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Development of a Maintenance Strategy to Optimise Maintenance in a World Scale Bioethanol Production Facility

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Abstract. Effective maintenance management systems can provide the right maintenance on the right assets at the right time [1]. Maintenance management at a bioethanol production facility can prove to be difficult. The combined nature of chemical plant and solids handling creates issues with varying levels of maintenance required. The aim of this paper is to determine the correct maintenance, at the correct time for the bioethanol facility by developing a new maintenance structure and the use of mathematical models to enhance decision making in maintenance. It is not uncommon for chemical plants to run six yearly campaigns, but a solid handling plant needs regular interventions to maintain operations. In order to gain a strategic advantage in the marketplace, ensuring the best maintenance and reliability practices are key to the long-term future of the factory and by keeping a focus on maintenance management improvements can be made to the position of the business both operationally and financially. The financial gains will be seen in the reduction of plant downtime for repairs and maintenance that is delivered on the correct frequency and thus lowering the costs of replacement machinery or parts and as the cost reduction is seen, the operation gains will be realised via the previous too. World scale refers to the factory being second largest producer in the EU27 and UK of bioethanol and the UK's largest producer of animal feed.

Keywords. Maintenance strategy, maintenance optimisation Bioethanol production.

1. Introduction

Maintenance is a very defined term, as too are the maintenance approaches. The British standards Institute [2] define maintenance as a "combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function" [2].

In maintenance best practices, Ramesh Gulati [4] defines it as tasks performed to prevent failure and tasks performed to restore an asset to its original condition. As a company's operational budget is greatly affected by maintenance costs, controlling maintenance is essential to minimise costs to the operational teams. [6] expands on the explanation above by stating that the term includes preservation of equipment conditions, the repair of broken equipment and the prevention of failure, citing that ultimately it reduces the cost of production losses. It also claims that maintenance has moved from a peripheral activity into an integrated part of the production process. The need for a sound maintenance strategy is not a new one. Since the 1970's the tide had shifted from research and development (R&D) being the "darling" in the engineering world and maintenance

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being an essential evil, but since the 1990's operation and maintenance (O&M) has since been occupying a peer position within organisations [8].

2. Approaches to maintenance management

Generalisation of the terms used in maintenance are mainly categorised in two functions, failure-based maintenance, and life-based maintenance. [4] has grouped maintenance approaches into four basic categories:

- Condition-based monitoring (Predictive Maintenance)
- Preventative Maintenance
- Proactive maintenance
- Corrective Maintenance

2.1 Condition-based monitoring (Predictive Maintenance)

The main philosophy in condition-based maintenance (CBM) or Predictive Maintenance (PdM) is to assess and evaluate the condition of a plant asset by either routinely or constantly monitoring its condition. Typically performed whilst the item is operating, it reduces the time an asset is shut down for maintenance and picking up on trends of potential issues, these can be scheduled in for corrective work. Common methods include.

- Vibration Analysis
- Thermography
- Oil Analysis
- Audio Visual Inspections (AVI's)

2.2 Preventative Maintenance

Maintenance such as oil changes and filter changes form a preventative maintenance program. This typically requires the asset to be shut down whilst intrusive work is carried out. These would normally involve a routine or checklist to check against and any tell-tale signs of wear and depreciation will be reported, and further work scheduled in. These are normally based on calendar time or asset run time [4].

2.3 Proactive maintenance

This can be typically described as work tasks done to avoid failures, including work that is carried out in the previous two sections and any other planned and scheduled routine maintenance [9]. This can be determined by equipment criticality and allows the user to use valuable resources to be assigned appropriately [3]. When a machine or component's life span can be classed as predictable, then items can be replaced or returned to an optimal condition of a time-based approach.

2.4 Corrective Maintenance

When an asset breaks down, it stops providing its required function. To rectify this, corrective maintenance must take place. This can be reactive maintenance and run to failure maintenance. Some forms of corrective maintenance can take place from the results of routines in CBM programs and rectify at a scheduled time [4]. Normal corrective maintenance is carried out after a failure or stoppage causes a severe decline in production [7].

3. Research methodology

The purpose of this paper is to investigate the most suitable strategy for maintenance on an upper-tier COMAH (Control of Major Accidents Hazards) chemical plant. COMAH is in reference to the regulations that ensure businesses “Take all necessary measures to prevent major accidents involving dangerous substances. Limit the consequences to people and the environment of any major accidents which do occur” [5] Papers in journals and other academic data will be used to determine the most effective way to build an entire maintenance process. Current methodologies and leading industry sources will also be used in the creation of mathematical modelling. Taking the information given from the leading industry sources a maintenance structure will be built. Published research papers in the field will be used to determine the mathematical models to create a system where the right type of maintenance can be carried out based on real factors in the industry. As all plant operating losses are recorded, being able to calculate the potential losses due to plant failures can help form the argument for maintaining or altering the maintenance practices.

4. Development of Maintenance processes

Determining the correct approach to building or rebuilding the maintenance department at the production facility was to be the vital and major task. [4] stated that the development and management of people are key in creating a productive, operating, and successful business. The section below will show how the maintenance process will operate to create a department that was able to fulfil its requirements to serve the wider operational team.

Figure 1- Bioethanol Maintenance Process

The maintenance process team consisting of the Maintenance Planners, Scheduler, Maintenance Delivery Coordinators, Maintenance Manager, CMMS Administrator and Engineering Manager convene weekly to review the maintenance activities completed and monitor performance against KPIs. Such as % scheduled compliance (i.e., work scheduled vs completed), work order backlog, overdue work orders etc. Maintenance work should be prioritised against the asset criticality ratings accordingly, and any reprioritisation can be discussed during the weekly maintenance process meeting.

5. The proposed mathematical model to calculate operational margin

Using current market data, an equation has been developed to calculate the margin of profit or loss per tonne of wheat converted into Ethanol and dried distiller's grains with Solubles (DDGS).

$$\frac{\left(\left(\frac{\left(\frac{Ethanol\,Price\,(Euro)}{Exchange\,Rate\,(£)}\right)}{0.789}\right)*Ethanol\,Tonnes\right)+(Animal\,Feed\,Price\,(£)-Animal\,Feed\,Tonnes)-(Wheat\,price*Wheat\,Tonnes)}{Wheat\,Tonnes\,per\,Year}$$

Equation 1- Operational Margin Equation

The margin is generated from the difference between the revenue from its products (ethanol and animal feed (DDGS)) and the cost of feedstock (wheat). Due to the nature of the markets in which it operates, this margin can be very volatile, and consequently, a bioethanol facility will actively manage the risks surrounding the pricing of its feedstock, products and utilities. In doing so in an effort to minimise the risk to the company of detrimental margins, whilst also capturing opportunities to maximise the margin.

6. Maintenance Case Study

Using the information gathered in the maintenance information loop demonstrated in Figure 2, data has been collected for the centrifuge separators within the bioethanol factory. The optimal interval times can then be determined using a mathematical model that will indicate the correct maintenance interval for the application of the asset.

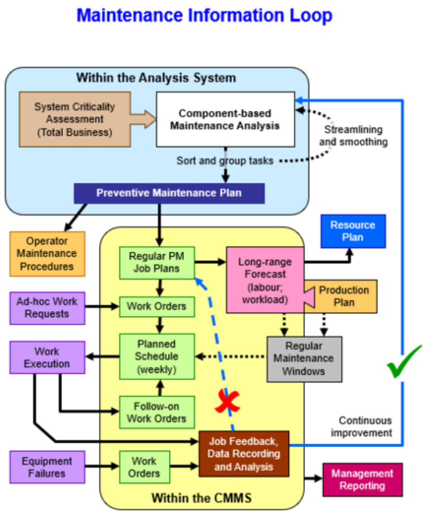

Figure 2 - Maintenance Information Loop

Given the feedback into the CMMS system around the failures that have been seen with the separators, it has been made the focus of this case study to identify the correct maintenance schedule for the machines.

7. The proposed Total Maintenance Cost Model

Maintenance costs are a key controllable for industrial companies in the battle to maintain operational advantages against the volatility of the commodities marketplace. Approximately 75% of total expenditure on life cycle costs are due to maintenance [1]. Equation 2 was used to calculate the total maintenance cost taking into consideration a balanced decision between preventive and corrective maintenance costs [10]

$$TMC = \frac{((C_{mc} * F\Delta t) + (P_{mc} * (1 - F\Delta t))}{T * (1 - F\Delta t)}$$

Equation 2 - Total Maintenance Cost Model

C_{mc} = Cost of Corrective Maintenance
P_{mc} = Cost of Predictive Maintenance
$F\Delta t$ = Probability of failure
T = Time

The use of a mathematical model to calculate the total cost of maintenance is a step forward for the maintenance department. Currently, the scheduling aspect of serviceable equipment is based largely on the Original Equipment Manufacturer (OEM) recommendations, with little analysis done to challenge the interval frequencies. The next section is to determine the factors that will form the basis for the model to be effective. Using the data that has been collected from the CMMS program and loss data the next steps are to calculate the cost of the spares (C_{sp}), calculate the probability of failure ($F\Delta t$) using equation 5, calculate cost of corrective maintenance (C_{mc}) using equation 3, calculate the cost of preventative maintenance (P_{mc}) using equation 4, and finally calculate the Total Maintenance Cost (*TMC*) using equation 2..

$$C_{mc} = ((\sum_{i=1}^{n} C_{sp} * P_{rp}) + (X_1 * S_{mh} * T_{ic})) + P_{lc}$$

Equation 3 - Cost of Corrective Maintenance

C_{sp} = Cost of spare parts
P_{rp} = Probability of replacing parts
X_1 = Number of Maintenance Personnel
S_{mh}= Maintenance Personnel Salary
T_{ic} = Time spent by maintenance personnel in corrective action
P_{lc} = Production Losses Cost

$$P_{mc} = ((\sum_{i=1}^{n} C_{sp} * P_{rp}) + (X_1 * S_{mh} * T_{ip}))$$

Equation 4 - Cost of Preventative Maintenance

C_{sp} = Cost of spare parts

P_{rp} = Probability of replacing parts

X_1 = Number of Maintenance Personnel

S_{mh}= Maintenance Personnel Salary

T_{ip} = Time spent by maintenance personnel in preventative actions

Using the Weibull distribution to calculate the rate of failure and identify the two variables 1. shape and 2. scale parameters. The data have been plotted on a graph to obtain the shape and scale parameters required for the failure calculations. 61 sets of delay data have been used to calculate the Weibull modulus obtained.

Shape Parameter (α) = 0.0909
Scale Parameter (β) = 0.01080

$$F\Delta t = 1 - e^{-(\frac{t}{\beta})^{\alpha}}$$

Equation 5 - Probability of Failure

β = Scale Parameter
α = Shape Parameter
t = Time Delay

Both values of preventative and corrective costs are used and inputted into the TMC equation seen in equation 2. The probability of failure that has been calculated and is used to complete the TMC model. Figure 3 displays the behavior of the TMC, it can be observed that the lowest cost of maintenance is found at 2016 hours running. This is nearly 1000 hours less than the OEM recommendation for the service.

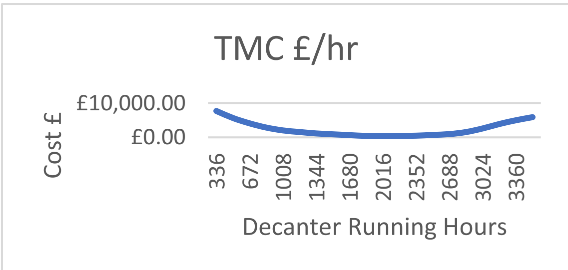

Figure 3 - Total Cost of Maintenance – Separators

8. Conclusion

The lowest cost for maintenance on the separators has been found to be at 2016 hours of running. as the maintenance frequency for the machine is set at 3000 running hours by the OEM it has not been proven and decided that the minor service maintenance frequency will be lowered by 1000 hours to 2000 hours. The next set is to change the service frequency in the CMMS system to 2000 hours and adapt our preventative maintenance sheet to reflect these changes. By using the proposed model to calculate the most optimum service frequency, we can apply this data to a live plant and follow up on its findings. This data has been taken from a live plant and reflects the real-life circumstances that are affecting the machines' operability. This model has highlighted that the servicing of the separators is insufficient to maintain the equipment properly and taking these findings, these will be reflected in the plant maintenance schedules going forward. The continuous improvement loop seen in figure 2 will reflect the changes that will be made to the scheduling of preventative maintenance work orders and in time will show a reduction in the corrective maintenance work order created. Given that the maintenance costs for servicing will be more frequent, we should be able to show some real savings due to a significant reduction in plant losses due to the separator reliability.

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