OPTIMISING MAINTENANCE STRATEGIES IN THE PROCESS INDUSTRY TO MAXIMISE THE ENVIRONMENTAL PERFORMANCES OF ASSETS

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Summary: Advantages and disadvantages have been associated with the different maintenance concepts. A major disadvantage of all of the maintenance strategies and related techniques is that environmental implications are typically not taken into consideration during the design stage of asset life cycle management, especially in developing countries such as South Africa. Maintenance strategies have primarily been concerned with cost risk parameters associated with maintainability and reliability only. The potential costs of environmental impacts are therefore not included as a specific risk management parameter in the design phase. However, considering the increasing legislation regarding the environment process industry companies must focus on the environmental impacts of operations and assets. Furthermore, if environmental risk considerations are taken into account during the design stage, problematic and costly cleanup programmes may be avoided during later asset life cycle stages. This paper proposes a modification of current maintenance strategies to adequately consider the environmental impacts of assets during maintenance cycles. Case studies in the South African process industry are subsequently used to demonstrate the incorporation of available environmental management tools and approaches into the maintenance management strategies and techniques.

Keywords: Maintenance strategies, maintenance models, life cycle management, asset management, environmental performance

1 INTRODUCTION

In the South African process industry, as in most other parts of the world, environmental implications were not taken into consideration thirty or more years ago when many present assets were designed in their life cycles. Maintenance strategies were concerned with the main parameters maintainability, reliability and cost. The risks of potential environmental impacts were therefore not incorporated into the design decision-making practices. However, more strict legislation regarding the environment force companies to focus on the environmental implications of their business. Therefore, the total life cycle of an asset and the associated maintenance strategy must be changed to accommodate the environmental impacts of the asset.

1.1 Research objectives

This research study is based on evaluations of typical asset management strategies in the South African process industry in relation to environmental impacts of the assets. The study subsequently aims to provide recommendations and propose best practices that can be implemented in the process industry. An improved life cycle and maintenance strategy model is introduced and utilised specifically for this purpose. Thereby, the potential future environment impacts and liabilities of assets can be assessed during the design stages of asset life cycles.

1.2 Current asset maintenance strategies

The different maintenance strategies that are currently being used in the process industry can be summarised as follows:

- Run-to-Failure or Breakdown Maintenance. The strategy is to run the asset to failure and then to repair it. The approach is totally reactive and is often justified by the uncomplicated and over design of assets [1]. A definition of corrective maintenance is "*any maintenance activity which is required to correct a failure that has occurred or is in the process of occurring*" [2].
- Preventive Maintenance. Preventive maintenance is an equipment maintenance strategy based on replacing, overhauling or re-manufacturing an item at a fixed interval, regardless of its condition at the time [2]. It can therefore be seen as a time-based maintenance strategy, which consists of the following elements:
    - Firstly, the periodic inspection of assets and the frequency of inspection are determined by experience or, in case of new equipment, by the manufacturer's recommendations.
    - Secondly, breakdowns or asset failures are reported and analysed so that corrective maintenance action may be taken to prevent such failures in future [3]. This maintenance strategy is very expensive because the asset needs to be taken off-line, inspected and any repairs done if necessary before being brought back into operation [4].
- Predictive Maintenance. Predictive maintenance is a more condition-based approach to maintenance. The approach is based on the measurement of an asset's condition in order to assess whether equipment will fail during some future period and then taking action to avoid the consequences of those failures. This approach is a more economically feasible strategy as labour materials and production schedules are used much more efficiently [4].
- Proactive Maintenance. Proactive maintenance is defined as "*a style of initiative that is anticipatory and planned for*" [5]. Proactive maintenance concentrates on the monitoring and correction of root causes to asset failures [4].

2 LIFE CYCLE MANAGEMENT OF ASSETS

Life Cycle Management (LCM) considers the lives of assets and associated products in a holistic way with the aim of achieving maximum performance [6]. The demand for a LCM approach to assets stems from economic, regulations and standards, and natural environment drivers [6]. In terms of the latter, process industries have been increasingly driven to minimise natural resource depletion through optimising resource usage and minimising pollution in addition to the reduction in costs throughout the asset and product life cycles. One of the main problems that arise is the consideration of immediate and long-term environmental implications of current and future operations, which may extend beyond the local to regional and global spatial scales.

Although maintenance forms part of the operational phase of asset life cycles, it is not incorporated in such a way that the maintenance and the environmental performance of these assets are combined in a holistic approach in order to maximise the environmental performance of physical assets in the process industry. Therefore, a new model is required whereby the available environmental performance assessment tools of LCM (see Table 1) are incorporated into the maintenance strategies, as introduced in section 1.2. Based on the strengths and weaknesses of the different LCM tools, Table 1 recommends that the Life Cycle Costing (LCC) [7], Life Cycle Assessment (LCA) [8] and Life Cycle Engineering (LCE) [9] tools be incorporated into the maintenance techniques, together with certain aspects of the formalised Environmental Impact Assessment (EIA) procedure [10].

Table 1. Summary of the environmental performance assessment tools of the Life Cycle Management approach.

Life Cycle Costing	
Strengths	**Weaknesses**
Focus on total life cycle regarding costs: Detail design, Construction, Operation/Maintenance & decommission.	May be subjective. Environmental and social risks may not be considered.
Environmental Risk Assessment	
Strengths	**Weaknesses**
Focus proactively on risks that can negatively affect the environment. Implement mitigation actions for these risks.	Focus only on risks and do not take total life cycle into account. No link between maintenance of assets to mitigate environmental risks.
Life Cycle Assessment	
Strengths	**Weaknesses**
Focus on total life cycle of an asset to achieve sustainable development: Detail design, Construction, Operation/Maintenance & decommission. Quantitative tool.	Often subjective. Only environmental impacts are considered and not social and cost aspects of the life cycle.
Life Cycle Engineering	
Strengths	**Weaknesses**
Focus on total life cycle of an asset: Detail design, Construction, Operation/Maintenance & decommission. Focus on maintenance strategies from the design phase.	May be subjective. Social considerations are excluded.

2.1 Asset life cycle and maintenance strategy model

A new asset life cycle and maintenance strategy model is proposed in order to integrate LCM tools and maintenance strategies into the life cycle of assets and associated products. Figure 1 illustrates the new model.

The model can be divided into two parts. The bottom part of the model can be seen as three sections. The first is the two life cycles of assets and products that are the basis for the model. The second is the Life Cycle Management (LCM) tools and the third section represents the maintenance strategies.

The LCM tools are positioned between the asset and product life cycles, which indicates that it must be incorporated into the total life cycles of the asset and associated products. The LCM tools that must be used are Life Cycle Costing (LCC), Life Cycle Assessment (LCA) and Life Cycle Engineering (LCE). It is not the intention to ignore other LCM tools, which must still be used for their specific purposes, but these tools have specific focuses that cannot be incorporated within the maintenance strategies.

The maintenance strategies are also between the two life cycles and on the same level as the LCM tools. Thereby, it emphasises the important relationship between the LCM tools and the maintenance strategies. Maintenance strategies must be part of the detailed design of each of the asset life cycles in the different phases of the product life cycle. In the detailed design and pre-manufacturing it must be decided which of the strategies will be followed to ensure long-term sustainability of the asset or the product. The strategies can either be run-to-failure, preventative, predictive or proactive maintenance.

The maintenance strategies must also form part of the LCM tools. When, for example, LCC is performed then the type of maintenance strategy that was decided upon in the design phase would influence the overall life cycle costs. If the strategies are not part of the calculation then the true and holistic costs will not be reflected. The same argument can be followed for the other two LCM tools. As for LCE, as well as for LCA, the maintenance strategies must be part of the design phase to ensure maintainability and minimal environmental impact in the long-term of the asset, which is required in the specific product phase.

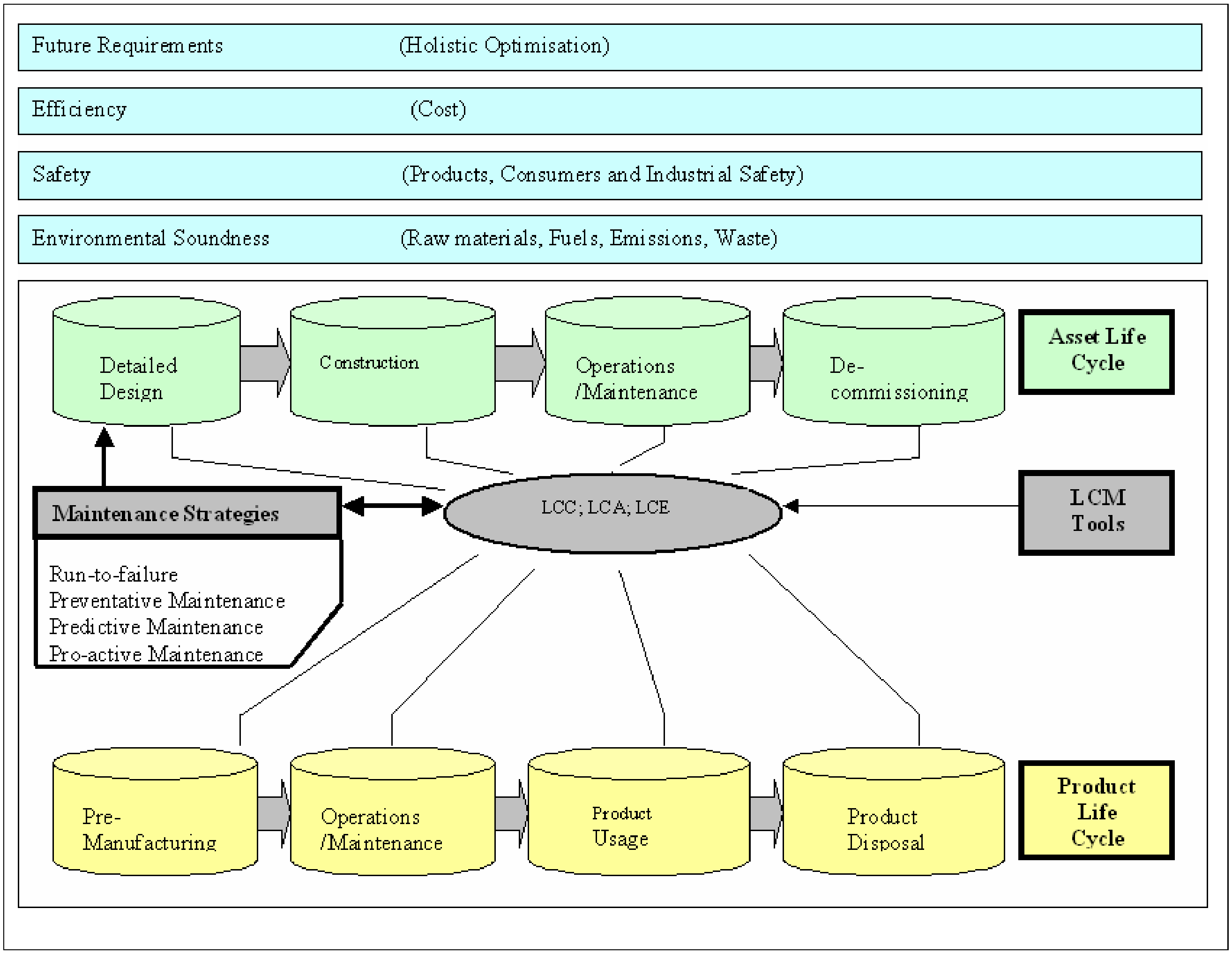

Figure 1. New integrated life cycle model for maintenance strategies of assets.

The bottom part of the model can be seen as the building blocks for the top part, i.e. the foundation. If the foundation is not sound then the top part of the model will not be sustainable.

The top part will create environmental soundness, safety and efficiency and will be able to adopt future requirements if it is needed. Environmental soundness refers to the raw materials and fuels usage, emissions and final waste that will do harm to the natural environment and society. These building blocks will create safety for the products, safety for the consumer and also industrial operational safety. It will increase the efficiency of the asset and will make the asset value driven, i.e. cost effective. If the requirements, regarding the environment, in the future will change, which will most probably be the case, this model will be able to adapt to these changes without severe effects to the business processes.

If this model is followed when a new asset is designed, this holistic approach will ensure long-term sustainability and a reduction in potential negative environmental liabilities.

3 CASE STUDY FINDINGS

Three case studies in a South African petrochemical facility have been used to compare the economic and environmental performances of previous maintenance practices in comparison with the new asset life cycle and maintenance management approach. The case studies are summarised in Tables 2, 3 and 4.

Table 2. Summary of case study 1: Surface bed cracking of road tanker loading bay and process area.

Previous maintenance strategy		
Major problems	• No maintenance strategy was followed. • The LCM tools were not incorporated into the design phase of the life cycle of the asset. The reconstruction of the slabs was subsequently required and cracks formed where expansion joints should be.	
Safety issues	• All cracks resulted in tripping hazards in the area.	
Efficiency issues	• No maintenance on the asset resulted that some of the slabs could not be repaired and had to be demolished. With maintenance on the asset the life of the concrete slabs may have been extended.	
Costs **(6 R = ± 1 US$)**	Old or existing concrete slabs: Construction Cost: Construction Joints: Crack sealing:	(6m x 6m) Run-to-failure strategy R3600 x 36m² = R129 600.00 R133/m x 24m = R3192.00 R100/m x 12m = R1200.00
Comments	The original slabs were constructed without construction joints as design specifications; therefore cracks were formed at 3m intervals. The crack sealing was done every 5 years and new saw cut joints formed. The total life cycle cost for this scenario was R272 367.00 for a 20-year period. Also, a significant environmental risk was associated with seepage of chemicals through the cracks into the soil.	
New integrated life cycle model approach		
Costs **(6 R = ± 1 US$)**	The new designed slabs: Construction Cost: Construction Joints:	(3m x 3m) Proactive maintenance strategy R5600 x 36m² = R201 600.00 R133/m x 48m = R6384.00
Comments	The new slabs were constructed with construction joints as per design specifications; therefore no cracks were formed at 3m intervals. The construction joints had to be resealed after 10 years and therefore the total life cycle cost was R214 368.00 for a 20-year period. Although the initial cost of the old slabs were much cheaper compared to the new designed slabs the total life cycle cost of the new slabs were 21 % less. Furthermore, the environmental risk associated with the seepage of chemicals through the cracks was removed.	

Table 3. Summary of case study 2: Rehabilitation and relining of an evaporation pond.

Previous maintenance strategy		
Major problems	• The maintenance strategy was run-to-failure. • The sludge/silt in the pond could not be cleaned without damaging the liner. • The old design had a herringbone system underneath the liner that was constructed in the soil.	
Safety issues	• To clean the pond without damaging the liner, the liquid and sludge should be vacuumed out of the pond, which could be dangerous for people working in such an environment.	
Efficiency issues	• No maintenance could be done on the liner, because of the sludge/silt build up. • No sludge/silt could be removed without damaging the liner. • No leak could be traced within the pond liner before entering the herringbone, which was laid in the soil.	
Costs **(6 R = ± 1 US$)**	The old design (pond without sludge basin): Construction Cost: Rehabilitation Cost:	Run-to failure maintenance strategy R6.5mil R3.0mil
Comments	The pond was silt up after 10 years and had to be totally relined in order to prevent a negative environmental intervention. The total life cycle cost for the old design was R16.0mil for a 20-year period.	
New integrated life cycle model approach		
Costs **(6 R = ± 1 US$)**	The new design (pond with sludge basin): Construction Cost: Clean-out cost for basin:	Predictive maintenance strategy R8.0mil R200 000.00
Comments	The clean out of the sludge basin will be done every 5 years and the expected life cycle of the liner is 20 years. Therefore the total life cycle cost for the new design is R8.6mil. Although the initial cost of the old design was much cheaper than the new designed the total life cycle cost of the new design was 46% less. Furthermore, a proactive approach to minimise environmental risks is followed.	

Table 4. Summary of case study 3: Rehabilitation of an oily storm water and process sewer.

Previous maintenance strategy		
Major problems	• The maintenance strategy was run-to-failure. • No proper cleaning of the sewer lines was done. • Effluent pipes were wrongly re-routed into a sewer that was not designed for that specific effluent.	
Safety issues	• The system had blockages that resulted in certain areas where the effluent could not drain away. In certain areas it was a safety hazard. • The leaking pipes could cause sinkholes in the ground.	
Efficiency issues	• The sewer was not used efficiently due to the blockages that were in the lines. Major blockage removal exercises were necessary. • Wrongly routed pipes caused a lot of unnecessary clean water to be treated at the water effluent plant.	
Costs **(6 R = ± 1 US$)**	The old management system: Construction cost per unit: Rehabilitation Cost:	Run-to-failure maintenance strategy R3.0mil R1.0mil
Comments	The life cycle of the asset was 15 years and the total replacement and rehabilitation cost occurred in year 15 and 30. The total life cycle cost for this strategy is R8.0mil over a 30-year period. Also, major environmental risks arose through possible overflows of untreated effluents.	
New integrated life cycle model approach		
Costs **(6 R = ± 1 US$)**	The new management system: Construction Cost: Cleaning and CCTV: 2% Maintenance cost of total replacement value: Relining of sewers	Predictive maintenance strategy R3.0mil R160 000.00 (must be done every 5 years) R60 000.00 (must be done every year) R1.0mil
Comments	The total life cycle cost of the asset will be R6.6mil over a 30-year period. Although the more regular cash flows occur during the predictive maintenance, the total life cycle cost of the asset 17.5% less than run-to-failure. To have more regular cleaning, maintenance work and to reline the pipelines in-situ before the pipes deteriorate beyond any point of repair, additional life of the asset can be obtain and the major environmental risk can be avoided.	

4 RECOMMENDATIONS

The case studies show that incorporating the LCM tools into the maintenance strategy assists the design and maintenance engineers to make the right decisions regarding the maintenance strategy, i.e. it is evident that run-to-failure cost compared to predictive or proactive maintenance in the total life cycle of this asset is much more expensive. Also, a holistic predictive or proactive maintenance and life cycle approach ensures that the environmental performances of the assets are optimised.

4.1 Modifications to the maintenance strategies based on the introduced model

In section 1.2 it is stated that proactive maintenance concentrates on monitoring the asset to define and eliminate the root cause of the failure. Predictive maintenance is a condition-based approached and the main focus is to monitor the condition of the asset to predict the failure or to avoid major consequences. When the recommended LCM tools are incorporated into these maintenance strategies, the modified proactive and predictive maintenance strategies will have the characteristics summarised in Figure 2.

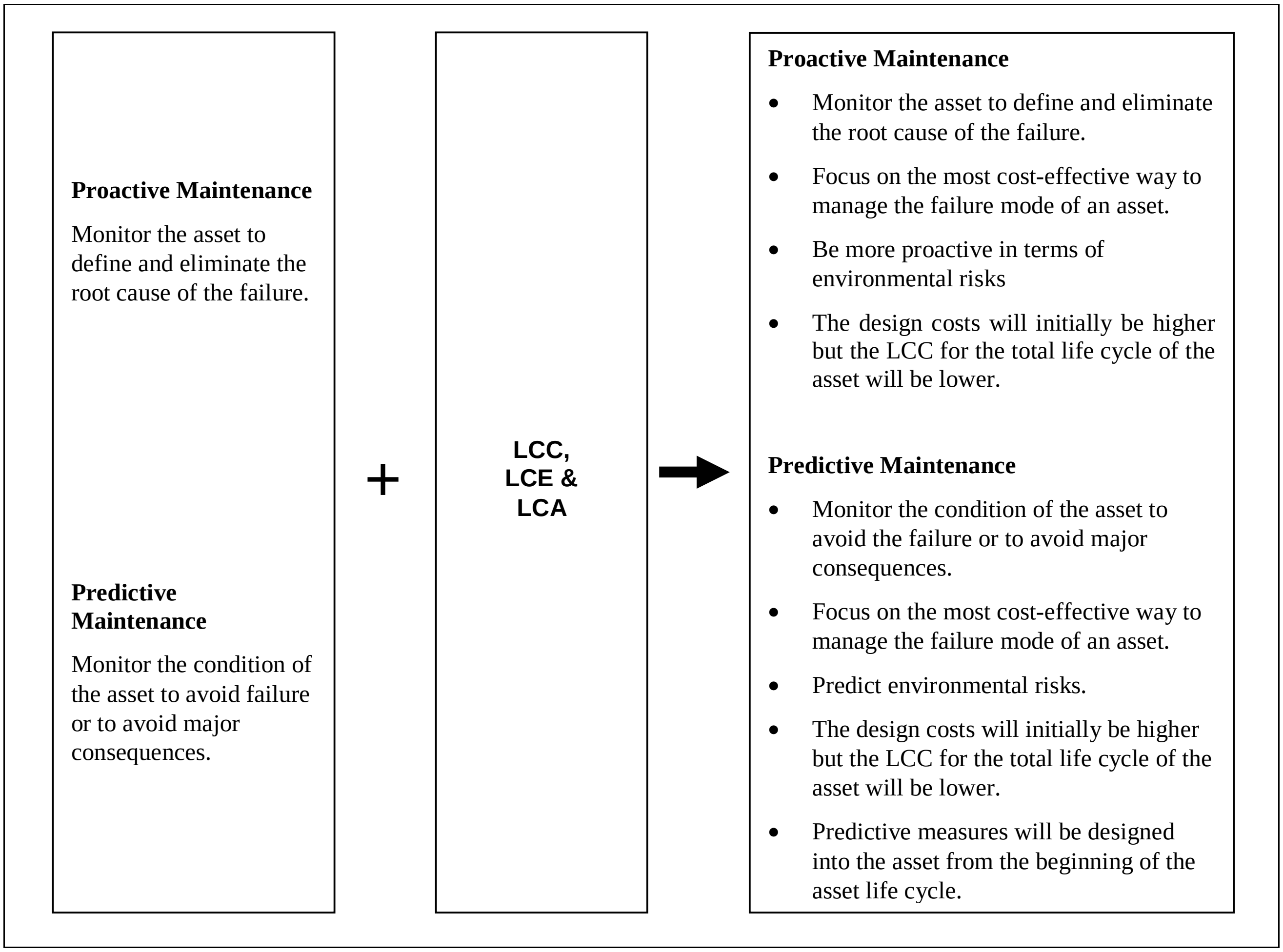

Figure 2. Optimised proactive and predictive maintenance strategies.

5 CONCLUSIONS

To adhere to the more strict legislation regarding the environment, the process industry will have to focus on its assets' environmental performances. The continual environmental trend will pressurise companies to focus on the total life cycles of assets to ensure that the associated product are acceptable. Only the companies who will be able to adhere to these changes will be sustainable into the future. This concept is also visible between companies, where larger companies force suppliers and smaller companies to produce and deliver "green products".

In the past, maintenance strategies and environmental performances were not integrated and incorporated into the design stages of asset life cycles. The model presented in this paper ensures that maintenance strategies and the tools of Life Cycle Management (LCM) are integrated to ensure the long-term sustainability of the asset related to the environment, whilst optimising life cycle costs.

5.1 Implications of incorporating LCM tools into maintenance strategies

When the maintenance manager and environmental expertise have input into the design, the design cost may initially be higher, but the total life cycle cost will be lower. If this is not the case the maintenance manager must manage the asset by optimising the current maintenance strategy that was built into the design phase, which may not be the most appropriate strategy. Based on the selected case studies of this research study, an early selection of an appropriate maintenance strategy may reduce to overall maintenance costs by 17.5% to 46%.

The model ensures that the total life cycle of an asset is taken into consideration and gives a holistic view of the asset's environmental performance from the design phase to the disposal phase, i.e. cradle-to-grave principle. This model will assist design engineers to ensure the operability, maintainability and disposal of a product to be environmentally acceptable. This will ensure that a company's environmental credibility is acceptable to all its stakeholders.

The most important aspect for maintenance (and asset) management strategies, in terms of environmental performance, safety and efficiency, is therefore to incorporate life cycle thinking into these strategies.

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