

Equipment Performance

REPORTING STRATEGY
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Abstract

Daniel Thomas, 2023. Equipment Performance Reporting Project. BEng Mechanical and Manufacturing Engineering. University of Wales Trinity Saint David

Renishaw is on a drive to increase productivity within its manufacturing division. This is being achieved through increasing the amount of equipment on site to cope with demand, however this is expensive. Increasing productivity could be done by increasing the reliability and maintainability of the equipment already within Renishaw. However, there has been no formal report that summarises the performance of the equipment within the plant. Basic reports are in place to summarise the mean time between failure of the plant. This report fails to distinguish which equipment within the plant require improvement in reliability or maintainability. Increasing these, will ultimately increase productivity.

Research has been carried out to learn and understand reliability and maintainability metrics used within engineering. A new report has been developed using the newly researched metrics.

Analysis of the new report shows clearly which pieces of equipment are unreliable or the least maintainable, by using availability, mean time between failure and mean down time. The report can breakdown the data to the reliability of sub systems and individual machines, also reporting on actions taken to rectify. This reports the maintainability of the sub systems and breaks it down to show how the downtime was distributed.

The report developed successfully reports on the performance of the equipment and can be used to develop performance improvement projects, increasing the productivity of the plant.

Keywords: Meant time between failure, mean time to repair, mean down time, availability.

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1 - Glossary

AM	Automatic Mill
AL	Automatic Lathe
CTS	Credits to Stock
Coswin	Computerised Maintenance Management System
KPI	Key Performance Indicator
MSD	Manufacturing Services Division
MTBF	Mean Time Between Failure
MTTR	Mean Time Between Failure
MDT	Mean Downtime
MTTF	Mean Time To Failure
RAMTIC	Renishaw Automated Milling Turning Inspection Centre

2 - Introduction

Renishaw is a global business supplying metrology products. Within their product lists are probing systems, CMM's, linear and rotary encoders. They also produce their own metal 3D printers and products to the medical sectors such as the NeuroMate.

Renishaw has been split into two divisions, Engineering and Manufacturing. The engineer's division is responsible for the design of new and existing product design, whilst manufacturing is responsible for manufacturing, the range of products that Renishaw sell. Within the manufacturing division, there are several departments, machine shop, responsible for the manufacturing of individual components, and assembly, responsible for the assembly and testing of products. Alongside these two departments is Works Engineering. Works engineering is split into three departments again, these are buildings, plant, and cleaning. Buildings look after the facilities across the UK and plant look after the equipment used for manufacturing products.

The manufacturing division have four sites for manufacturing, these are Stonehouse, Miskin, Woodchester and New Mills. Stonehouse is primarily a machine shop, Woodchester is primarily an assembly plant, whilst Miskin and New Mills are responsible for both. The Miskin site in South Wales is the largest of the plants, which is currently being doubled in size to meet the future demand for Renishaw products.

This project is going to be looking at the reporting strategy that plant maintenance use to monitor the performance of the equipment and the department. Specifically, this project will be looking at the reporting strategy for the machine shops at Miskin, Stonehouse and New Mills.

3 - Problem Statement

Renishaw are on a drive to increase productivity of the manufacturing division. This is to keep up with demand for their products. The high availability of their products has been instrumental in recent years, especially since the pandemic when production lines across the world have been impacted. Renishaw has managed to maintain 94% delivery schedule whilst their main competitors have been 30-60%. Major machinery manufacturers have made the change to Renishaw products due to their availability.

Increasing productivity at Renishaw has meant the automation of some production lines and increase the number of machines. Along with increasing capacity with new equipment, there is a drive to increase the performance of existing equipment, this will need to be done by improving the reliability of the equipment and the performance of the department.

To be able to do this, a reliable, accurate report is required to evaluate where the equipment and department currently stand and where these need to be in future. Currently this report is created in an ad hoc way, must be manually created, and does not concisely pull together data from different sources to report the current reliability of the plant and equipment.

4 - Project Aims

There are several aims and objectives throughout the project that need to be met to succeed in changing the reporting strategy. Below lists the key objectives, including what is in and out of scope.

Objectives

- Research and use industry standard techniques to report performance.
- Use suitable graphical techniques to display the key metrics and show the worst offending pieces of equipment.
- Develop KPI's for the methods to establish when reliability projects need to be implemented.
- Develop the report so Senior engineers, and maintenance managers can use for analysis.

In Scope

- MSD Stonehouse and Miskin machine shops.
- Data from Coswin database.
- Use of Microsoft products which the company has licences to use.
- Run time data from Syteline.

Out of Scope

- Other MSD sites and divisions in the company – as Works Engineering are not involved at this time.
- Assembly maintenance – Due to the different equipment and set up, will be within scope once this project is complete.

Key stakeholders

- Works Engineering Manager
- Plant Maintenance Manager
- Senior and Leading Engineers
- Production Managers

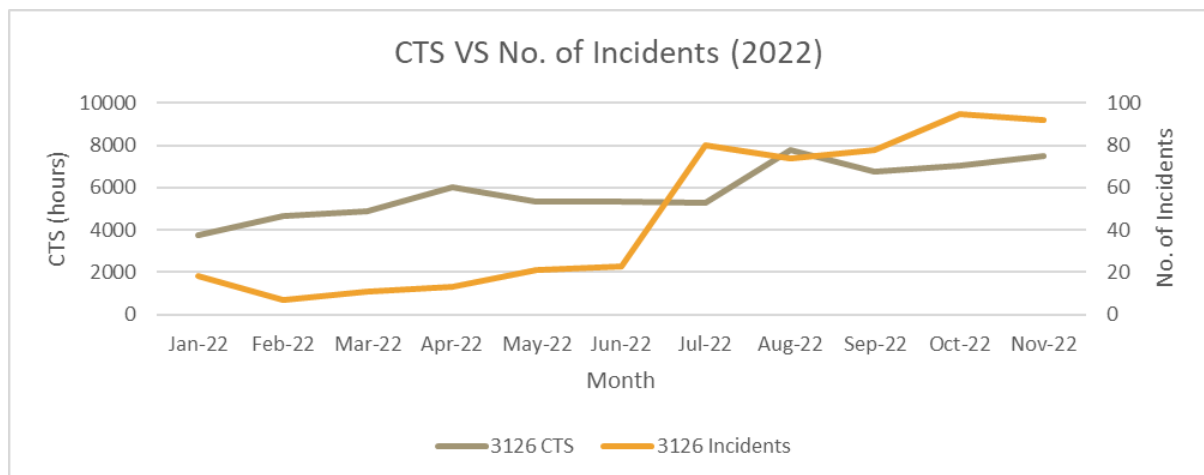
5 - Current reporting strategy

The current reports are manually calculated at the end of every month and are presented to the Works Engineering manager. Occasionally these reports are interrogated further, but due to the way their built, lacks critical information. It requires the plant maintenance manager to manually search for the information in the system.

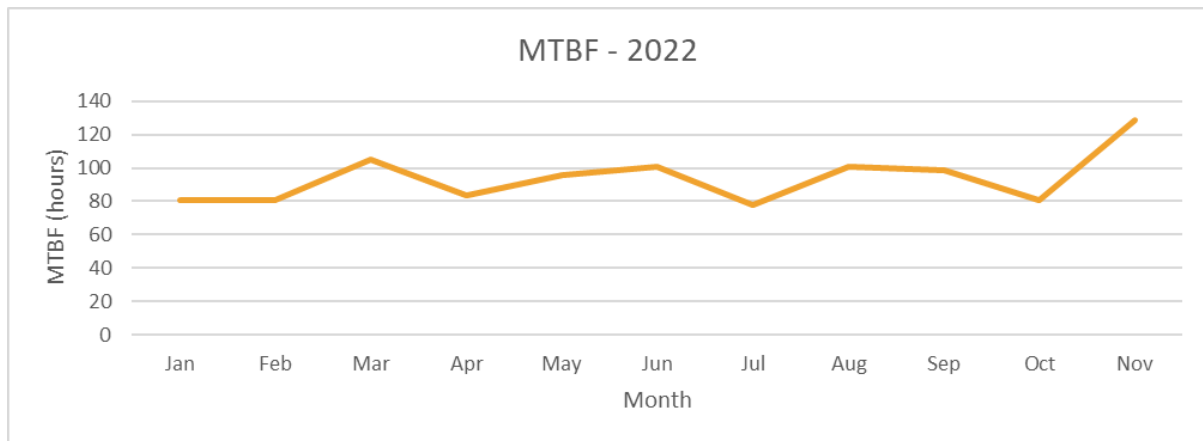
Works Engineering use a system called Coswin for all their maintenance records. Coswin is used to raise and complete work orders, account for all spares, calculate downtime and store planned maintenance schedules.

Syteline is the second system that is used for data to incorporate in the reports. Syteline is a system that the machine shop and assemblies used go control spends, production output, quality, calibration and much more. The data on Syteline that plant maintenance require is Credits to Stock, CTS. One CTS is equivalent to one hour of production time.

Below shows the report that was in use by the plant maintenance team.



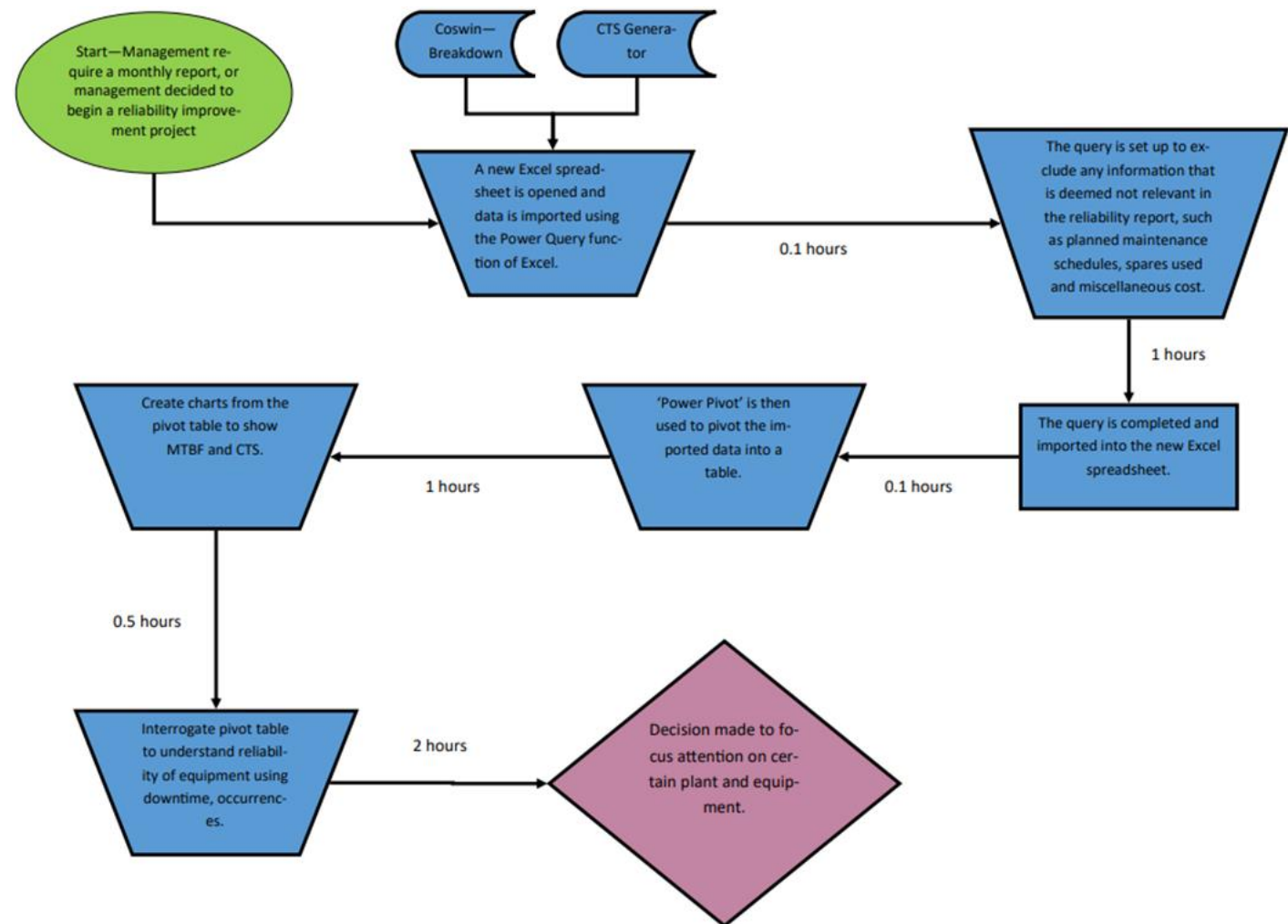
The above graph shows the credits to stock vs incidents. The graph very simply shows that the more work that gets loaded onto the equipment, the more breakdowns they suffer. This graph is only displaying equipment under department 3126. A lower incident rate would mean a more reliable equipment.



The second graph, as above, shows the mean time between failure of all equipment under department 3126. This is an important metric to track the reliability of the equipment. A higher MTBF is better as there are less breakdowns and more production time

6 – Current Process of Reporting

To aid the evaluation of the current method used to report the reliability of the plant and equipment, it has been chosen to use a Process Map. This has been chosen as it easily identifies each process it takes to generate a report, highlights the times it takes at each process, and identifies how each of the processes work. It is an effective method of highlighting inefficiencies within the entire process.



7 - Strategy evaluation

The current reporting strategy adopted by the maintenance team is not fit for purpose. To begin with, these reports have been manually updated monthly using Microsoft Excel. To generate the report the user is required to use Pivot tables and run macros, which requires a certain skill set to achieve. This could be overcome by training the management team to do themselves, but as it is manually created, there is room for human error. Not only does this create errors in the data evaluation, but it is time consuming to carry out, time that is better spent improving the equipment reliability. As is highlighted in the process map, it can take up to 5 hours to develop a report each time.

Also, as the process map highlights, most steps within the report generation process is manually completed. Only one step in the process is completed automatically. This does implement many areas of human errors, from importing the correct data, querying the data correctly, and pivoting the data correctly.

This reporting strategy uses both meant time between failure (MTBF) and credits to stock (CTS). From initial research, the strategy does use MTBF correctly, as a metric to measure equipment performance. MTBF is an industry standard metric used to measure the performance of equipment in terms of reliability. MTBF is the average amount of time the machine has ran between each breakdown. However, the use of MTBF on this strategy is as a plant. Due to the variance in equipment types, ideally, MTBF needs to be broken down into the different machine classes, to focus resources at the most unreliable machine class. Again, this can be drilled down further to give us MTBF per machine within that class, where focus can be made to the most unreliable in that class.

The MTBF graph does not clearly explain or give reasons as to why the MTBF changes have occurred. As can be seen from the CTS vs No. of Incidents graph shows a large increase in the number of incidents around June, however there is no explanation or reason on the graph to explain why.

Credits to stock, CTS, is used as part of the reporting strategy. CTS is the number of hours that machines have run and contributed to stockable components. This doesn't contribute much value to the reports on its own but is used within the MTBF charts. There is no real value to seeing this in the report for reliability, as its accounted for the MTBF. A critical issue with CTS, is that it does not account for any machine that have been running scrap. As this part have been scrapped it has not added any value to stock, this is an issue. For instance, a machine could run 36 hours, but all components are scrap as a operator has changed a tap to a drill bit by mistake. If running on the RAMTIC line, these tapped holes wouldn't be checked until the carousel is on the kitting station being during a quality check. These 36 hours wouldn't be accounted for in the CTS and later into the MTBF.

If these reports were to be used for reliability improvement projects, then the report needs to have the ability to break the data down into usable reports. To be able to break this data down to focus resource in the correct areas, another Pivot Table would need to be created and used. Again, this would take time, involve a certain amount of skill and create room for error. Due to the nature of how data is pulled in from Coswin, the management team need a certain level of skill to query the data using Microsoft's Power Query, application. Again, this all takes value time that could be better spent investigating reliability issues. The data from the pivoted table is useful and gives a breakdown of where the downtime is accumulated, and does show the cause, action and defect of the breakdown. Using Coswin the senior engineer and manager would need to check each ticket for the description of the work carried out, this description is important as it advises how much time was spent on waiting parts, the type of parts changed, the diagnostics used and is more descriptive of the faults than the cause, defects and actions.

The current reporting strategy does not have any KPIs listed or tracked. This is important to have on a report like this as it's a quick indicator if the reliability of the equipment us within the specified limits of the organisation and can easily show which machines are the worst offending. Setting KPIs and graphically displaying these would give a clear indication as to how the machines are running and which ones need to be looked at.

The current reporting strategy is an Excel workbook that is saved in the shared Maintenance drive. The folder is locked to the senior engineers and maintenance managers. As its locked away in the folder, and due to the amount of work that is currently going on with other projects, training and new equipment, this report tends to be forgotten about until a review comes around within other teams. The senior engineers barely use this report to recognise how their teams and equipment are doing. Having this information on display all the time would attract other to look at it, especially if these reports had KPIs displayed on them.

This report only uses one of the key reliability metrics, there are many others used by industry to report on other reliability issues, this could include mean time to repair, MTTR. MTTR is used not only to measure the performance of the department but can be used of reliability and measure the maintainability of the equipment. This could lead to other projects to reduce downtime but correct stocking of spares and consumables, improving maintenance practises and improving the maintainability of the equipment. MTTR is not strictly used for equipment performance but is an important factor in reliability of equipment. There are several issues with the current reporting strategy, this can be improved upon.

8 - Project plan

To plan the projects, it has been decided that the best method is using a Gantt Chart. The initial Gantt chart is shown in appendices 1 to 4.

The project is part of the working group set up by the plant maintenance manager to focus resource into improving the department in key areas. These key areas are health and safety, condition monitoring, resourcing, planned maintenance, stock and finally equipment performance.

As part of the working group, there will be regular reviews and meetings held to update progress and aid in the steering of a project and decision making. A 'Steering group' session will involve the management team and will be held in person at New Mills. These have been scheduled in for the last Thursday of every month. Along with these steering groups, are working groups. The aim of the working groups is to collaborate with others on the project, these have been scheduled for every two weeks. Along with these regular reviews, the first onboarding presentation has been scheduled in right at the beginning of the projects, this is where the projects are to be set out, with aims, objectives, and the scope of the project. The projects have been planned to follow a six-sigma project loosely. It loosely follows a six-sigma project as the aim of the project is to change the current reporting process, but it also adds many more areas to the process than currently used. Using the six-sigma ethos through the project is important as the process of creating the report needs to be accurate and made as efficient as possible. The project will involve using vast amounts of data, and using six-sigma techniques, will help check the accuracy of the data being used in the report, and aid in how the data should be displayed for easy analysis.

The key areas of the projects have been highlighted in the plan are; planning, research, design, implement and control. The project begins on the 7th of September and is due to complete on the 19th of May. This gives the project a float of 2-3 weeks for any unforeseen issues or additional steps.

The decided budget of this project has been set to £2000 for any research, equipment or resource required. This can be increased, if good justification is given, and if the return will be substantial.

9 - Brainstorming

One of the first tasks for the project is to brainstorm the project. The brainstorming took place within a working group with Russell Peace. Using the initial research and current reporting techniques, a brainstorm was developed to discuss the requirements of the projects now and in future.

The brainstorm was created using the Mind Manager app, that again Renishaw have licences. Mind Manager allows the user to easily create mind maps and adjust them. These can be later exported to word, excel and JPEG if they wish.

This brainstorming technique allows for creativity when starting out a project. At the beginning of the project, it can be difficult to understand where it will lead to and the process to that point. Some ideas may, at first, seem unachievable or completely out of the box, but could be the solution needed for the project. Brainstorming will encourage thinking of the scope of the project, goals, and solutions.

From the brainstorming goals for the project were identified, as described in section 3, the scope of the project was also given, and finally, the initial ideas were discussed. The reliability metrics were discussed, but going forward with the project, more research is needed to find out which metrics are used within industry, and how these could be used within Renishaw to review the reliability of the plant and equipment.

The brainstorming was recorded on Mind Manager and can be seen in appendix 5.

10 - Research Plan

From the brainstorming it was clear what needs to be researched. A plan is drawn up to guide the research to meet the requirements of the research, outlining goals and methods to the research.

The main goals of the research are:

- What are reliability metrics and are they used within industry?
- Which metrics are achievable within Renishaw?
- What types of data are required to calculate the metrics?
- Does Renishaw have access to this data?
- Where is the data stored and is it usable?

A literature review will be conducted to research reliability metrics that are used within industry. This literature review can be seen in section 11.

Along with the literature review, a data collection plan will be developed to ascertain the data that is available within Renishaw. The data collection plan can be seen in section 12.

11 - Literature Review

For the project, research was carried out on the subject of equipment reliability and performance. For this, multiple sources have been used in the decision of talking forward key metrics. These sources include books, whitepapers, and online articles. In the following section, arguments for each will be brought together and appraised. The full list of references used can be seen in section 20.

Source information

The first source being used for research is a company called Maxgrip.com (Maxgrip.com, 2021). This company was founded in 1997 in the Netherlands, originally conceived to focus on reliability and maintenance services, which later expanded to asset management in 2000. The company sells products and services to large manufacturers such as Petronas, Shell, TATA Steel to aid asset management, bring the companies to industry 4.0 and reduce costs. Due the nature of their business, selling products for reliability and asset management, the information on the sources may be biased towards their products. As can be seen at the end of each of their articles, it asks the person if they want more information, to contact them. The articles are relatively current, only being written in October, November, and December of 2021.

The second source used for the research is a white paper written by Wendy Torell and Victor Avelar, (Wendy Torell, 2004). The article was published by APC or American Power Conversion, who both the authors work for. APC are manufacturers of uninterruptible power supplies, and their slogan is 'Legendary Reliability'. It's clear to see that APC are driven to design and manufacture reliable UPS', and clearly, they are knowledgeable in the field of reliability based on their products. The white paper is unbiased, there's no reference to any products that they sell and do not boast about themselves. The white paper only described the reasoning behind using MTBF and its pitfalls. The white paper has been cited 113 times in other works, according to Google Scholar, which indicates that it is to be reliable. The paper was published in 2004, but when comparing their arguments to other more recent publications, it indicates the arguments are still current.

The third source used for research is a book written by John Bentley called, An Introduction To Reliability & Quality, (P.Bentley, 1993). This book is a first edition, written in 1993. The book is about reliability engineering, focusing on the design of new products and equipment, and how to predict the reliability of them. Section 1 and section 14 of the book has been

most useful, section 1 briefly explains the reliability metrics, and section 14 dives deeper at how these are affected by reliability in maintenance. This source is unbiased, as it is not affiliated with any business as the first two sources, and John Bentley himself is a university lecturer at the time at the University of Teesside. There is a second edition of the book printed in 1998, meaning this first edition is not current.

The fourth source used for research is Practical Reliability Engineering by Patrick D.T.O'Connor. This is the third edition of the book, printed in 1993. The last edition is edition 5 that was published in 2012. This source is no longer current, but the arguments in the book are still valid, as later sources still use the same argument. Most of the sections in the book are discussing reliability prediction, calculations, and testing of components in the design stages. However, sections 14 were aimed, again, at maintenance reliability, where the key reliability metrics were discussed, and the impact of maintenance strategies have on them.

The last source used for research is the lean six sigma pocket toolbox, (Michael L George, 2005). This has not been included in the research for reliability, rather it has been used to aid the planning and execution of the project. This was written in 2005 and is the only edition of the book. This source is unbiased.

Source Arguments

The main arguments in all three articles researched from Maxgrip's website is the importance of reporting breakdowns correctly. The point is stressed, that a kept definition is needed to determine what a breakdown is. The white paper, (Wendy Torell, 2004), also stresses this point as one of the key issues that need to be defined when using the metrics such as mean time between failure, MTBF. From both of their arguments, a breakdown can either be described as:

- Lost in production due to a failure in the plant or equipment.
- Any individual component in a plant or piece of equipment that fails to its job.
- Failure to run at 100% uptime.

Renishaw has never determined what the definition of a breakdown is formally, but informally it has been defined as a point 2 above, any individual component in a plant or piece of equipment that fails to its job. When calculating the downtime for this breakdown, the system will only track the time tacked to fault find, and replace the defective item, and

does not start the downtime as the point of the machine being booked on. Further discussion of the definition needs to be had with the plant manager, and communicated formally to the production staff to ensure breakdowns are registered correctly.

All sources have argued that MTBF, mean time between failure, is a key but simple metric that can be used within maintenance to assess the current reliability of the equipment. Both (D.T.O'Connor, 1992) and (P.Bentley, 1993), are books written in the early nineties, and both mention that MTBF should be used for repairable components and assets. At Renishaw, most, if not all assets maintained by the plant maintenance team are repairable.

The Maxgrip article, (Maxgrip.com, 2021), also argues that one of the reliability metrics that can be used is MTBF, as this metric can be used to calculate KPIs, key performance indicators, such as budgeting for repair costs and future capital expenditure. However, as discussed earlier, Maxgrip's article, also argues the pitfalls of using MTBF, if the data collection has not been properly defined and used. Documents such as maintenance records, might not be fully completed, and poor data capture will skew the results.

Each source has a slight variation for calculating the MTBF, as see below.

$$MTBF = \frac{\text{Total operation hours}}{\text{number of breakdowns}} \text{ (Maxgrip.com, 2021)}$$

$$MTBF = \frac{\text{Uptime}}{\text{No.of Failures}} \text{ (Bentley, 1993)}$$

The key difference in the equations is the numerator, it has not been defined what is meant as either uptime or operational hours. When relating these definitions with the equipment at Renishaw, uptime could mean the number of hours the machine was available for, and not broken down. Total operation hours in Renishaw terms would mean the number of hours the piece of equipment has been running for.

Availability has also been another metric widely discussed in all but two sources as a key metric in determining the reliability of a piece of equipment or plant. (Wendy Torell, 2004) argues that the definition of availability is the proportion a piece of equipment or plant is accessible for use.

(D.T.O'Connor, 1992) argues that availability is an important factor as reliability will directly affect the reliability. Knowing the availability of the equipment will aid the reliability analysis of the plant or equipment.

However, there is a difference in the availability equation in each source, as seen below. The white paper states that the available equation is:

$$\text{Availability} = \text{MTBF} / (\text{MTBF} + \text{MTTR})$$

(D.T.O'Connor, 1992) States the equation used should be:

$$\text{Availability} = \text{MTBF} / (\text{MTBF} + \text{MTTR} + \text{MPMT})$$

Where MPMT is mean preventative maintenance time.

And (P.Bentley, 1993) states that the availability equation is:

$$\text{Availability} = \text{MTBF} / (\text{MTBF} + \text{MDT})$$

Both (P.Bentley, 1993) and (Maxgrip.com, 2021) both discuss the importance of using mean downtime, MDT, as another reliability metric. According to (Maxgrip.com, 2021), MDT encompasses all downtime, both scheduled and unscheduled, and it can be used as a direct KPI for the plant and equipment. MDT is used to measure the effectiveness of an asset's maintenance schedule and highlights the inefficiencies. MDT takes into account all of the downtime including wait time before any repair work is carried out, unlike MTTR which only includes repair time.

(P.Bentley, 1993) has a different view to MDT, in that it is only used for breakdowns, and does not include scheduled maintenance, for comparison. It does however state the importance of using MDT as one of the measures to assess an asset's reliability. Both calculations are seen below.

$MDT = \frac{\text{Total Downtime}}{\text{Number of Failures}}$ (P.Bentley, 1993)

$MDT = \frac{\text{Total Downtime}}{\text{Number of downtime events}}$ (Maxgrip.com, 2021)

The last metric discussed in all sources is MTTR or mean time to repair. This metric calculates the amount of time it takes to get a piece of equipment in running condition from a breakdown. This only calculates the repair time including, fault finding, waiting spares and repair the equipment.

Each source has a slightly different view of the use of MTTR within reliability. (Wendy Torell, 2004) discusses MTTR within the reliability paper as it directly affects the availability of the equipment along with MTBF. This would be important to consider if using availability as a metric, as MTTR would need to be used within the calculation. In the paper it is argued that MTTR does not influence the reliability of equipment.

(Maxgrip.com, 2021) argue that this metric is important for measuring the equipment reliability as it indicates issues with the support program for equipment, through the effectiveness of the strategy and can positively influence the investment strategy for the equipment. This is done by pinpointing upgrades on the equipment, stocking correct spares and increased training for engineers. According to (Maxgrip.com, 2021), this metric needs to be used in conjunction with MTBF to analyse the reliability of the equipment thoroughly and cannot be used on its own.

The calculation of MTTR is below.

$MTTR = \frac{\text{Total repair time}}{\text{Total number of failures}}$ (Maxgrip.com, 2021)

The calculation remains the same across all sources.

Whilst researching, most sources mentioned the used of MTTF, or mean time to failure.

However, on further research this metric can only be used on non-repairable assets.

(P.Bentley, 1993).

Critical Appraisal of Metrics

All sources discuss MTBF in detail and all have stated that this type of metric is simple, but an effective way of assessing the reliability of an asset. (D.T.O'Connor, 1992) and (P.Bentley, 1993) were written in the early nineties, and both have stated that this metric is important, even the newer sources (Wendy Torell, 2004) and (Maxgrip.com, 2021) both state the same.

Having so many sources that argue the importance of MTBF, ensure that this metric is important to this project. Only (Wendy Torell, 2004) and (Maxgrip.com, 2021) both argue the importance of recording the breakdown data accurately. (Wendy Torell, 2004) goes into detail about how important this is. The other sources failed to mention the importance of logging this data, perhaps due to the context of both books. Both books discuss reliability for new products in the design, test and first implementation phase. It might be assumed that this data would be logged properly. (Maxgrip.com, 2021) mentions the use of CMMS, computerised maintenance management system, which is used at Renishaw. Carrying out a data analysis on samples of available data would ascertain the quality of the information that is available.

Two of the sources use a different numerator. Each of the equations would calculate a very different value for MTBF. Taking John P.Bentley's equations, the total uptime would mean the number of hours the equipment was available to use, this would include equipment that is on standby. At this present time, Renishaw do operate over the weekends as overtime, around 60% of the equipment is on standby at the weekends, including these hours of availability into the MTBF calculation would show the equipment to be far more reliable than using (Maxgrip.com, 2021)'s equation. Maxgrip's equation uses, operational time, or run time. For Renishaw's purposes, this would be the better value to use as it would account for the number of hours the equipment has been running, and it would automatically consider any overtime worked at weekends. Using operation hours would be the best and reliable for Renishaw to use.

The use of operational time would give a much more accurate MTBF as this data is easy and already captured within the machine and on databases help on the servers at Renishaw. The use of this numerator would give a much more meaningful figure, when equipment is in idle at Renishaw, they go into an energy saving mode. This effectively powers the machine down, including pumps, motors, and a lot of the electrical system. Same basic functions are

still turned on such as the drives to apply the brakes to the axes. In this state the machine typically has no faults.

As discussed previously, availability is a metric that can and is used to measure the reliability of an asset. However, each source that argues that different equations are used.

The equation used within the white paper, (Wendy Torell, 2004), uses MTBF and MTTR. Using only these two metrics does not account for downtime from any scheduled maintenance. Some scheduled maintenance can take a few days depending on the severity of the work required, not including this could dramatically change the availability calculation. It will show that the equipment is more available than it is.

The reasoning behind this looks to be definition of availability used within the white paper, the definition is given as *“Availability, on the other hand, is the degree to which the system or components is operational and accessible when required for use”* (Wendy Torell, 2004). This could indicate that if a piece of equipment is scheduled to be out of production, then it's already been accounted for.

(P.Bentley, 1993) uses a similar equation but uses MDT rather than MTTR. This is used as it better captures the downtime associated with breakdowns. As discussed, earlier MDT captures all the downtime, as MTTR only captures the time taken to repair an item. This is a more accurate calculation of availability, but again it does not incorporate scheduled maintenance associated downtime.

By contrast, (D.T.O'Connor, 1992) uses an equation that includes the downtime associated with scheduled maintenance in the form of MPMT or mean preventative maintenance time. In this equation, MTTR is again used, rather than MDT. However, using this equation would give a more accurate availability of the equipment as it includes schedule maintenance downtime. This equation could be modified to use MDT rather than MTTR to give an even more accurate availability figure.

MDT and MTTR are similar metrics, in that they calculate the amount of time the machine is on stop due to a breakdown. However, both (Bentley, 1993) and (Maxgrip.com, 2021) argue that each of these metrics measure different lengths of time. The other sources no not mention MDT. As discussed earlier, MDT includes all the downtime associated with a breakdown, including the amount of time it takes to recognise a fault with the equipment,

whilst MTTR only accounts for time it takes to repair the equipment. MDT will be included in the availability calculation.

It's argued in all sources, that MTTR is an important metric for reliability. MTTR can highlight the maintainability of the equipment, either but how long it takes to diagnose and repair a fault, to the support that the maintenance strategy has for the equipment.

From the initial research of the data available from servers, there is no data for the amount of time it takes to recognise a fault on the equipment. The data start at the time the equipment is booked on to maintenance. It is not in the scope of this project to capture that piece of data, however there is a log for the total downtime the machine has suffered once the fault has been recognised.

Conclusion

From research, the following metrics will be used within the new report, and the equations associated with them.

$$\text{Availability} = \frac{MTBF}{MTBF + MDT + MPMT}$$

$$\text{Mean Time Between Failure} = \frac{\text{Run time (operational time)}}{\text{Number of breakdowns}}$$

$$\text{Mean Down Time} = \frac{\text{Total downtime (breakdown)}}{\text{Number of breakdowns}}$$

$$\text{MTTR} = \frac{\text{Total Repair Time}}{\text{Total breakdowns}}$$

Using these 4 metrics will be the core of reporting and monitoring equipment reliability.

12 - Data Collection Plan

From the literature research it is clearly known what type of data is needed to successfully calculate the metrics that will be used. Below is the data collection plan.

Metric Data Type	Operational definition	Sample Size	Source and location	Collection Method	Data collection person
MDT	Continuous	All	Record from 'Downtime' field from Coswin. Coswin 'Fact sheet', at SQL server gbvuap28	Query data from SQL server to Excel spreadsheet	Dan Thomas
Total run hours	Continuous	All	Record from Syteline using run hours recorded from the machines.	Query data from Syteline to the new spreadsheet.	Dan Thomas
MPMT	Continuous	All	Record actual hours field within the Coswin database for Job Class type PPM. Coswin 'Fact sheet', at SQL server gbvuap28.	Query data from SQL server to Excel spreadsheet	Dan Thomas
Number of Breakdowns	Continuous	N/A	Use Count feature within power query to count the number of breakdowns under job class BD. Coswin 'Fact sheet', at SQL server gbvuap28.	Query data from SQL server to Excel spreadsheet	Dan Thomas
Equipment	Discrete	N/A	Keep equipment ID and Machine Class within the query for later use. Coswin 'Fact sheet', at SQL server gbvuap28.	Query data from SQL server to Excel spreadsheet.	Dan Thomas
Defect		All	Check that this field has been filled in.	Query data from SQL server to	Dan Thomas

				Excel spreadsheet.	
Cause		All	Check that this field has been filled in. Coswin 'Fact sheet', at SQL server gbvuap28.	Query data from SQL server to Excel spreadsheet.	Dan Thomas
Action		All	Check that this field has been filled in. Coswin 'Fact sheet', at SQL server gbvuap28.	Query data from SQL server to Excel spreadsheet	Dan Thomas

Consideration has been made to the sample size required to check the accuracy of the data. Due to all the data being available on either a spreadsheet or SQL server, it allows the use of Pivot tables within Microsoft Excel, allowing all the data to be checked for accuracy. The next section shows the results from the testing.

13 - Data Analysis

The data collection has been compiled to show the accuracy of each piece of data required. This has been put in the table below. This data has been extracted from 3 years of breakdown data, between January 2020 and January 2023.

It is not possible to pull through accurate data from before this time due to a software update. Before this time, the cause, action and defect field was not recorded.

Data Description	Error (% of grand total)	Data Size
Mean Down Time	2.61	69339
Run Hours	5.81	3 months
MPMT	3.28	61100
Defect	3.62	69339
Cause	3.62	69339
Action	2.75	69339

Using the power query and pivot tables within Microsoft Excel, it was possible to determine the percentage of work orders that had no downtime recorded against them, and determine, as a percentage, the number of work orders that did not have any cause, action, or defect assigned to them.

As can be seen, the accuracy of the fields within Coswin being filled out is good. A maximum error of 3.62% of unfilled work orders can be seen.

However, this type of check does not mean it was completed correctly. An engineer might have diagnosed the fault incorrectly, or accidentally selected the incorrect field when completing the work orders. This type of data solely relies on the engineers diagnosing and imputing data correctly, there will be an element of human error and difference of opinion between the engineers.

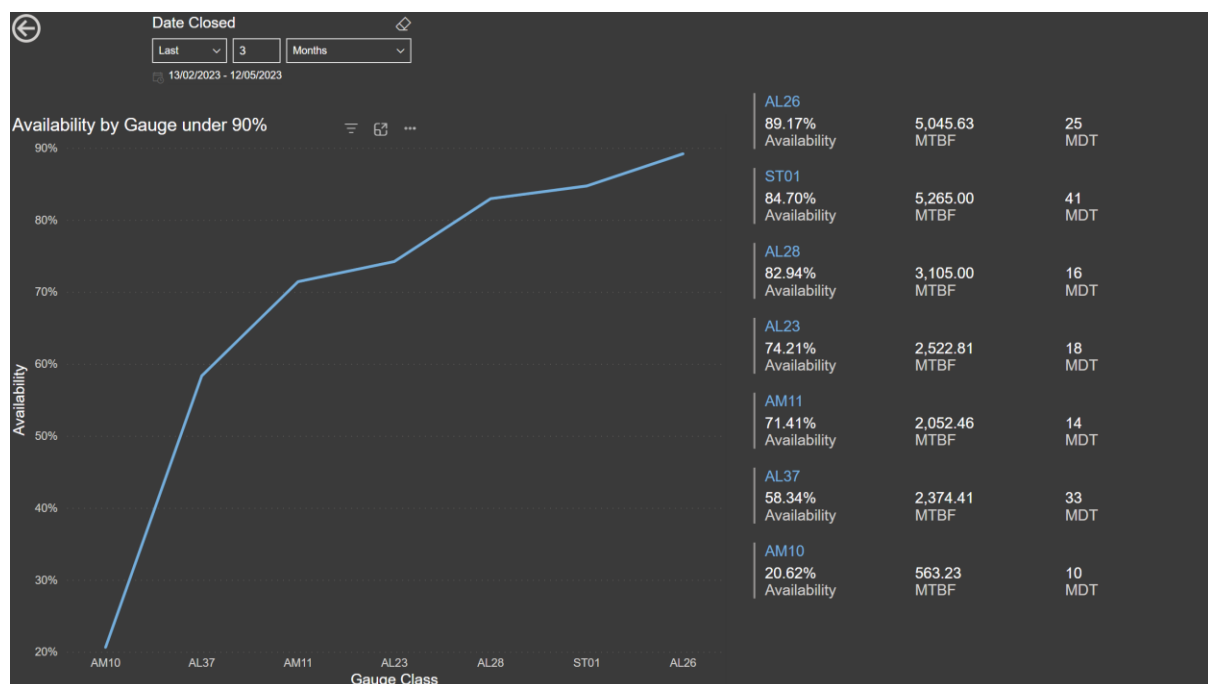
However, this data is reliable enough to calculate the important metrics.

CTS was compared with the total run hours of equipment, stored within Syteline. As can be seen from the data above, the error between CTS and run hours is 5 hours, for the last three-month period. This shows that CTS is not the most accurate data to use within the calculations. From this point, run hours from Syteline will be used.

15 - New Report

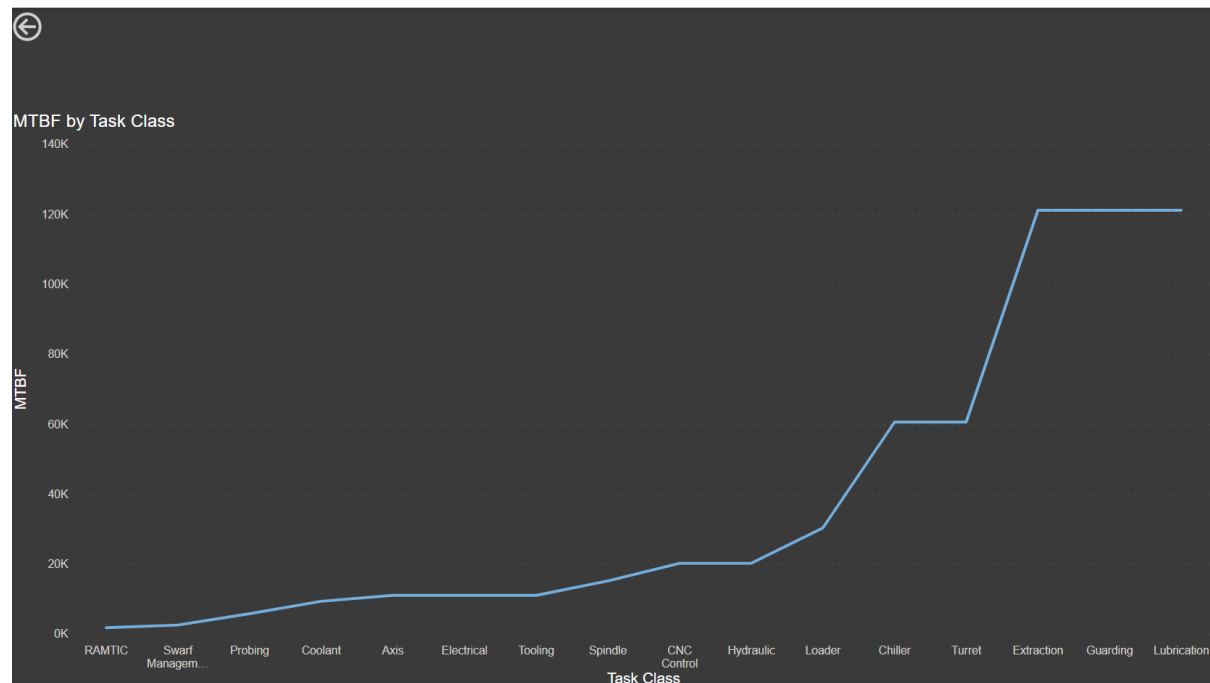
The layout has been improved and data sets simplified to keep the data concise and current with the report. All metrics from the research have been used and layered in the report depending on their use.

The first page of the report shows the availability of the equipment class. The availability of the equipment is displayed within the line graph, this graph has been filtered to only show equipment with an availability of less than 90%. This has been decided to allow for visibility of machine classes close to the 80% availability target. Along with the line graph, a table has been set up to display the availability, MTBF and MDT. This first page clearly shows which machine class needs a performance improvement project, and these can be easily prioritised based on their availability.



As can be seen above, the AM10 class of machine has a very low availability, of just 20%. However, looking at the MTBF and MDT, MDT is very low compared with other machines, showing a good amount of support for the equipment in terms of spares and maintainability. It looks from this page that the machines themselves are unreliable.

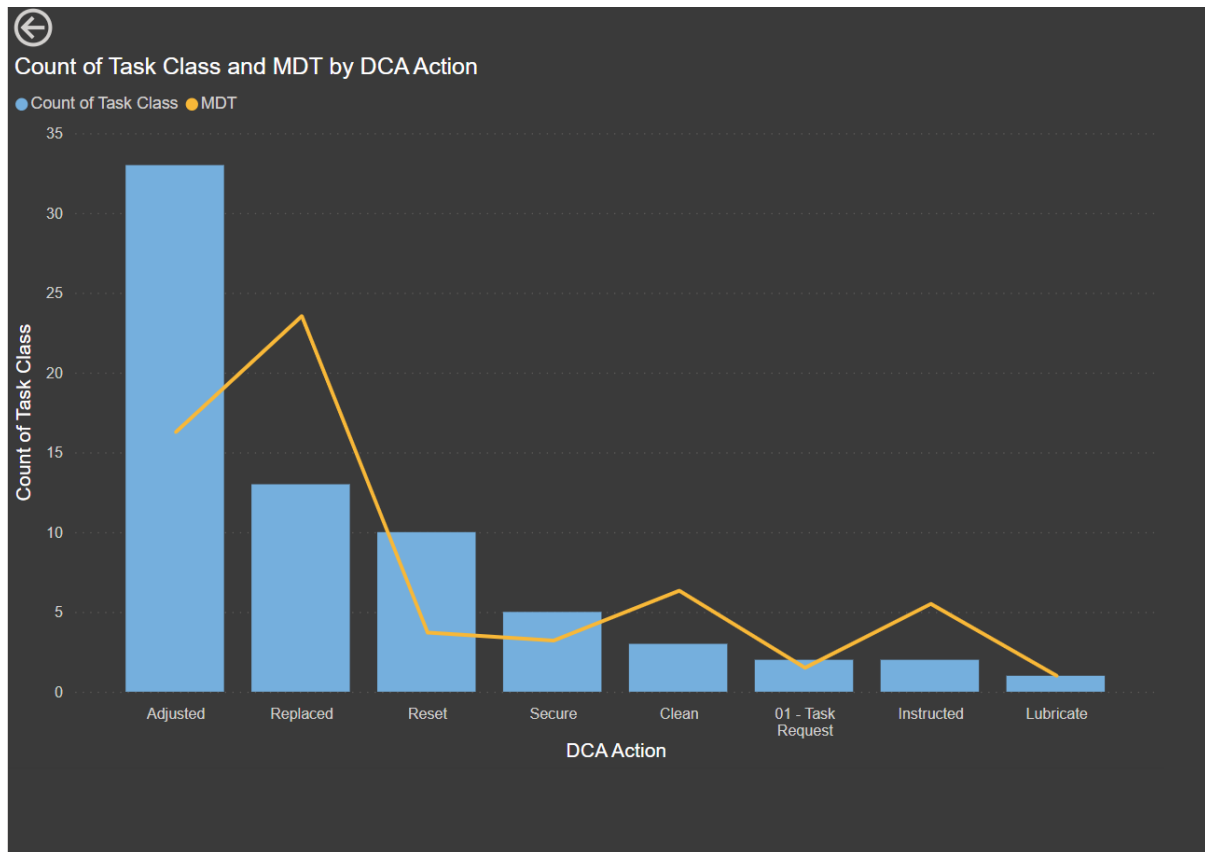
From this page, the users have the choice to drill through to either MTBF or MDT. As both metrics directly affect the availability, it's been chosen that these should be two separate areas of analysis. MDT would consider spares holding, resource and the maintainability of the equipment, and would thus require a different line of analysis to MTBF. MTBF would be affected by the reliability of the equipment, so data such as cause, action and defect would need to be reported on.



Concentrating on MTBF, the user can drill through to the MTBF by Task Class page. This graph displays the MTBF figures of each sub system of the selected equipment previously. As can be seen above, on the AM10 class of machine, it's clear to see that the MTBF is poor for RAMTIC related faults and Swarf Management. The graph is useful as it can show the sub system of the equipment that is the least reliable. This guides the user to investigate the sub system, which is least reliable, and can help prioritise workload.

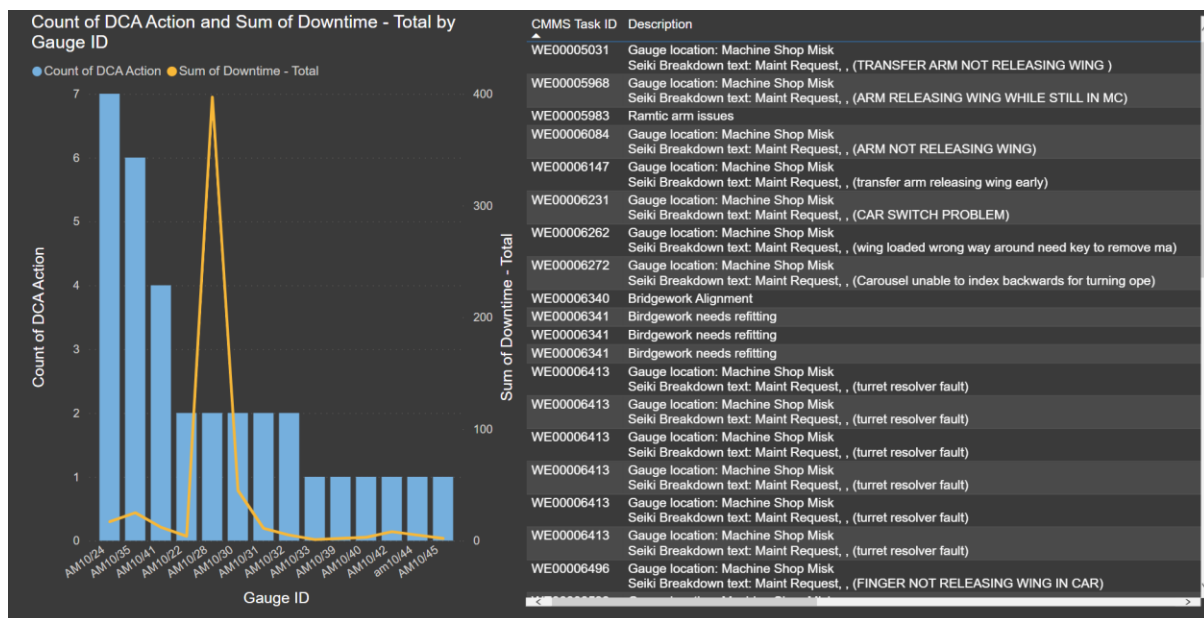
This graph also shows the overall reliability of the machine. Looking at the graph, most of the sub systems on this equipment have a low MTBF. Using this graph, the user can begin the reliability investigation by selecting the least reliable system. To investigate further, the user can drill through the selected sub system to display the actions page.

The page summarises the actions that have been taken to repair the filtered sub system to being operational. This is important as it narrows down the faults that the machine has had, and again prioritises the reliability projects.

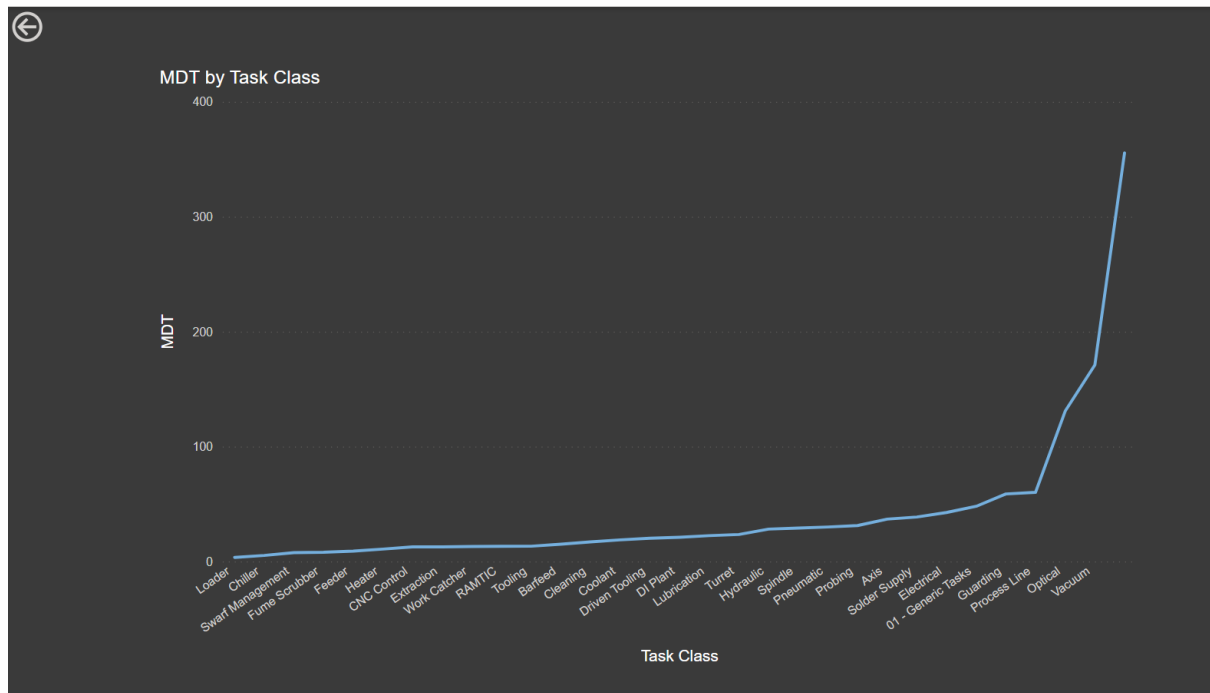


From this graph it is clear to see that most down time is accumulated through replacement of items and the adjustments made to the RAMTIC system. By displaying the count of the actions, it's clear to see the occurrence of issues with the equipment.

And finally, the page can be drilled down to the task details tab. This collates all the breakdown data associated with the action taken to fix the fault. This page shows the number of faults the machine has had with the same sub system, and information from Coswin has been pulled through such as the fault description, description of the work carried out, when the work was carried out and by which engineer. This information can lead suggest if there are repairs being carried out, are not correct or up to standard. Or highlight operational issues that might be cause the breakdown. It can also highlight a lack of training or experience within the engineering team when the same fault reoccurs.



Once the MTBF reports have been complete, the user can analyse the MDT. This begins at the first page for availability. The user can drill through the MDT figures, and it takes them to the MDT/Class page. This page again, filters the machine class from the availability section, and displays the MTD associated with the sub system of the equipment.



This page can be used to highlight any sub system that takes the most amount of time to repair. Highlighting this shows sub system that can potentially be made easier to repair, or quicker by stocking correct parts or additional training and experience.

To better understand how the downtime was accumulated, another visual can be displayed. This page displays the time the sub system has been in each sub status. The sub status shows whether the machine was running, waiting parts, waiting external engineer, other priority and waiting business systems. The report also shows the spares that were used, including spares that were ordered in. In the table it shows the purchase order number for spares ordered in, allowing the user to analyse the parts and lead times. This could influence the spares being stocked.

CMMS Task ID	New Sub Status	Year	Month	Day	CMMS Task ID	Item	Source	Gauge ID	Downtime - Total
WE00007104	Running - Othr Prior	2023	April	27	WE00007104	PLANT MISKIN	Purchase Order: PU03640686 Line: 1	ST01/02	495.00
WE00007104	Broken - Othr Prior	2023	April	25	WE00007104	PLANT MISKIN	Purchase Order: PU03640686 Line: 2	ST01/02	495.00
WE00007413	Complete	2023	April	25	WE00007413	PLANT MISKIN	Purchase Order: PU03641575 Line: 1	ST01/02	369.00
WE00007413	Running - Wtng Ext E	2023	April	25	WE00007413	PLANT MISKIN	Purchase Order: PU03641575 Line: 2	ST01/02	369.00
WE00007413	Running - Wtng Parts	2023	April	25					
WE00007413	Broken - Wtng Ext E	2023	April	24					
WE00007413	In Progress	2023	April	21					
WE00007413	Running - Wtng Ext E	2023	April	21					
WE00007413	Running - Wtng Parts	2023	April	20					
WE00007413	Broken - Othr Prior	2023	April	17					
WE00007413	In Progress	2023	April	17					
WE00007413	Running - Wtng Parts	2023	April	17					
WE00007413	Broken - Othr Prior	2023	April	16					
WE00007413	In Progress	2023	April	16					
WE00007413	In Progress	2023	April	15					
WE00007104	Running - Wtng Parts	2023	April	12					
WE00007104	Complete	2023	April	11					
WE00007104	In Progress	2023	April	11					
WE00007104	Complete	2023	May	2					
WE00007413	Complete	2023	May	2					
WE00007104	In Progress	2023	May	2					
WE00007413	In Progress	2023	May	2					
WE00007413	Running - Othr Prior	2023	May	2					

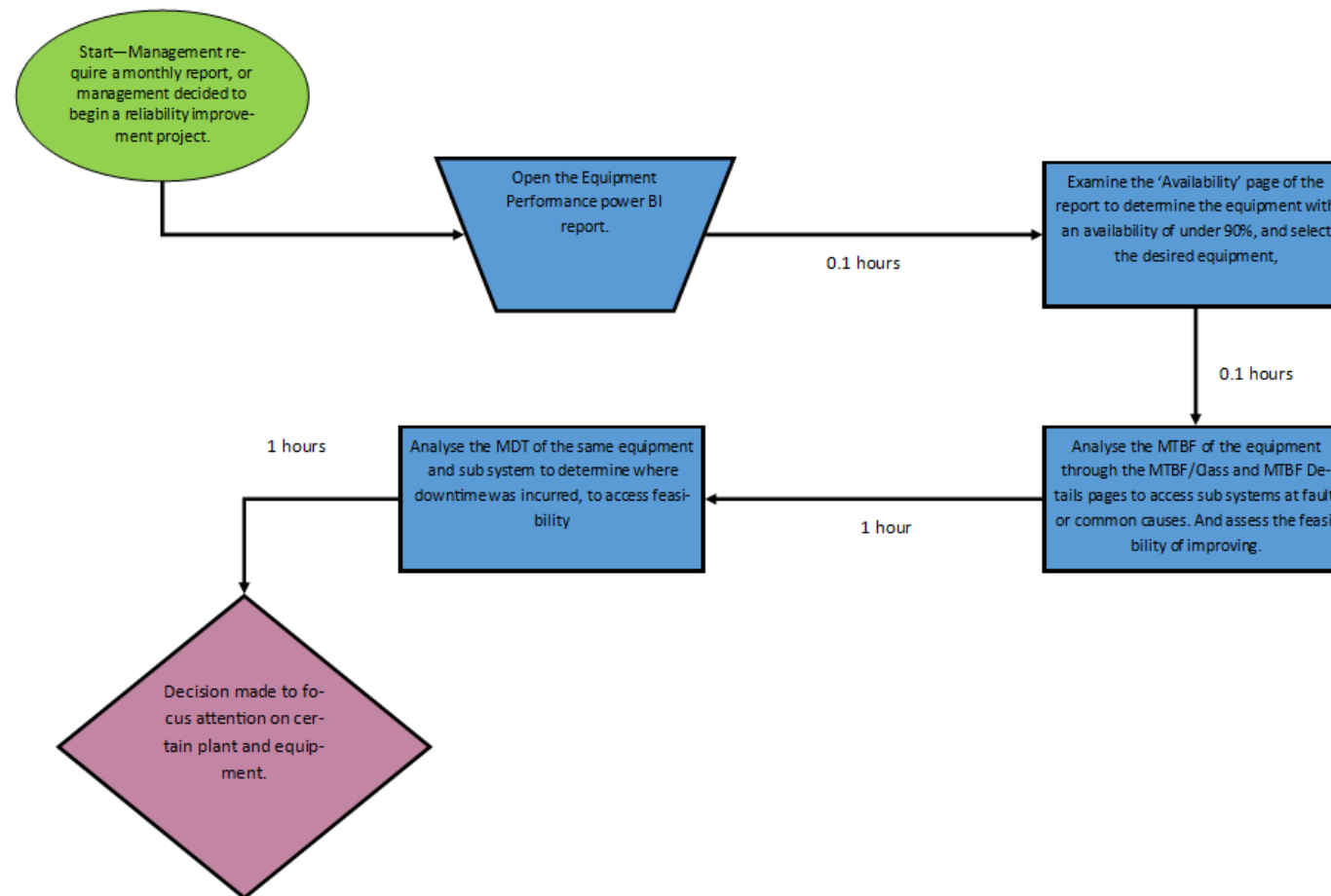
Vendor Item (Line)	Description	Sum of Item Cost
Carriage	Delivery	25.00
CARRIAGE-CHARGE	Carriage	15.00
SPEC/000257378	IFM-KQ6005 sensor	142.09
TECNOLOGIC K39 REGULATOR	DOUBLE DISPLAY	159.62
Total		341.71

Downtime breakdown will also report on the maintainability of the sub system and equipment overall. This would be given in the downtime attributed to the 'In Progress' sub status, but it can also show time waiting for external engineers, which could drive training requirements. The page also shows the amount of time the machine has been set to 'Other priority', this sub system is used when resource is unavailable, which could drive the increase in headcount, or drive the need to carry out performance improvement projects.

This page is the final stage of the report to analysing the mean down time of the equipment

16 - Process map of new report

To aid comparison of the new and old reports, another process map has been used. This map shows the same stages that are required to assess the current situation and determine which equipment requires performance improvement projects. Below is the new process flow.



17 - Evaluation of New Report

The first part of the report, availability, is a good metric to use. Within the report, it breakdowns each machine class for availability. The old report didn't use this metric, and thus was unable to tell how the equipment was performing. The old report also reported the plant as a whole, whereas the new report breaks this down into the different machine classes within the plant. This is much more beneficial, as it easy to see which types of machines are performing poorly, and in need of further investigation.

As Renishaw is driving productivity, is key to understand where this can be improved. The old report was unable to do this. The new report certainly does, by using availability. To increase productivity, the machines need to incur less downtime and less breakdown. Increasing the availability of the equipment will increase productivity, allowing for more components to be machines. Availability calculates, in percentage, if the equipment can run the amount of work required.

Not having visibility of this metric wouldn't allow for a full understanding of the plant's performance from a maintenance point of view.

Along with the availability, the user can see whether availability can be improved either by improving the reliability or reducing mean down time when breakdowns occur. The old report was unable to do this for two reasons. First, the report only considered MTBF across the entire plant, and thus unable to pinpoint any issues towards individual equipment, the second, downtime was not reported.

Equipment can be very reliable, a high MTBF, but suffer from high MDT. This can be more disruptive to the plant than having unreliable equipment. Having both side by side, in a table, can aid decisions when setting out on a reliability project. Resource is not abundant, meaning that any resource needs to be deployed at the correct area. The old report wouldn't be able to do this, and focus could be aimed at making the equipment more reliable, but still suffer from high MDT.

The new report reports on two important metrics. The first to consider is MTBF, the new report displays the MTBF of the equipment class. This drills down further than availability, so that the user can see of the machine is suffering from reliability issues. The report goes further and can breakdown the MTBF of the each of the sub-systems within the piece of equipment. This can highlight which part of the equipment is least reliable. This can focus resource when carrying out improvement projects and shows where MTBF can be improved the most to improve the availability of the machine, increasing productivity.

Being able to drill through the data again for the MTBF of the sub system, the actions taken to correct the sub system. The report ranks the actions taken on based on the MTTR of the task and the number of times this action has been done. At this stage reporting on the MTTR is useful as it shows where most of the downtime has occurred. Targeting this through reliability projects could drive down the downtime, increasing productivity. Again, the report allows the MTBF of the actions to be drilled down to gain further information on these faults.

This part of the report, Task Details, reports the MTTR and number of breakdowns for the action and sub system collected for each individual piece of equipment. This part of the report can highlight if certain equipment has repeat issues. It also details the fault the equipment had; the actions taken by the engineer to resolve this issue. This section of the report is very informative as decision can be made as to which piece of the equipment to carry out reliability projects first, it can highlight the need for training in certain engineers and it can show any anomalies to repairs. Improving training, skill and decrease downtime all positively affect the productivity of the plant.

By reporting on the engineer who worked on the equipment, and the date of the faults, it can be seen if the work that the engineer has carried out has been successful. Sometimes with inexperience, tasks can be booked back on as the work hasn't been done quite correctly. This can drive additional training to prevent these occurrences.

The old report was not able to report the maintainability of the equipment, but the new report does. Starting at the beginning of the report, availability, this page shows the MDT of the plant. A high MDT can be disruptive to production. It is important to understand how where the downtime is being accumulated and what can be done to improve this. Reducing downtime will improve productivity.

The new report can report on the MDT of the equipment, and drill down further in the data to report on the MTTR of the sub system. The report changes to use MTTR to remove downtime as it's important now to understand how maintainable the sub systems on the equipment are. This part of the report highlights where downtime is accumulated during a breakdown. This is important as it could highlight certain sub systems that are difficult to maintain, improvements could be made to increase the maintainability of the systems. Again, this could also drive training requirements as it can highlight lack of understanding for the systems when fault finding.

Again, the new report can drill down to report on the reason for the downtime associated with the sub systems of the equipment. Within this drill down it can show where the downtime was incurred. This information could drive additional resource, it can drive stock holding, and drive training requirements. This will drive the improvement in productivity whilst keeping

costs at an acceptable amount. With the cost of parts being so large, its key to stock the correct parts at the correct number, this report can aid these decisions.

However, the table showing this downtime distribution can be difficult to read and understand how it is distributed. This could do with improvement within the further work to calculate the hours spent within each sub status.

KPI's have been set for the new report, that is for availability. The availability KPI has been set to 80% total availability. This has been decided during a steering group session, equipment with an availability of under 80% has the ability to improve it's availability. Research has shown that industry standard target for equipment performance should be 80% availability. The report shows any under 90% availability to give sight of any equipment nearing the 80% target.

The report is also self-updating and no longer requires any user input now that it is set up and published. All calculations are done within the report. The report has cut down the time to carryout out an investigation in the reliability of the plant quite considerably. The old report would take 5 hours to create and update, and failed to contain all the information required, adding more time when working through individual work orders. The new report is takes around 2 hours to work through and understand where the reliability project needs to be carried out.

The report can be used to monitor the equipment over time, and any equipment that falls under 90% availability, will trigger an investigation into the reason why. This could mean a reliability projects to be carried out, additional stock holding, resourcing, or training.

Overall, the new report successfully reports on the reliability of the equipment, and it can be used to successfully analyse the reasons why the plant is not reliable or easily maintainable. Using this report with guide resource in improving the productivity of the plant, using the data from the report.

18 - Conclusion

In conclusion the new report successfully meets the aims of the project and overcomes the problem statement. Renishaw wants to increase productivity, the old report would not have been able to report on the reliability of the equipment effectively, or report on the maintainability of the equipment.

By using this new report, it is now possible to determine the availability, reliability, and maintainability of the equipment. The report displays the data for each sub system to highlight any issues and highlights individual machines if they have reoccurring faults. The report can drive stock holding, training and drive reliability projects in the most effective areas.

The new report uses industry standard techniques, including MTBF, MTTR, MDT and Availability. These metrics have been reported using graphical techniques that effectively show the current state the equipment is at. These metrics have now been used as KPIs for the equipment, especially availability. Once the availability hits below 90%, then this triggers a investigations into the reasons why, and later improve upon it.

As discussed, earlier the report does update itself, making it easy for the management team, and works engineering staff to use without needing to create the report. This has cut down a time that it takes to investigate issues such as reliability, and it has removed a large aspect of human errors.

However, the data used in this report is entered into Coswin by the engineers. This could cause confusion when analysing the data or change the data displayed in the report. From the data analysis, the data is relatively accurate with around 3% of error.

More information was needed overall to create the new report. This was only realised whilst developing the first report. Additional information such as sub status times, materials used, purchase orders attributed to the task and actions taken by the engineer. These were required to be able to carryout the final analysis of the equipment to have an effective report.

The report also took much longer to develop than anticipated. The original plan was to complete the final report within 8 days; however, this took 14 days to completed, partly due to workload of other tasks. Training documents have not been produced, as it was felt during the steering sessions that the report was easy to use and analyse. A reporting session will be run to educate the users at how each metric affects each other.

The data surveys also took longer than expected, this was due to not knowing the location of the data and not having the permissions to access.

The true effectiveness of the report is not yet known, this will only be known when the report is used to assess the availability of the equipment and actions taken to improve it. This will become part of the further work for this project.

Overall, the new report successfully reports on the reliability of the equipment, and it can be used to successfully analyse the reasons why the plant is not reliable or easily maintainable. Using this report will guide resource in improving the productivity of the plant, through data driven decisions.

19 - Recommended Further Work

Further improvement can be made to the report by calculating the time between each status for the downtime breakdown page. This will make it easier to understand how the downtime is split up between each status to drive decision in resource and stock.

The next stage of the project is to carryout a full analysis of the equipment using the new report. The data should be drilled through as intended and corrective actions put in place. Focus should be made at the worst performing equipment class. Once the actions have been put in place, the new report shall be used again to access the effectiveness of the actions and the effectiveness of the report itself.

Further to the above, this report needs to be developed and tested for the equipment on the assembly division of MSD. These areas have a completely different range of equipment and are not within designated classes as machine shop is.

20 - Bibliography

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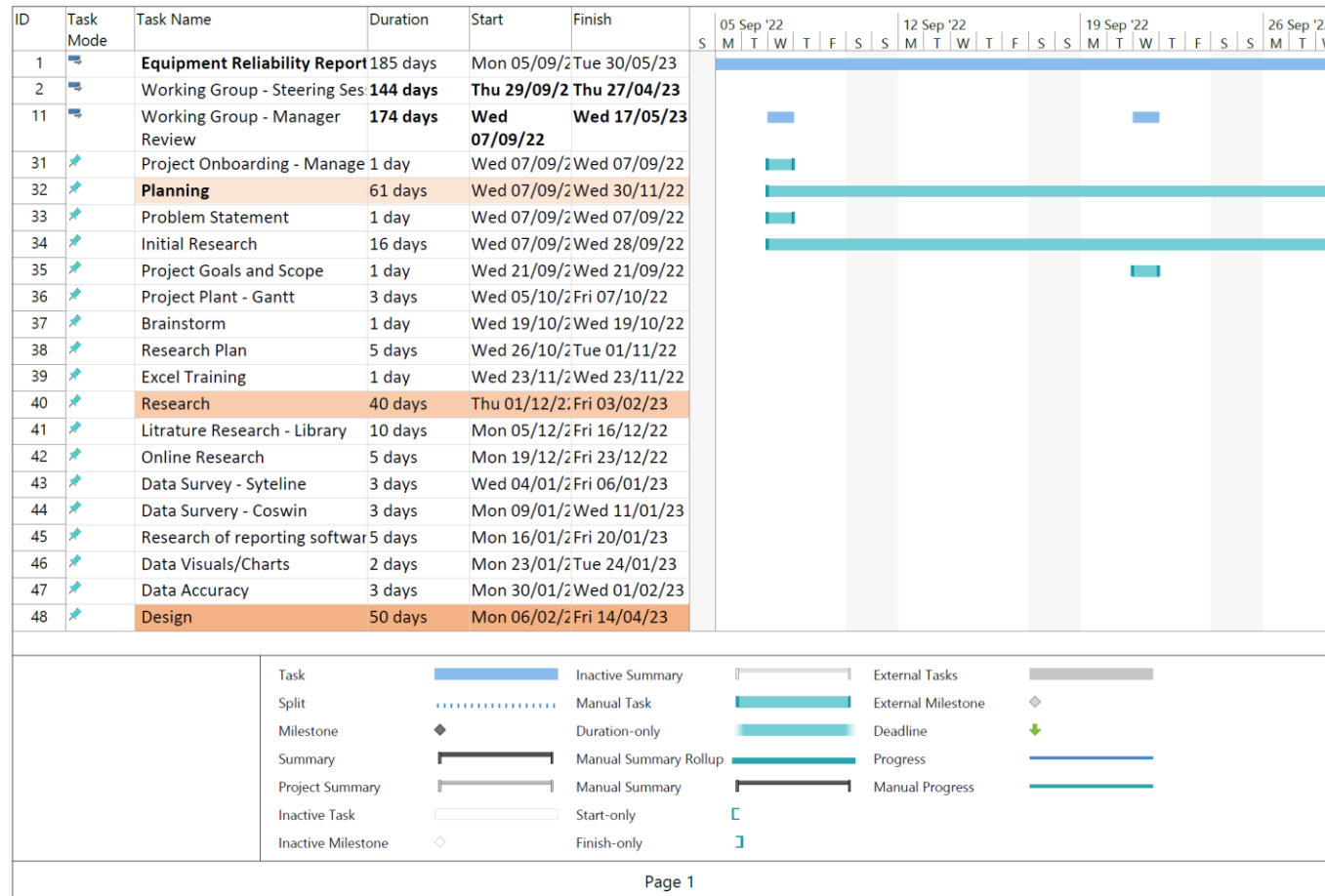
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21 - Appendices

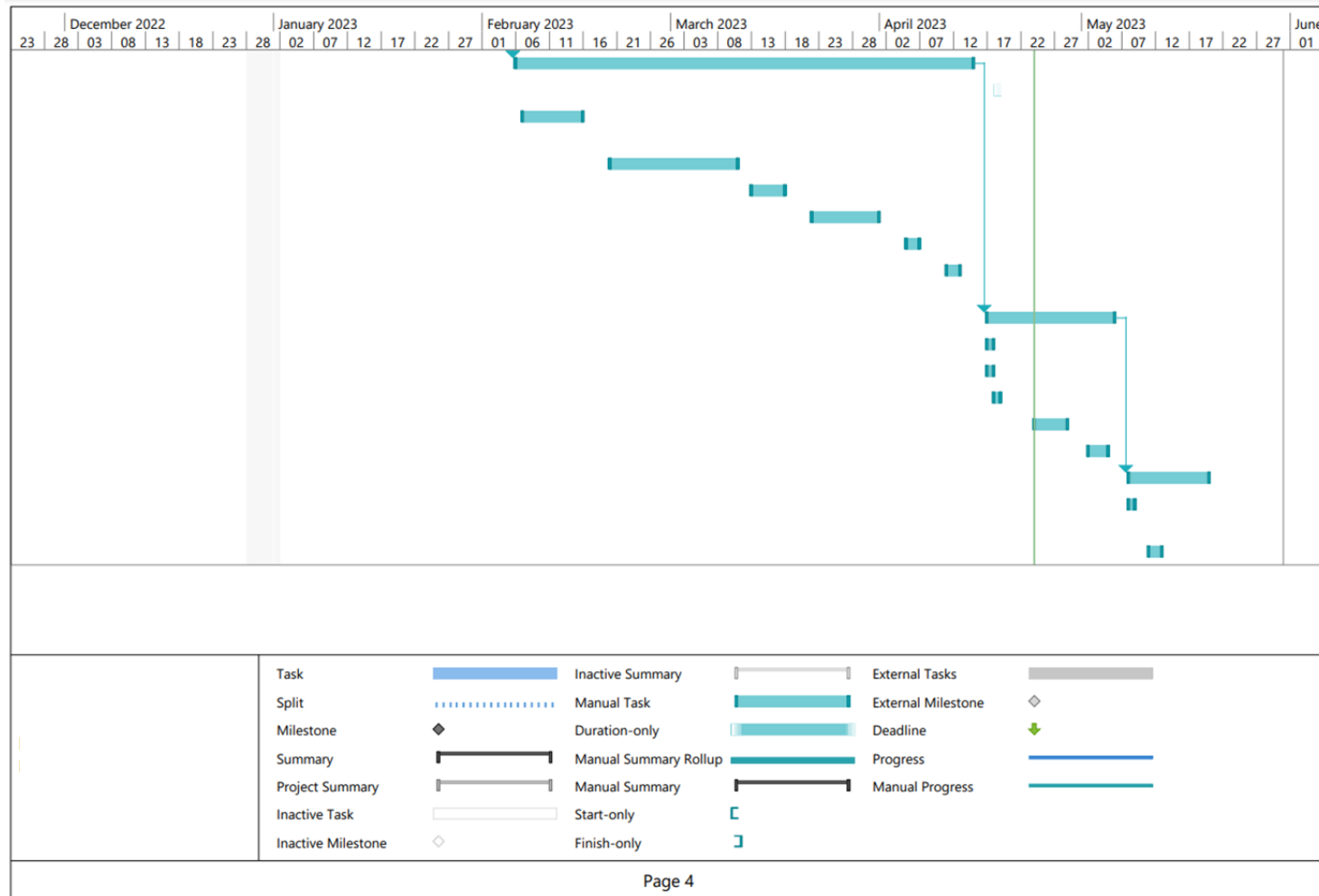
Project Plan – Appendix 1



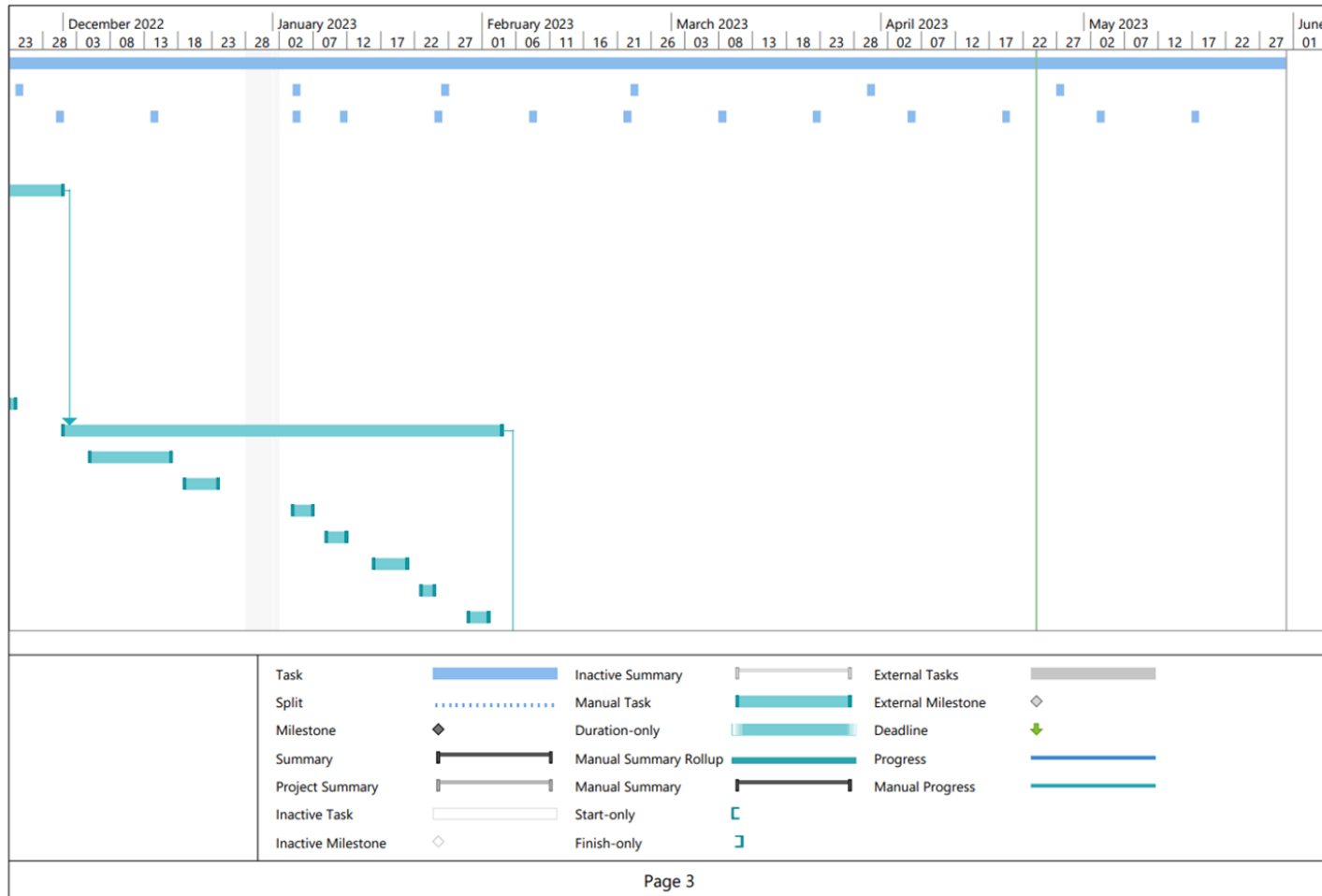
Project Plan – Appendix 2

ID	Task Mode	Task Name	Duration	Start	Finish	05 Sep '22	12 Sep '22	19 Sep '22	26 Sep '22
						S M T W T F S S	M T W T F S S	M T W T F S S	M T W T F S S
49		Additional Software Training	1 day						
50		Reliability Metrics Review/Chosen	7 days	Tue 07/02/23	Wed 15/02/23				
51		Initial Design of Report	15 days	Mon 20/02/23	Fri 10/03/23				
52		Final Design of Report	15 days	Wed 22/03/23	Tue 11/04/23				
53		Implement	15 days	Mon 17/04/23	Fri 05/05/23				
54		Pubish Completed Report	1 day	Mon 17/04/23	Mon 17/04/23				
55		Display Report Appropriately	1 day	Tue 25/04/23	Tue 25/04/23				
56		Correctly Store Published Rep	1 day	Wed 26/04/23	Wed 26/04/23				
57		Control	10 days	Mon 08/05/23	Fri 19/05/23				
58		Consider Regular Review Meetings	1 day	Mon 08/05/23	Mon 08/05/23				
59		Review New Reporting Strategie	2 days	Thu 11/05/23	Fri 12/05/23				
Task Split Milestone Summary Project Summary Inactive Task Inactive Milestone Inactive Summary Manual Task Duration-only Manual Summary Rollup Manual Summary Start-only Finish-only External Tasks External Milestone Deadline Progress Manual Progress									
Page 2									

Project Plan – Appendix 3



Project Plan – Appendix 4



Brainstorm – Appendix 5

