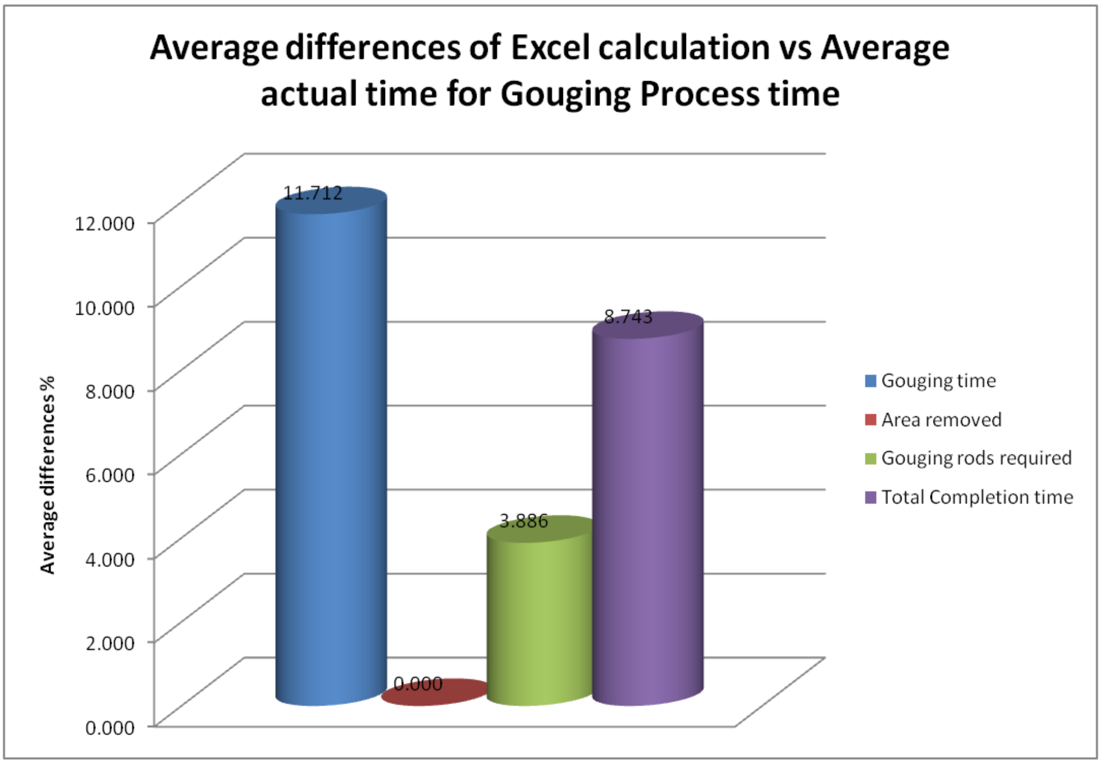


Figure 4.26 Average differences of Excel calculation vs. Average actual time for Gouging Process time

From Figure 4.26 it shows that the highest average differences are the gouging time followed by the area removed. The differences are quite considerable. The speed of gouging also depends on the technique and skills of the gouger. But speed does not necessarily good as quicker work might give the gouging to be too deep or too shallow.

4.15. Back Grinding Estimation Time

Back grinding is the grinding activity to remove slugs and debris after the gouging process. Figure 4.27 shows the process flow diagram for back grinding.

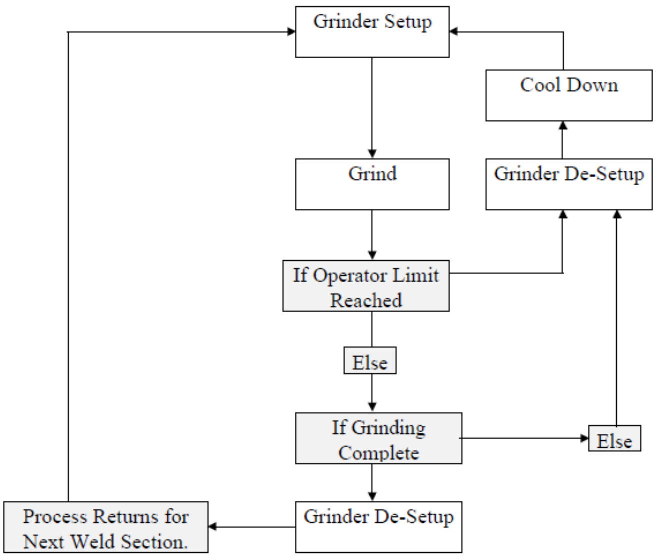


Figure 4.27 Process flow diagram for back grinding (De Swardt)

Table 4.39 shows the formulas for the back grinding activity.

Table 4.39 Back grinding time estimation Formulas (De Swardt)

Back Grinding Process Time			
Description	**Constant/Formula**	**Unit**	**Variable Declaration**
Back grinding time	$\frac{L}{915.56 \cdot D^{-0.7922}} \cdot 60$	s	L : Length of weld section to be back ground [mm] D : Depth to be back ground [mm]
StartStop	$round\left(\frac{T_{grind}}{364}\right)$		T_{grind} : Back grinding time Rounding is to the higher integer
Non grinding time	$\frac{L}{885 \cdot D^{-0.7922}} \cdot 60 + 52 \cdot StartStop$	s	

Table 4.40 shows the details of the parts to be welded. There were three test pieces both consist of two parts that have already been fit up.

Table 4.40 Details on parts for welding fabrication process

Material	Steel (EH36)
Welding length	210
Depth to be back ground	3.6 mm
Sections to be grind	3
Code	3-0-0-0-0-4-2-6-1

Table 4.41 Back grinding time estimation results

L, Length of weld section to be back ground (mm)	210
D, Depth to be back ground (mm)	3.6
T_{grind}, Back grinding time	100

Table 4.41 (a) The data above shows the variables that were inputted into the formula.

Test Piece	1	2	3	Average
Back grinding time	1	0.5	0.5	0.666667
StartStop	0.2	0.2	0.5	0.3
Non grinding time	45	55	47	49
Total Completion time in seconds	46.2	55.7	48	49.96667

Table 4.41 (b) The data above shows the time for each process of the grinding process. The average time for each process was then found.

Fabrication Process	Excel calculation (s)	Average actual time (s)	Percentage difference (%)
Back grinding time	0.499	0.667	-28.799
StartStop	0.275	0.300	-8.795
Non grinding time	39.276	49.000	-22.030
Total Completion time per piece	40.050	49.967	-22.033

Table 4.41 (c) Above shows the comparison in percentage differences for the estimated EXCEL calculation estimated time from the framework database with the average actual time obtained from Table 4.41 (b).

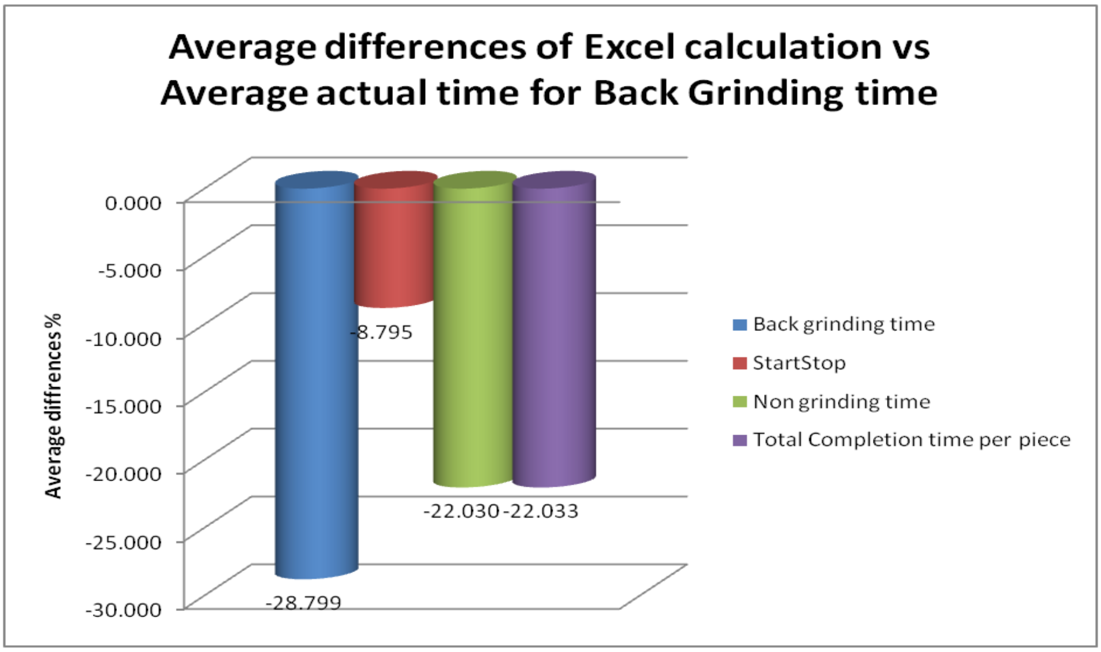


Figure 4.28 Average differences of Excel calculation vs. Average actual time for Back Grinding time

In figure 4.28 the highest average differences is the back grinding time which is 28.799% followed by the non grinding time which 22.030% and Start Stop period 8.795%. The speed of the activity largely depends on the technique and skills of the grinder handling the tool.

4.16. Surface Grinding and Polish Estimation Time

Surface grinding and polishing activity is the fabrication process where a surface is required to be polished into certain required roughness. The activity was done by using a hand held polishing device where a brush is rotated to remove fine metal on the surface. Figure 4.29 shows the process flow diagram for the surface grinding.

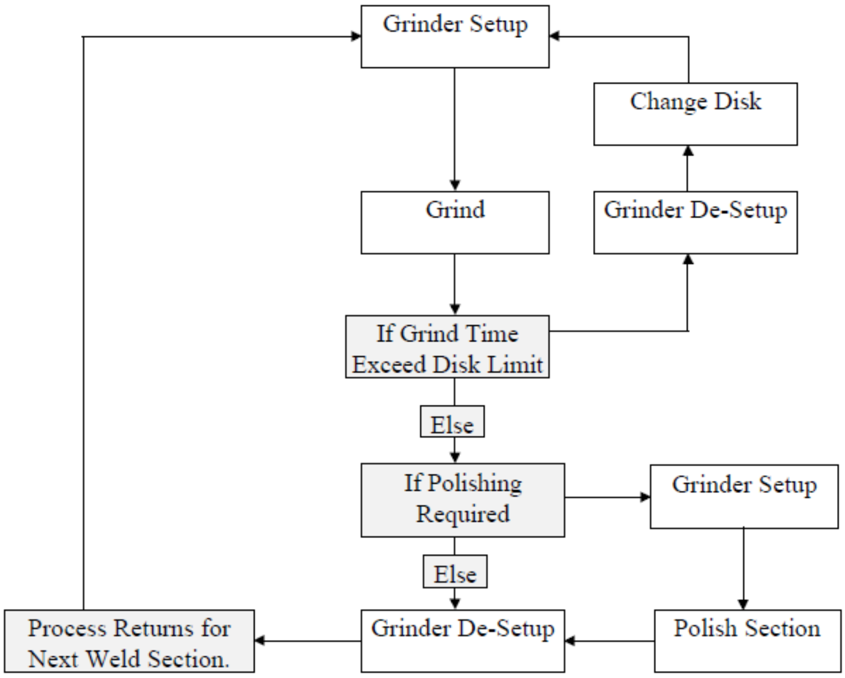


Figure 4.29 Process flow diagram for surface finish grinding (De Swardt)

Table 4.42 shows the formulas for the surface finish grinding.

Table 4.42 Surface finishing time estimation formulas (De Swardt)

Blend Grinding Process Times			
Description	**Formula**	**Unit**	**Variable Declaration**
Grind Time	$\frac{L \cdot W}{3425} \cdot 60$	s	L : Length of weld section to be surface finished [mm] W: Width of weld section on surface[mm]
Polish time	$\frac{L \cdot W}{14200} \cdot 60$	s	
Start Stop	$round\left(\frac{T_{Grind}}{900}\right)$		Round to higher integer T_{grind} : Surface grinding time
Non grinding time	$(30+22+107) \cdot StartStop$	s	
Non polishing time	30+22	s	

Table 4.43 shows the details of the parts for the gouging process.

Table 4.43 Details on parts for surface grinding process

Material	Steel (EH36)
Welding length to be back gouged	210 mm
Width of weld section	3 mm
Depth	50 mm
Parts needed to be weld	3
Code	3-0-0-0-0-3-2-6-1

Table 4.44 Surface finishing time estimation results

L, Length of weld section to be back ground (mm)	210
W, Width of weld section on surface (mm)	3
D, Depth to be back ground (mm)	50
T_{grind}, Back grinding time	100

Table 4.44 (a) The data above shows the variables that were inputted into the formula.

Test piece	1	2	3	Average
Grind time	12	9	9	10
Polish time	1	1	1	1
Start Stop	0.2	0.2	0.2	0.2
Non grinding time	156	134	154	148
Non Polishing time	34	54	43	43.66667
Total Completion time per piece	203.2	198.2	207.2	202.8667

Table 4.44 (b) The data above shows the time for each process of the surface grinding process. The average time for each process was then found.

Fabrication Process	Excel calculation (s)	Average actual time (s)	Percentage difference (%)
Grind time	11.036	10.000	9.854
Polish time	0.634	1.000	-44.828
Start Stop	0.111	0.200	-57.143
Non grinding time	159.000	148.000	7.166
Non Polishing time	52.000	43.667	17.422
Total Completion time per piece	222.781	202.867	9.357

Table 4.44 (c) Above shows the comparison in percentage differences for the estimated EXCEL calculation estimated time from the framework database with the average actual time obtained from Table 4.44 (b).

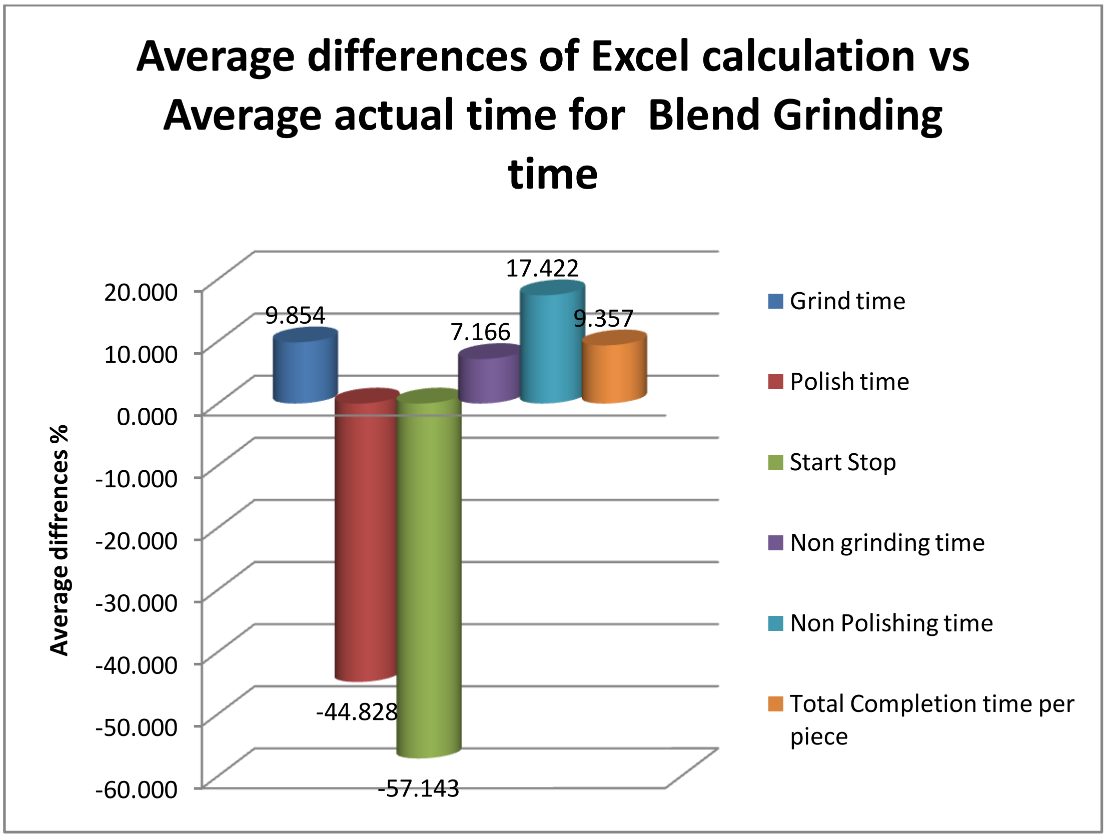


Figure 4.30 Average differences of Excel calculation vs. Average actual time for Blend grinding time

In Figure 4.30 the highest average differences is the back grinding time which is 57.143% followed by the polish time which 44.828%, non polishing time 17.442%, grind time 9.854% and lastly non grinding time which is 7.116%. The speed of the activity largely depends on the technique and skills of the grinder handling the tool

4.17. Estimating Electrode Change Estimation Time

Electrode change process is the process of inserting the electrode rod and removing the rod after it have been used. There are no specific process flow for this activity. Table 4.45 shows the formulas for changing electrode time.

Table 4.45 Electrode change time estimation formula (De Swardt)

Electrode Change Time			
Description	**Constant/Formula**	**Unit**	**Variable Declaration**
Total Electrode Change Time	$\frac{M_{electrode}}{M_{Pack}} \cdot 685$	s	$M_{electrode}$: Mass of electrode required to fill all weld sections [kg] M_{pack} : Mass of electrode per roll [kg]

Table 4.46 shows the details for the electrode change process. Electrode

Table 4.46 Details on parts for electrode change process

Material	FCAW Electrode
Required electrode mass for all weld section	6 kg
Mass of electrode per roll	0.3 kg
Test pieces for welding process	5

Table 4.47 Estimating Electrode Change Time Results

$M_{electrode}$, Mass of electrode required to fill all weld (kg)	6.000
M_{pack}, Mass of electrode per roll(kg)	0.300

Table 4.47 (a) The data above shows the variables that were inputted into the formula.

Test piece	1	2	3	4	5	6	Average
Total Electrode change time	22	21	19	23	21	32	23
Total Completion time in seconds	22	21	19	23	21	32	23

Table 4.47 (b) The data above shows the time for each process of the electrode change process. The average time for each process was then found.

Fabrication Process	Excel calculation (s)	Average actual time	Percentage
Total Electrode change time	20.000	23.000	-13.953
Total Completion time	20.000	23.000	-13.953

Table 4.47 (c) Above shows the comparison in percentage differences for the estimated EXCEL calculation estimated time from the framework database with the average actual time obtained from Table 4.47 (b).

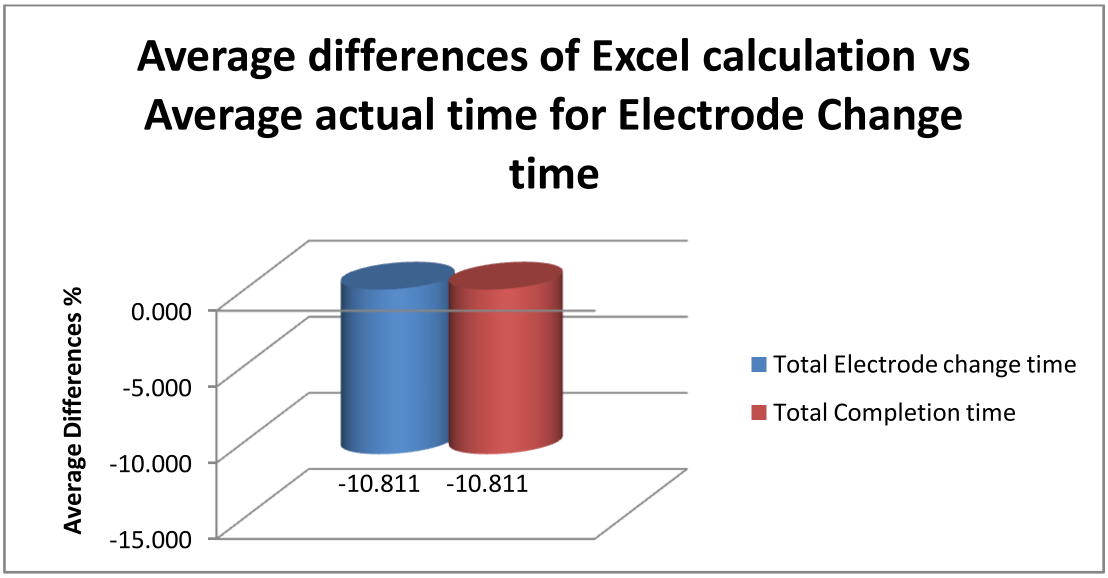


Figure 4.31 Average differences of Excel calculation vs. Average actual time for Electrode Change time

In Figure 4.31the average differences for the electrode change time is 10.811%. This activity largely depends on the welder's skills and technique. Therefore their level of welding skills is quite challenging to be estimated.

4.18. Overall Results

All the results of the fabrication process are shown in Table 4.48 and Figure 4.32 shows the percentage differences between EXCEL calculation and actual average production of fabrication process.

Table 4.48 Results for EXCEL calculation vs. Actual time for Large Fabrication Assembly Processes

Fabrication Process	EXCEL VBA Calculation time Per piece (s)	Actual Average Production Time per piece (s)	Percentage Differences (%)
Flame Cutting	132855.3	126651.2	**4.8**
Burr removal	301.7	469.6	**-43.5**
Mechanised Bevelling	1038.967	1111.8	**-6.8**
Manual Bevelling	933.1	1105.2	**-16.9**
Grinding time	765.1	689.4	**10.4**
Bending	7575.9	7621.9	**-0.6**
Fit up Tack Welding	149	119.8	**21.7**
Basic Tack Welding	413.1	396.1	**4.2**
Fetling	2.3	3.3	**-35.7**
F-CAW Setup and de-setup time	15.917	40.667	**-87.5**
Gouging	498.1	456.3	**8.8**
Back Grinding	40.1	49.9	**-21.8**
Surface Grinding	222.8	202.8	**9.4**
Electrode change	20	22.3	**-10.9**
Total Average			**-11.7**

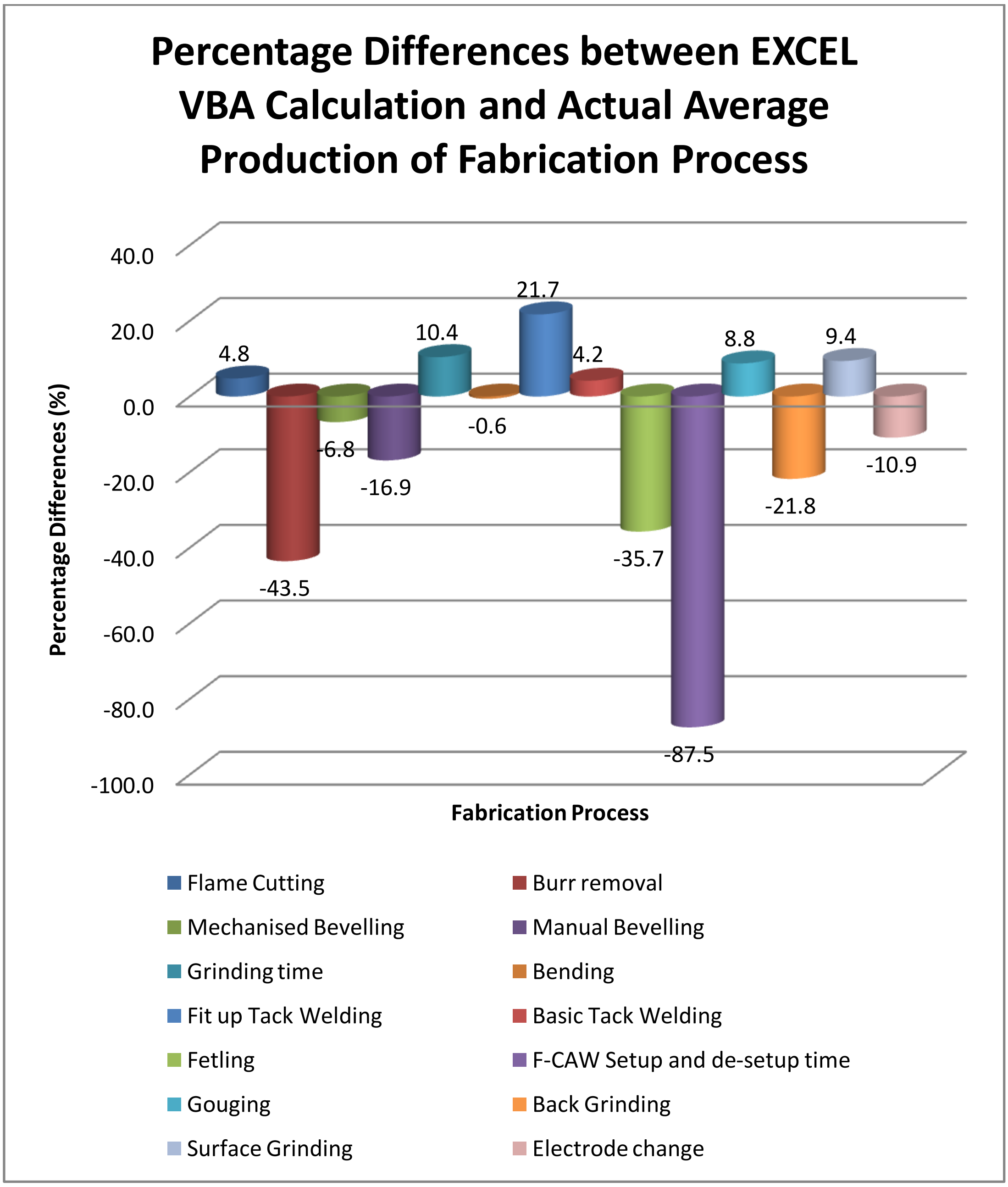


Figure 4.32 Differences of production time in Large Fabrication Assembly Processes

4. 17. Summary of the results

The followings are the summary of the results

- In Table 4.1 shows the parts classification coding based on parts design attributes.
- In Table 4.2 and Table 4.3 the parts that were covered in the structure of the subsea were identified and classified to their respective shapes. The parts were identified in their classes that can be seen coded by the numbers.
- The database has been successfully developed as in Table 4.6 (Appendix A). The parts have been digit coded and the image of the parts can be viewed in the technical drawings attached in the appendices. There are 189 parts that have been coded and sufficient enough to cover the basic parts that are related to large manufacturing assembly.
- The EXCEL calculation and the real application of fabrication activities were compared. From the result, it can be said that the activities that largely depends on the users technique and skills of using their tools gives about more than 30% average differences compared to the value calculated in EXCEL. Whereas automated machinery like the CNC Flame profile gives off a very low percentages of average differences. This shows that it is more challenging to estimate fabrication time when the fabrication depends on skills and technique.
- Even though the percentage is big, the time taken can be considered not too high where those activities are mostly required to finish in quick time succession.

CHAPTER 5

CONCLUSION & RECCOMENDATION

5.0 CONCLUSION

The objective of the study is to use Group Technology approach to estimate fabrication time of Subsea Manifold. The study has successfully developed a systematic approach of estimating production time. The approach adopted a production estimation model with added improvement of database development using the EXCEL spreadsheet. Using the application of Group Technology, parts and components in the manufacturing processes were classified according to its geometrical and technological features. The parts classification coding is based on the Opitz system which the classification were based on the design attributes. The framework database contains 189 parts of the Subsea Manifold have been identified and classified which covers the basics of fabrication process for Large Manufacturing Assembly. The Group Technology framework was shown as in Table 4.1 and the parts database as in Table 4.6. The basic part of the calculation have been assessed which was by comparing the estimated fabrication time with the actual fabrication time of GWF Subsea Manifold fabrication. From the results, it can be said that the activities that largely depends on the users technique and skills of using their tools gives about more than 30% average differences compared to the value calculated in EXCEL. Whereas automated machinery like the CNC Flame profile gives off a very low percentages of average differences. This shows that it is more challenging to estimate fabrication time when the fabrication depends on skills and technique. Even though the percentage differences are big, however considering the time taken, the differences are not too high where those activities are mostly required to finish in quick time succession. Taking support time in consideration where the difference is quite low, it can be said that the application is very good at estimating production time.

5.1 RECCOMENDATION

To get the optimum results of the framework development, the database should incorporate Visual Basic Applications in the EXCEL software which will provide ease of access to the information. Visual Basic Applications requires a substantial knowledge in programming and further testing.

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APPENDICES

- **APPENDIX A**
  - **Table 4.6 Parts Classification Database**
- **APPENDIX B**
  - **Technical Drawings of parts for Parts Classification Database Table**

APPENDIX A

Attached Table 4.6 Parts Classification Database

No	Drawing number	Part Number	Descriptions	Material	Digit								
					1	2	3	4	5	6	7	8	9
1	TPA-DU400051177-05-SP1-01	12a	Plate, thermal cut, bend	EH36	3	0	0	0	1	8	2	6	1
2	TPA-DU400051177-05-SP1-01	12b	Plate, thermal cut, bend	EH36	3	0	0	0	1	8	2	6	1
3	TPA-DU400051177-05-SP1-01	11n	Plate, thermal cut	EH36	3	0	0	0	1	8	2	6	1
4	TPA-DU400051177-05-SP1-01	11p	Plate, thermal cut	EH36	3	0	0	0	0	6	2	6	1
5	TPA-DU400051177-03-SP-01	16a	I Beam, thermal cut	A572 GR50	3	0	0	0	0	5	2	6	1
6	TPA-DU400051177-03-SP-01	16b	I Beam, thermal cut	A572 GR50	3	0	0	0	0	7	4	4	1
7	TPA-DU400051177-03-SP-01	16a	Pipe, thermal cut, bend	x52	3	0	0	0	0	5	4	4	1
8	TPA-DU400051177-03-SP-01	11a	Plate, thermal cut	EH36	3	0	0	0	0	5	0	3	1
9	TPA-DU400051177-03-SP-01	11b	Plate, thermal cut	EH36	3	0	0	0	0	7	2	6	1
10	TPA-DU400051177-03-SP-01	11g	Plate, thermal cut	EH36	3	0	0	0	0	7	2	6	1
11	TPA-DU400051177-03-SP-01	11d	Plate, thermal cut	EH36	3	0	0	0	0	7	2	6	1
12	TPA-DU400051177-03-SP-01	11e	Plate, thermal cut	EH36	3	0	0	0	0	7	2	6	1
13	TPA-DU400051177-03-SP-01	11f	Plate, thermal cut	EH36	3	0	0	0	0	5	2	6	1
14	TPA-DU400051177-03-SP-01	11c	Plate, thermal cut	EH36	3	0	0	0	0	5	2	6	1
15	TPA-DU400051177-03-SP-01	11h	Plate, thermal cut	EH36	3	0	0	0	0	5	2	6	1

16	TPA-DU400051177-03-SP-01	11j	Plate, thermal cut	EH36	3	0	0	0	0	5	2	6	1
17	TPA-DU400051177-03-SP-01	11k	Plate, thermal cut	EH36	3	0	0	0	0	5	2	6	1
18	TPA-DU400051177-03-SP-01	11m	Plate, thermal cut	EH36	3	0	0	0	0	5	2	6	1
19	TPA-DU400051177-03-SP-01	13a	Plate, thermal cut, aux hole	EH36	3	0	0	0	0	5	2	6	1
20	TPA-DU400051177-03-SP-01	14a	Plate, thermal cut, CNC maching	EH36	3	0	0	0	1	4	2	6	1
21	TPA-DU400050323-04-SP1-01	2a	Plate, thermal, bend	EH36	3	0	0	0	0	3	2	6	1
22	TPA-DU400050323-04-SP1-01	3a	Plate, thermal, bend	EH36	3	0	0	0	0	7	2	6	1
23	TPA-DU400050323-04-SP1-01	4e	Plate, thermal, bend	EH36	3	0	0	0	0	7	2	6	1
24	TPA-DU400050323-04-SP1-01	5a	Plate, thermal, bend	EH36	3	0	0	0	0	4	2	6	1
25	TPA-DU400049049-06-SP1-01	1a-1	Plate, thermal, bend	EH36	3	0	0	0	0	7	2	6	1
26	TPA-DU400049049-06-SP1-01	1a-2	Plate, thermal, bend	EH36	3	0	0	0	0	7	2	6	1
27	TPA-DU400049049-06-SP1-01	5a-1	Plate, thermal, bend	EH36	3	0	0	0	0	5	2	6	1
28	TPA-DU400049049-06-SP1-01	2a-1	Plate, thermal cut	EH36	3	0	0	0	0	6	2	6	1
29	TPA-DU400049049-06-SP1-01	2b-1	Plate, thermal cut	EH36	3	0	0	0	0	3	2	6	1
30	TPA-DU400049049-06-SP1-01	2c-1	Plate, thermal cut	EH36	3	0	0	0	0	5	2	6	1
31	TPA-DU400049049-06-SP1-01	2d-1	Plate, thermal cut	EH36	3	0	0	0	0	6	2	6	1
32	TPA-DU400049049-06-SP1-01	1b-1	Plate, thermal cut	EH36	3	0	0	0	0	3	2	6	1

33	TPA-DU400049049-06-SP1-01	1b-2	Plate, thermal cut	EH36	3	0	0	0	0	3	2	6	1
34	TPA-DU400049049-06-SP1-01	1d	Plate, thermal cut	EH36	3	0	0	0	0	5	2	6	1
35	TPA-DU400049049-06-SP1-01	1e	Plate, thermal cut	EH36	3	0	0	0	0	5	2	6	1
36	TPA-DU400049049-06-SP1-01	6a	Plate, thermal, bend	EH36	3	0	0	0	0	5	2	6	1
37	TPA-DU400049049-06-SP1-01	7a-1	Plate, thermal, bend	EH36	3	0	0	0	0	5	2	6	1
38	TPA-DU400048562-06-SP1-02	9z	I Beam, thermal cut	A572 GR50	3	0	0	0	0	6	2	6	1
39	TPA-DU400048562-06-SP1-02	9aa	I Beam, thermal cut	A572 GR50	3	0	0	0	0	9	4	4	1
40	TPA-DU400048562-06-SP1-02	9ab	I Beam, thermal cut	A572 GR50	3	0	0	0	0	8	4	4	1
41	TPA-DU400048562-06-SP1-02	9ac	I Beam, thermal cut	A572 GR50	3	0	0	0	0	9	4	4	1
42	TPA-DU400048562-06-SP1-02	9ad	I Beam, thermal cut	A572 GR50	3	0	0	0	0	8	4	4	1
43	TPA-DU400048562-06-SP1-02	9ak	I Beam, thermal cut	A572 GR50	3	0	0	0	0	3	4	4	1
44	TPA-DU400048562-06-SP1-02	9am	I Beam, thermal cut	A572 GR50	3	0	0	0	0	7	4	4	1
45	TPA-DU400048562-06-SP1-02	8a	I Beam, thermal cut	A572 GR50	3	0	0	0	0	5	4	4	1
46	TPA-DU400048562-06-SP1-02	8b	I Beam, thermal cut	A572 GR50	3	0	0	0	0	9	4	4	1
47	TPA-DU400048562-06-SP1-02	10a	I Beam, thermal cut	A572 GR50	3	0	0	0	0	9	4	4	1
48	TPA-DU400048562-06-SP1-02	10b	I Beam, thermal cut	A572 GR50	3	0	0	0	0	0	4	4	1
49	TPA-DU400048562-06-SP1-02	10c	Plate, thermal cut	EH36	3	0	0	0	0	0	4	4	1

50	TPA-DU40004856 2-06-SP1-02	10e	Plate, thermal cut	EH36	3	0	0	0	0	0	2	6	1
51	TPA-DU40004856 2-06-SP1-02	11a	Plate, thermal cut	EH36	3	0	0	0	0	0	2	6	1
52	TPA-DU40004856 2-06-SP1-02	11b	Plate, thermal cut	EH36	3	0	0	0	0	0	2	6	1
53	TPA-DU40004856 2-06-SP1-02	11c	Plate, thermal cut	EH36	3	0	0	0	0	0	2	6	1
54	TPA-DU40004856 2-06-SP1-02	11d	Plate, thermal cut	EH36	3	0	0	0	0	0	2	6	1
55	TPA-DU40004856 2-06-SP1-02	11e	Plate, thermal cut	EH36	3	0	0	0	0	0	2	6	1
56	TPA-DU40004856 2-06-SP1-02	12a	Plate, thermal cut	EH36	3	0	0	0	0	0	2	6	1
57	TPA-DU40004856 2-06-SP1-02	12b	Plate, thermal cut	EH36	3	0	0	0	0	0	2	6	1
58	TPA-DU40004856 2-06-SP1-02	11f	Plate, thermal cut	EH36	3	0	0	0	0	0	2	6	1
59	TPA-DU40004856 2-06-SP1-02	9a	I Beam, thermal cut	A572 GR50	3	0	0	0	0	0	2	6	1
60	TPA-DU40004856 2-06-SP1-02	9b	I Beam, thermal cut	A572 GR50	3	0	0	0	0	9	4	4	1
61	TPA-DU40004856 2-06-SP1-02	9c	I Beam, thermal cut	A572 GR50	3	0	0	0	0	8	4	4	1
62	TPA-DU40004856 2-06-SP1-02	9d	I Beam, thermal cut	A572 GR50	3	0	0	0	0	9	4	4	1
63	TPA-DU40004856 2-06-SP1-02	9e	I Beam, thermal cut	A572 GR50	3	0	0	0	0	8	4	4	1
64	TPA-DU40004856 2-06-SP1-02	9f	I Beam, thermal cut	A572 GR50	3	0	0	0	0	3	4	4	1
65	TPA-DU40004856 2-06-SP1-02	9g	I Beam, thermal cut	A572 GR50	3	0	0	0	0	7	4	4	1
66	TPA-DU40004856 2-06-SP1-02	9h	I Beam, thermal cut	A572 GR50	3	0	0	0	0	5	4	4	1

67	TPA-DU40004856 2-06-SP1-02	9m	I Beam, thermal cut	A572 GR50	3	0	0	0	0	9	4	4	1
68	TPA-DU40004856 2-06-SP1-02	9n	I Beam, thermal cut	A572 GR50	3	0	0	0	0	9	4	4	1
69	TPA-DU40004856 2-06-SP1-02	9p	I Beam, thermal cut	A572 GR50	3	0	0	0	0	0	4	4	1
70	TPA-DU40004856 2-06-SP1-02	9g	I Beam, thermal cut	A572 GR50	3	0	0	0	0	0	4	4	1
71	TPA-DU40004856 2-06-SP1-02	9r	I Beam, thermal cut	A572 GR50	3	0	0	0	0	0	4	4	1
72	TPA-DU40004856 2-06-SP1-02	9t	I Beam, thermal cut	A572 GR50	3	0	0	0	0	0	4	4	1
73	TPA-DU40004856 2-06-SP1-02	9u	I Beam, thermal cut	A572 GR50	3	0	0	0	0	0	4	4	1
74	TPA-DU40004856 2-06-SP1-02	9v	I Beam, thermal cut	A572 GR50	3	0	0	0	0	0	4	4	1
75	TPA-DU40004856 2-06-SP1-02	9w	I Beam, thermal cut	A572 GR50	3	0	0	0	0	0	4	4	1
76	TPA-DU40004856 2-06-SP1-02	9x	I Beam, thermal cut	A572 GR50	3	0	0	0	0	0	4	4	1
77	TPA-DU40004856 2-06-SP1-02	9y	I Beam, thermal cut	A572 GR50	3	0	0	0	0	0	4	4	1
78	TPA-DU40004835 3-13-SP1-01	13ax	I Beam, thermal cut	A572 GR50	3	0	0	0	0	0	4	4	1
79	TPA-DU40004835 3-13-SP1-01	13ay	I Beam, thermal cut	A572 GR50	3	0	0	0	0	8	4	4	1
80	TPA-DU40004835 3-13-SP1-01	13az	I Beam, thermal cut	A572 GR50	3	0	0	0	0	5	4	4	1
81	TPA-DU40004835 3-13-SP1-01	13ba	I Beam, thermal cut	A572 GR50	3	0	0	0	0	5	4	4	1
82	TPA-DU40004835 3-13-SP1-01	13bb	I Beam, thermal cut	A572 GR50	3	0	0	0	0	6	4	4	1
83	TPA-DU40004835 3-13-SP1-01	13bc	I Beam, thermal cut	A572 GR50	3	0	0	0	0	7	4	4	1

84	TPA-DU400048353-13-SP1-01	13bd	I Beam, thermal cut	A572 GR50	3	0	0	0	0	5	4	4	1
85	TPA-DU400048353-13-SP1-01	13be	I Beam, thermal cut	A572 GR50	3	0	0	0	0	9	4	4	1
86	TPA-DU400048353-13-SP1-01	13bn	I Beam, thermal cut	A572 GR50	3	0	0	0	0	6	4	4	1
87	TPA-DU400048353-08-SP1-03	14h	I Beam, thermal cut	A572 GR50	3	0	0	0	0	6	4	4	1
88	TPA-DU400048353-08-SP1-03	14f	I Beam, thermal cut	A572 GR50	3	0	0	0	0	3	4	4	1
89	TPA-DU400048353-08-SP1-03	14g	I Beam, thermal cut	A572 GR50	3	0	0	0	0	3	4	4	1
90	TPA-DU400048353-08-SP1-03	16a	I Beam, thermal cut	A572 GR50	3	0	0	0	0	3	4	4	1
91	TPA-DU400048353-08-SP1-03	16b	I Beam, thermal cut	A572 GR50	3	0	0	0	0	4	4	4	1
92	TPA-DU400048353-08-SP1-02	13af	I Beam, thermal cut	A572 GR50	3	0	0	0	0	4	4	4	1
93	TPA-DU400048353-08-SP1-02	13ag	I Beam, thermal cut	A572 GR50	3	0	0	0	0	9	4	4	1
94	TPA-DU400048353-08-SP1-02	13ah	I Beam, thermal cut	A572 GR50	3	0	0	0	0	6	4	4	1
95	TPA-DU400048353-08-SP1-02	13aj	I Beam, thermal cut	A572 GR50	3	0	0	0	0	5	4	4	1
96	TPA-DU400048353-08-SP1-02	13ak	I Beam, thermal cut	A572 GR50	3	0	0	0	0	9	4	4	1
97	TPA-DU400048353-08-SP1-02	13am	I Beam, thermal cut	A572 GR50	3	0	0	0	0	5	4	4	1
98	TPA-DU400048353-08-SP1-02	13an	I Beam, thermal cut	A572 GR50	3	0	0	0	0	7	4	4	1
99	TPA-DU400048353-08-SP1-02	13ap	I Beam, thermal cut	A572 GR50	3	0	0	0	0	7	4	4	1
100	TPA-DU400048353-08-SP1-02	13ag	I Beam, thermal cut	A572 GR50	3	0	0	0	0	6	4	4	1

101	TPA-DU400048353-08-SP1-02	13ar	I Beam, thermal cut	A572 GR50	3	0	0	0	0	5	4	4	1
102	TPA-DU400048353-08-SP1-02	13av	I Beam, thermal cut	A572 GR50	3	0	0	0	0	5	4	4	1
103	TPA-DU400048353-08-SP1-01	13x	I Beam, thermal cut	A572 GR50	3	0	0	0	0	7	4	4	1
104	TPA-DU400048353-08-SP1-01	13y	I Beam, thermal cut	A572 GR50	3	0	0	0	0	3	4	4	1
105	TPA-DU400048353-08-SP1-01	13z	I Beam, thermal cut	A572 GR50	3	0	0	0	0	3	4	4	1
106	TPA-DU400048353-08-SP1-01	13aa	I Beam, thermal cut	A572 GR50	3	0	0	0	0	3	4	4	1
107	TPA-DU400048353-08-SP1-01	13ab	I Beam, thermal cut	A572 GR50	3	0	0	0	0	3	4	4	1
108	TPA-DU400048353-08-SP1-01	13ac	I Beam, thermal cut	A572 GR50	3	0	0	0	0	3	4	4	1
109	TPA-DU400048353-08-SP1-01	13ad	I Beam, thermal cut	A572 GR50	3	0	0	0	0	3	4	4	1
110	TPA-DU400048353-08-SP1-01	13ae	I Beam, thermal cut	A572 GR50	3	0	0	0	0	3	4	4	1
111	TPA-DU400048353-08-SP1-01	13au	I Beam, thermal cut	A572 GR50	3	0	0	0	0	3	4	4	1
112	TPA-DU400048353-07-SP1-02	13j	I Beam, thermal cut	A572 GR50	3	0	0	0	0	3	4	4	1
113	TPA-DU400048353-07-SP1-02	13k	I Beam, thermal cut	A572 GR50	3	0	0	0	0	5	4	4	1
114	TPA-DU400048353-07-SP1-02	13l	I Beam, thermal cut	A572 GR50	3	0	0	0	0	9	4	4	1
115	TPA-DU400048353-07-SP1-02	13m	I Beam, thermal cut	A572 GR50	3	0	0	0	0	6	4	4	1
116	TPA-DU400048353-07-SP1-02	13n	I Beam, thermal cut	A572 GR50	3	0	0	0	0	7	4	4	1
117	TPA-DU400048353-07-SP1-02	13o	I Beam, thermal cut	A572 GR50	3	0	0	0	0	5	4	4	1

118	TPA-DU400048353-07-SP1-02	13p	I Beam, thermal cut	A572 GR50	3	0	0	0	0	6	4	4	1
119	TPA-DU400048353-07-SP1-02	13q	I Beam, thermal cut	A572 GR50	3	0	0	0	0	5	4	4	1
120	TPA-DU400048353-07-SP1-02	13r	I Beam, thermal cut	A572 GR50	3	0	0	0	0	6	4	4	1
121	TPA-DU400048353-07-SP1-02	13s	I Beam, thermal cut	A572 GR50	3	0	0	0	0	5	4	4	1
122	TPA-DU400048353-07-SP1-02	13t	I Beam, thermal cut	A572 GR50	3	0	0	0	0	9	4	4	1
123	TPA-DU400048353-07-SP1-02	13u	I Beam, thermal cut	A572 GR50	3	0	0	0	0	4	4	4	1
124	TPA-DU400048353-07-SP1-02	13v	I Beam, thermal cut	A572 GR50	3	0	0	0	0	7	4	4	1
125	TPA-DU400048353-07-SP1-02	13w	I Beam, thermal cut	A572 GR50	3	0	0	0	0	7	4	4	1
126	TPA-DU400048353-07-SP1-02	13aw	I Beam, thermal cut	A572 GR50	3	0	0	0	0	5	4	4	1
127	TPA-DU400048353-07-SP1-01	13a	I Beam, thermal cut	A572 GR50	3	0	0	0	0	7	4	4	1
128	TPA-DU400048353-07-SP1-01	13b	I Beam, thermal cut	A572 GR50	3	0	0	0	0	9	4	4	1
129	TPA-DU400048353-07-SP1-01	13c	I Beam, thermal cut	A572 GR50	3	0	0	0	0	5	4	4	1
130	TPA-DU400048353-07-SP1-01	13d	I Beam, thermal cut	A572 GR50	3	0	0	0	0	7	4	4	1
131	TPA-DU400048353-07-SP1-01	13e	I Beam, thermal cut	A572 GR50	3	0	0	0	0	7	4	4	1
132	TPA-DU400048353-07-SP1-01	13f	I Beam, thermal cut	A572 GR50	3	0	0	0	0	5	4	4	1
133	TPA-DU400048353-07-SP1-01	13g	I Beam, thermal cut	A572 GR50	3	0	0	0	0	5	4	4	1
134	TPA-DU400048353-07-SP1-01	13h	I Beam, thermal cut	A572 GR50	3	0	0	0	0	5	4	4	1

135	TPA-DU400048353-07-SP1-01	13as	I Beam, thermal cut	A572 GR50	3	0	0	0	0	5	4	4	1
136	TPA-DU400048353-07-SP1-01	13at	I Beam, thermal cut	A572 GR50	3	0	0	0	0	7	4	4	1
137	TPA-DU400048353-05-SP1-01	14a	Pipe, thermal cut, bend	x52	3	0	0	0	0	5	4	4	1
138	TPA-DU400048353-05-SP1-01	14b	Pipe, thermal cut, bend	x52	3	0	0	0	0	9	0	3	1
139	TPA-DU400048353-05-SP1-01	14c	Pipe, thermal cut, bend	x52	3	0	0	0	0	9	0	3	1
140	TPA-DU400048353-05-SP1-01	14d	Pipe, thermal cut, bend	x52	3	0	0	0	0	9	0	3	1
141	TPA-DU400048353-05-SP1-01	14e	Pipe, thermal cut, bend	x52	3	0	0	0	0	9	0	3	1
142	TPA-DU400048353-05-SP1-01	14f	Pipe, thermal cut, bend	x52	3	0	0	0	0	6	0	3	1
143	TPA-DU400048353-05-SP1-01	15a	Pipe, thermal cut, bend	x52	3	0	0	0	0	9	0	3	1
144	TPA-DU400048353-05-SP1-01	15b	Pipe, thermal cut, bend	x52	3	0	0	0	0	9	0	3	1
145	TPA-DU400048353-05-SP1-01	15c	Pipe, thermal cut, bend	x52	3	0	0	0	0	9	0	3	1
146	TPA-DU400048353-05-SP1-01	15d	Pipe, thermal cut, bend	x52	3	0	0	0	0	8	0	3	1
147	TPA-DU400048353-05-SP1-01	15e	Pipe, thermal cut, bend	x52	3	0	0	0	0	8	0	3	1
148	TPA-DU400048353-05-SP1-01	15f	Pipe, thermal cut, bend	x52	3	0	0	0	0	9	0	3	1
149	TPA-DU400048353-05-SP1-01	15g	Pipe, thermal cut, bend	x52	3	0	0	0	0	8	0	3	1
150	TPA-DU400048353-05-SP1-01	15h	Pipe, thermal cut, bend	x52	3	0	0	0	0	9	0	3	1
151	TPA-DU400048353-05-SP1-01	15i	Pipe, thermal cut, bend	x52	3	0	0	0	0	3	0	3	1

15 2	TPA-DU40004835 3-05-SP1-01	15j	Pipe, thermal cut, bend	x52	3	0	0	0	0	7	0	3	1
15 3	TPA-DU40004835 3-05-SP1-01	17a	Plate, thermal cut	EH36	3	0	0	0	0	4	0	3	1
15 4	TPA-DU40004835 3-05-SP1-01	17b	Plate, thermal cut	EH36	3	0	0	0	0	7	2	6	1
15 5	TPA-DU40004835 3-05-SP1-01	17c	Plate, thermal cut	EH36	3	0	0	0	0	7	2	6	1
15 6	TPA-DU40004835 3-05-SP1-01	17d	Plate, thermal cut	EH36	3	0	0	0	0	4	2	6	1
15 7	TPA-DU40004835 3-04-SP1-02	11a	I Beam, thermal cut	A572 GR50	3	0	0	0	0	7	2	6	1
15 8	TPA-DU40004835 3-04-SP1-02	11b	I Beam, thermal cut	A572 GR50	3	0	0	0	0	7	4	4	1
15 9	TPA-DU40004835 3-04-SP1-02	18e	Plate, thermal, bend, aux hole	EH36	3	0	0	0	0	7	4	4	1
16 0	TPA-DU40004835 3-04-SP1-02	18f	Plate, thermal, bend, aux hole	EH36	3	0	0	0	1	5	2	6	1
16 1	TPA-DU40004835 3-04-SP1-02	18m	Plate, thermal cut, aux hole	EH36	3	0	0	0	1	5	2	6	1
16 2	TPA-DU40004835 3-04-SP1-02	18n	Plate, thermal cut	EH36	3	0	0	0	1	5	2	6	1
16 3	TPA-DU40004835 3-04-SP1-02	18k	Plate, thermal cut	EH36	3	0	0	0	0	2	2	6	1
16 4	TPA-DU40004835 3-04-SP1-02	18h	Plate, thermal, bend	EH36	3	0	0	0	0	5	2	6	1
16 5	TPA-DU40004835 3-04-SP1-02	18g	Plate, thermal, bend	EH36	3	0	0	0	0	5	2	6	1
16 6	TPA-DU40004835 3-04-SP1-02	18u	Plate, thermal, bend	EH36	3	0	0	0	0	5	2	6	1
16 7	TPA-DU40004835 3-04-SP1-02	10b	Plate, thermal cut	EH36	3	0	0	0	0	5	2	6	1
16 8	TPA-DU40004835 3-3A-SP1-01	11a	C Channel, thermal cut	A572 GR50	3	0	0	0	0	5	2	6	1

169	TPA-DU400048353-3A-SP1-01	11d	C Channel, thermal cut	A572 GR50	3	0	0	0	0	7	4	4	1
170	TPA-DU400048353-3A-SP1-01	14f	Pipe, thermal cut, aux hole	x52	3	0	0	0	0	7	4	4	1
171	TPA-DU400048353-3A-SP1-01	18v	Plate, thermal cut, aux hole	EH36	3	0	0	0	1	3	4	4	1
172	TPA-DU400048353-3A-SP1-01	18w	Plate, thermal cut	EH36	3	0	0	0	1	7	2	6	1
173	TPA-DU400048353-3A-SP1-01	18x	Plate, thermal cut	EH36	3	0	0	0	0	7	2	6	1
174	TPA-DU400048353-3A-SP1-01	19b	Plate, thermal cut	EH36	3	0	0	0	0	7	2	6	1
175	TPA-DU400048209-01-SP1-01	ITEM1	Plate, thermal cut, bended, welded part	EH36	3	0	0	0	0	7	2	6	1
176	TPA-DU400048209-01-SP1-01	ITEM2	Plate, thermal cut, aux hole	EH36	3	0	0	0	0	7	2	8	1
177	TPA-DU400048209-01-SP1-01	ITEM3	I Beam, thermal cut	A572 GR50	3	0	0	0	1	1	2	6	1
178	TPA-DU400048209-01-SP1-01	ITEM4	Plate, thermal cut	EH36	3	0	0	0	0	7	4	4	1
179	TPA-DU400042396-05-SP1-02	3f	Plate, thermal cut, mult aux hole	EH36	3	0	0	0	0	6	2	6	1
180	TPA-DU400042396-05-SP1-02	3d	Plate, thermal cut, mult aux hole	EH36	3	0	0	0	1	9	2	6	1
181	TPA-DU400042396-05-SP1-02	3e	Plate, thermal cut, mult aux hole	EH36	3	0	0	0	1	9	2	6	1
182	TPA-DU400042396-05-SP1-01	3a	Plate, thermal cut, mult aux hole	EH36	3	0	0	0	1	9	2	6	1
183	TPA-DU400042396-05-SP1-01	3b-1	Plate, thermal cut, mult aux hole	EH36	3	0	0	0	1	9	2	6	1
184	TPA-DU400042396-05-SP1-01	3c	Plate, thermal cut, mult aux hole	EH36	3	0	0	0	1	9	2	6	1
185	TPA-DU400042396-05-SP1-01	3b-2	Plate, thermal cut, mult aux hole	EH36	3	0	0	0	1	9	2	6	1

186	TPA-DU400042396-04-SP1-01	2a	Plate, thermal cut	EH36	3	0	0	0	1	9	2	6	1
187	TPA-DU400042396-04-SP1-01	2b	Plate, thermal cut, bended	EH36	3	0	0	0	0	9	2	6	1
188	TPA-DU400042396-04-SP1-01	2c	Plate, thermal cut	EH36	3	0	0	0	0	9	2	6	1
189	TPA-DU400042396-04-SP1-01	2d	Plate, thermal cut	EH36	3	0	0	0	0	9	2	6	1

APPENDIX B

TECHNICAL DRAWINGS