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Title: Statistical Analysis to Find Root Cause of Quality Defects in Hot Rolling Operations
Module: Quality and Business Improvement (ACMA4008)

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Abstract

A technical report to convey the tools used to find a root causes, and main contributing factors to a significant increase in defective steel coils being produced within hot rolling operations at Port Talbot works, hot strip mill. The tools used, and omitted are discussed with reasoning and judgement in a statistical analysis contextual framework to solve a workplace problem that negatively affects the products, the business and its customers.

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1 Introduction

At Port Talbot, Cast Steel Slabs are processed through Hot Rolled Products where they are reheated in a furnace, then processed from a cast steel slab into a hot rolled coil through a series of reduction mills. See below **Fig 1** the process flow for the current configuration of Hot Rolled Products. For additional information on the process at Hot Rolled Products please see '[Appendix 1](#)' ('Port Talbot Hot Strip Mill Process Flow', Leighton Williams, 2024)

This report is specifically relating to low temperature quality issues found on hot rolled coils exiting the 'Edging & Rougher Mills' from **Fig 1, (from this point on known as 'The Reversing Roughing Mill')**, a part of the process in the operation of processing Cast Steel Slabs, into Hot Rolled Coils.

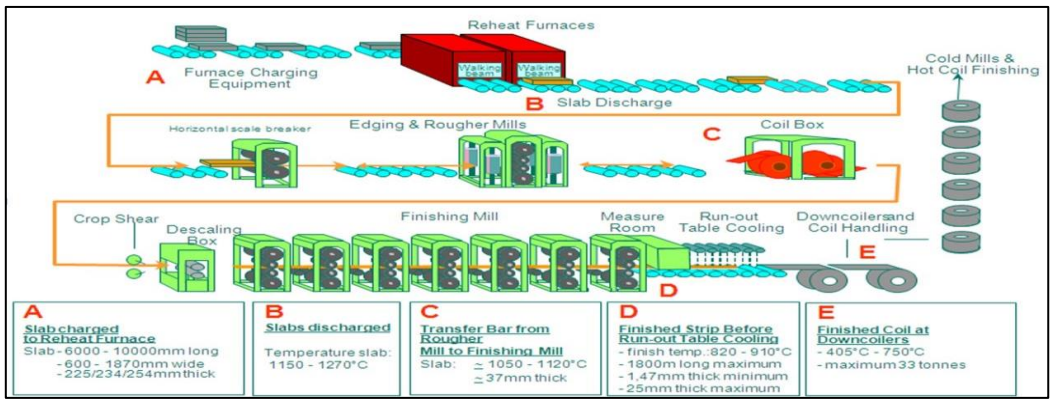


Fig 1 - Hot Rolled Products Process

The objective of this report is to identify, analyse and investigate a series of intermittent low temperature related quality defects on the material being processed using only the 7 basic tools of quality management. Through this data driven investigation the root cause can be determined, analysed and then mitigated through implementing an improvement. This report will also demonstrate through statistical analysis and presentation of data taken after the process improvement initiative the increased level of performance and reduced level of defective coils thereafter.

The area of scope for this report is centred around the Reversing Roughing Mill (**Fig 2, Fig 3**). This is a four high reduction mill that will reduce slab thickness down from between 260-215mm to 38-42mm, depending on the end thickness requirements by the customer (Gauge).

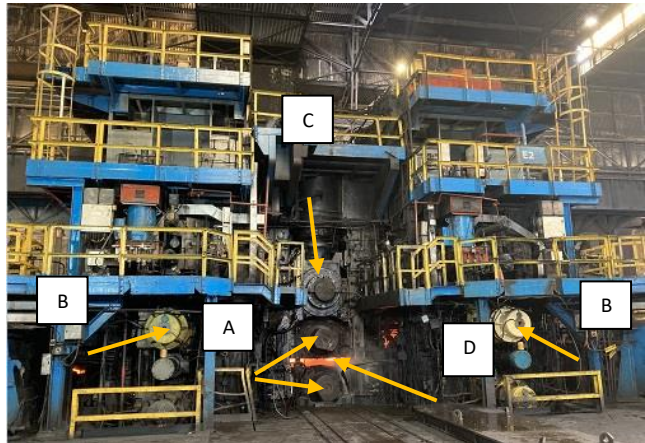


Fig 2 – Reversing Rougher at Hot Rolled Products

The slab will pass back and forth through the mill either five or seven times, with each 'pass' reducing the thickness (gauge) of the product prior to moving to the next part of the process (**Fig 3**). The width of the end product is achieved here in the roughing mill and is done with 'edger rolls' on both sides of the four high mill.

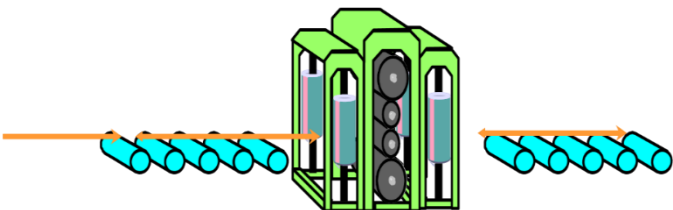


Fig 3 – Reversing Rougher Process Illustration

The material being processed enters the roughing mill in the form of a Cast Steel Slab that has been heated in the reheat furnaces. There is a lot of in-built variability within the process, largely due to the variety of products that can be processed. The varying range of slab dimensions from 6,000 – 10,050mm in length, and 625 -1,900mm in width. Also, the temperature range for slabs being processed

will be between 1140-1270 degrees, these are pre-determined by the end user specifications, required mechanical/metallurgical properties and the chemical composition of the steel slab to begin with (known as grade).

2 Literature Review
2.1 Overview

This entire report is centred around an increase in intermittent negative deviations of expected product temperature during processing. Its effects, causes and eventual mitigation. These increased number of product defects culminating in product losses, rejections, and re-works. Acceptable tolerance for defects is 3%. Temperature deviation derived defects had risen closer to 50% over a period of a few days in January 2025 a 1500%+ increase.

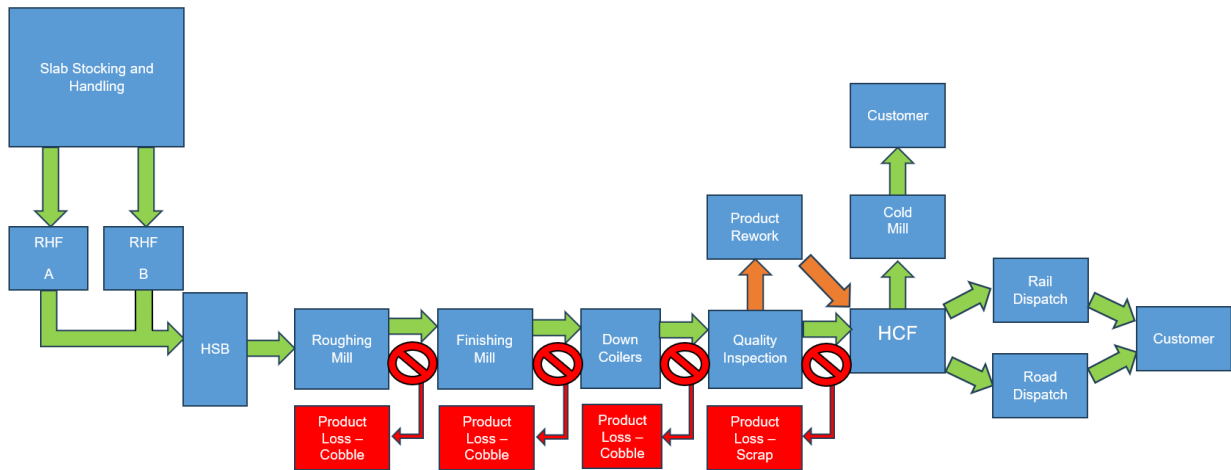


Fig 4 – Process flow for HRP indicating impact of quality and product loss routing.

The increased quality defects change the process flow of Hot Rolled Products and congest the quality inspection area (Fig 4). More significantly, due to the linear formation of the plant product losses stop production and cause lengthy delays in production. As well as equipment damage.

There are three carefully measured and controlled parameters that aim to ensure a product can be kept on temperature whilst going through the roughing mill.

- **Processing Speed and Process Delays** – The speed of which a slab is processed is a ranging variable and has a significant impact on heat loss/retention. The slower a product is processed the higher the heat loss.
- **Gauge** – The thickness of the steel slab to begin with, the reduction with each pass, and the end gauge of the coil all dictate the rate of heat loss, thereby contribute to the final quality parameters.
- **Water** – water use on the product is carefully measured, monitored, and controlled due to its cooling effects. There are two reasons water is used on material being processed.
 - **Descaling** – Scale is formed on the surface of the material as the iron within it reacts with the oxygen in the atmosphere at temperatures above 1000°C (Tanai Phanpat, 2017). This needs to be removed before each pass in the roughing mill or it can cause quality issues.
 - **Temperature Control** – water is used to reduce the temperature of the material to process the material within preset temperature ranges.

Measured roughing exit temperatures are taken by a non-contact infra-red detection device, and the results are displayed on a graph like illustration on software known locally as ‘The Met-Man’ see below examples (Fig 5, and Fig 6):



Fig 5 – Example of a temperature trace within range

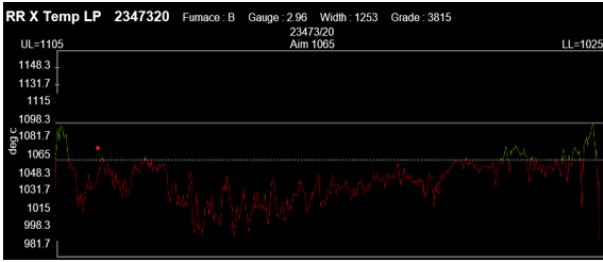


Fig 6 – Example of a temperature trace below target, typically leading to a defective coil.

During January 2025 there was an increase in seven particular types of quality issues/defects on the processed material. These were:

- **Product Losses** – Products too cold to roll and causing product failures(cobbles). This causes unplanned down time and potential plant damage.
- **Edge Cracking** – This is caused when ductility of the steel is reduced due to lower temperatures during processing (Saxena et al., 1997).
- **Surface Cracking** – Very much like edge cracking, where reduced ductility in the steel through the rolling process causes cracking on the surface of the steel strip, of varying sizes, directions, and locations (Hwang et al., 2005).
- **Shape Defects (Non-Uniform Thickness)** – This variation in thickness is caused by uneven temperature distribution, causing applied stresses and strains. (Serajzadeh et al., 2002). This leads to shape defects such as crown or wedge (Serajzadeh et al., 2002).
- **Laminar Defects** – typically cause laminations, or delamination's of layers within the strip being processed, this is caused by inconsistency of temperature on the top and bottom surfaces of the product (Wu et al., 2022).
- **Residual Stresses** – Cold temperature ratio between surfaces leads to differential in cooling during processing, and this leads to uneven stresses and strains being imbued into the product, very much linked to non-uniform thickness type defects. This can cause a pitted surface, and/or uneven flatness, a defect in itself, but also creates uneven scale oxide formation and can cause a number of surface defects as a result. (Wu et al., 2022)
- **Poor Surface Finish** – Scale Oxide formation can be inconsistent in thickness. Thinner scale can be more adherent to the steel, and more likely to be rolled in to the product as opposed to removed (Kennedy, 2010).

3 Methodology

3.1 Identifying the problem

Expected and acceptable levels of defects is around 3% of products produced, whilst product losses are expected to be around 1%. Having a rate increased to 50% of products getting classified as defective in one way or another and product losses increase to 24% action was needed. The first step is to ascertain potential causes using as illustrated in **Fig 7** - Cause and Effect Diagram. The process of Hot Rolling Steel Slabs into Coils has a lot of ingrained variability. Considerations needed to include the variations within the products, and operating parameters for each.

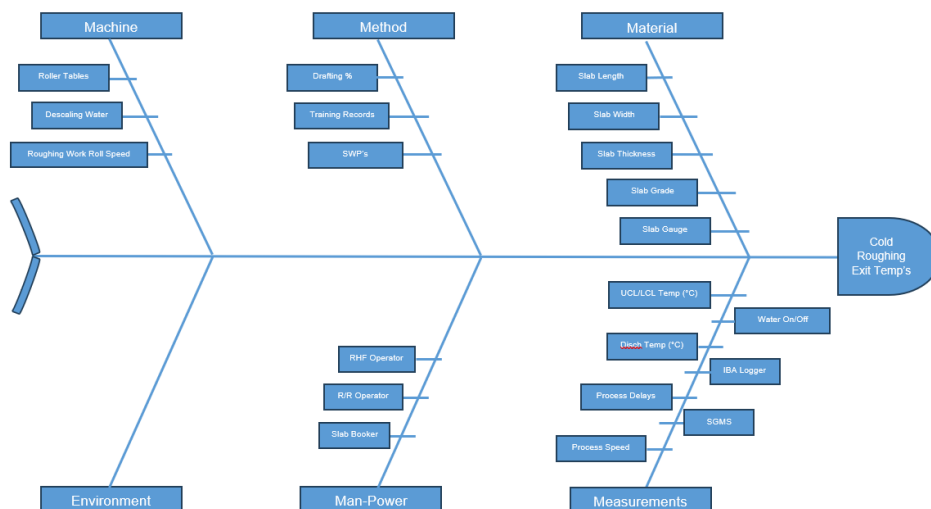


Fig 7 – Cause and Effect Diagram of Potential Contributing Factors

Further elaboration on this cause-and-effect approach was undertaken and completed as a full Root Cause Analysis Review and can be accessed via '[Appendix 2](#)' ('RCA', Leighton Williams, 2025). This RCA identified six potential contributing factors to this intermittent problem of cold temperature defects. Due to the considerable number of variables to consider, and the variation range within each variable the only way to proceed was to take a sample of data from the processed material and analyse it statistically. There was a need to collate both quantitative and qualitative data for each slab being processed into a coil. After deciding on the variables to consider the data was collated over a 12-hour period, the sample size was one hundred slabs. The quantitative data was recorded via system/instrument measurements that are taken, logged, and retrieved via an SQL type system. The defect data is more of a descriptive judgement, or qualitative nature. To collect this a check sheet was used and the defect type categorised and graded by an operator both before '[Appendix 3](#)' and after '[Appendix 4](#)' the Improvement Initiative. Both these data collections were combined, organised, and classified before being analysed. This can be seen in '[Appendix 5](#)' – ('Sample Data and Statistical Analysis', Leighton Williams, 2025).

3.2 Solving the problem

To solve the problem, implementation of recognised and proven methods to collate and then analyse data was carried out. The variables deemed to be significantly important to identifying and solving the cold temperature related defects were:

- Slab Dimensions – Length, Width, Thickness and Gauge.

- Slab Chemical Composition – Grade
- Furnace Discharge Temperature – Target, Actual and Deviation
- Processing Speed – Target, Actual and Delays
- Water Usage – Descaling Valve Opening/Closing Times
- Reversing Rougher Temperature – Target, UCL, LCL, Deviations to Target and LCL

Once the data had been collected organised and classified appropriate methods were used to analyse and find correlations between the variables and the defects. What was noticed immediately was methods such as Pareto, X-bar and R Charts were not entirely suitable methods to illustrate the extrapolated data in this dataset in a useful way. The variables all have a range of acceptable tolerance, and the target for each variable differs from slab to slab. Isolating the combination of multiple variables one at a time against the cold processing temperature at the roughing mill was needed to definitively find a correlation.

4 Combined Results & Analysis Section

The full statistical analysis of all the data can be seen in ‘Appendix 5’ – (‘Sample Data and Statistical analysis’, Leighton Williams, 2025). But here is the summary of the significant findings.

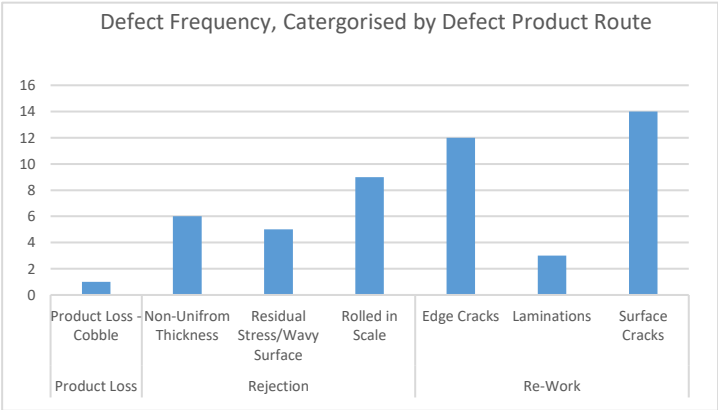


Fig 8 – Defect Type and Frequency

Fig 9 illustrates the measured temperature of material being processed. The target temperature varies from slab to slab, with the UCL and LCL being set at +/-40°C from target. This data sample shows a deviation from LCL of 50%. In this data set that is fifty out of one hundred slabs measured are being processed below the temperature LCL at the roughing mill, these are the slabs that are then classed as defective. To find the main contributing factors, the data collected was analysed comparing this deviation from the LCL of the roughing exit temperature against the variables collated in the data sample.

Fig 8 shows there are seven defect type categories also the routing that product would take. There are three routes:

1. **Product Loss** – Product breaks during processing bringing the operation to a halt. This also causes unexpected downtime, and potential equipment damage.
2. **Rejection** – There is no ability to re-work this product to meet customer requirements. They become product losses after inspection.
3. **Re-Work** – These defects are not product losses but incur significant cost to put right and cause congestion in the quality inspection department, and further processing units. This can lead to unexpected down time as a result.

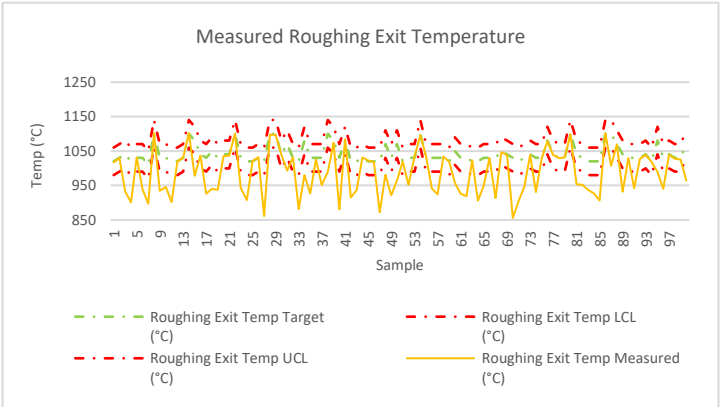


Fig 9 – Product Measure Temp Vs UCL/Target/LCL

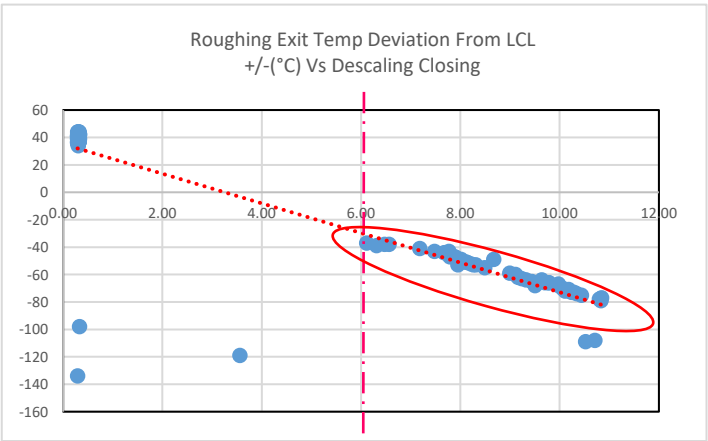


Fig 10 – Scatter Plot of Descaling Valve Closing Delay Against Temp Deviation at the roughing mill

The analysis was able to rule out 8 of 9 variables as non-contributory to the cold temperature deviations, and one variable as contributory but not in a significant manner to the fifty defects.

Heat loss in the hot rolling operations is predominantly done through descaling water used to remove the build-up of oxide forming on the surface (Scale). The process is an automatically controlled function at each processing unit. The control of these descaling operations is carefully measured, monitored, and controlled. The valve has a proximity switch built in that can signal when the valve is physically open/closed. By using the measurements, the delay between being asked to open/close and the valve physically being open/closed can be measured. It is within this data that the root cause can be found (Fig 10).

Here the delay in valve operation to the closed position can be seen varying from between 0 and 11 seconds. The valve operation being slower to reach closed position leads to excess unwanted water being dumped on the slab as it is being processed causing unwanted and unexpected heat loss. A direct correlation between the temperature deviation from the LCL at the roughing mill, and excess water being used by a delayed closure of a water valve.

5 Conclusions

From the analysis of the data, the team was able to isolate and compare data from a range of variables against the temperature deviation from the roughing mill exit. The correlation or lack thereof was easily identified. Using this statistical approach to finding the root cause definitively identified the contributing factor and the engineering teams were then able to take the appropriate action. In this case the descaling water automatic valve worked within parameters when going from the closed position to the open position. But when being operated to return to the closed position there was significant delay in achieving this movement. The resulting excess water being dumped on the steel strip as it was being processed dropped the temperature of the steel product below the acceptable LCL. Also evident is the longer the valve takes to close, the further below the LCL the steel strip went. **Significantly, the valve operation only caused defective coils when it took 6 seconds or longer.**

6 Evaluations

After finding the root cause of this particular data sets deviation from expected parameters, the engineering teams went on to change the valve in question. A pneumatically actuated poppet valve with solenoid pilot. System pressure requirements are in the region of 200bar. Going forward the valve operation times will be added to production KPI's. After the valve change the first one hundred slabs processed were subject to the same data collection as before. As can be seen in **Fig 11** and **Fig 12** there is no deviation from the LCL of the temperature target at the roughing mill after the valve has been changed.

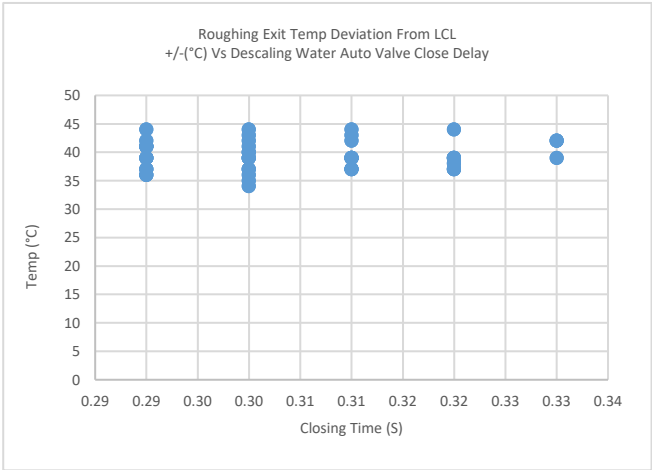


Fig 11 – Descaling Valve Close Delay After Change

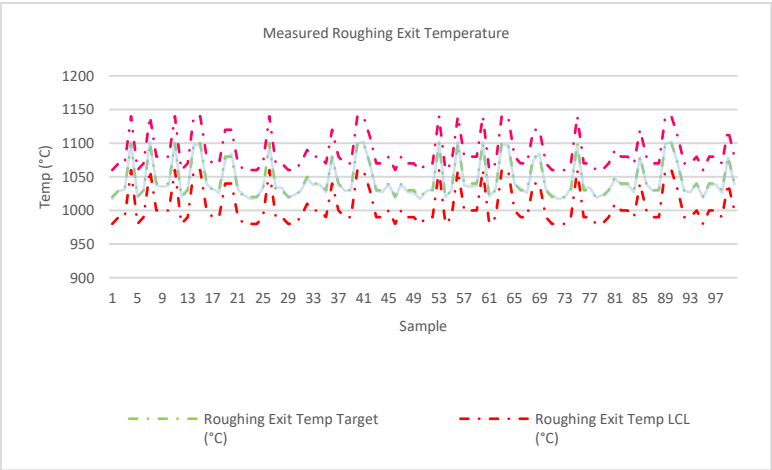


Fig 12 Measured Roughing Exit Temperature/Target/UCL/LCL

7 Recommended Further Works

Further finding through this investigatory project was the deterioration of the valve had been taking place for quite some time. The data for the valve operation can be traced back over many months. Although defects begin to occur when the valves operation is delayed for 6 seconds or longer. There is substantial evidence the valve closing time differed from the opening time over a period of around 6 months. This was not picked up in real time and has only become apparent after the fact. The data is now recorded and reviewed weekly as part of a KPI target towards continuous improvement. Any deviation found will be reviewed before the valve deterioration can impact upon the quality of the steel being rolled.

8 References

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9 Appendices

1. [Appendix 1- Port Talbot Hot Strip Mill Process Summary.pdf](#)
2. [Appendix 2 - RCA.xlsx](#)
3. [Appendix 3 - Checksheet - After Improvement.pdf](#)
4. [Appendix 4 - Checksheet - Before Improvement.pdf](#)
5. [Appendix 5 - Sample Data and Statistical Analysis.xlsx](#)