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This paper presents a case study demonstrating life cycle cost (LCC) analysis as a major and critical activity of engineering asset management decisions and control. The objective is to develop a maintenance policy to control the economics of replacement and repair practice of refractory lining of an electric arc furnace (EAF). The replacement & repair policies involve the optimum life policy, the repair versus replacement policies, the repair limit method and the comparison of lining material types from different suppliers. The developed models provide a method for defining the most important factors involved in decision making with respect to operational and managerial levels. The approach also involves deciding the remaining age value as the repair limit criteria while avoid lining failure due to unavoidable deterioration caused by variation in operation conditions. The decision criteria are established as: a) what type of lining material is better to use? b) When to replace lining in a cyclic manner? c) At what sequence is hot repair required and d) whether to replace or use cold repair between replacements. Finally, the model output values for the decision criteria are presented in tables and graphs to guide decision making in operation and maintenance.

Keywords

life, role, asset, management, engineering, cost, cycle

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The Role of Life Cycle Cost in Engineering Asset Management

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Abstract This paper presents a case study demonstrating life cycle cost (LCC) analysis as a major and critical activity of engineering asset management decisions and control. The objective is to develop a maintenance policy to control the economics of replacement and repair practice of refractory lining of an electric arc furnace (EAF). The replacement & repair policies involve the optimum life policy, the repair versus replacement policies, the repair limit method and the comparison of lining material types from different suppliers.

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Keywords: Life Cycle Cost · Engineering Asset Management · Decision-making Criteria · Optimal Maintenance · Decision-making Model

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1 Introduction

The concept of asset management utilizes the LCC analysis in managing the life of assets. There is a common understanding that Engineering Asset Management; AM involves life cycle management which is based on LCC as a dominant criteria for decision making within the AM system (Asset Management Council 2009). The AM system is defined as: “The system that plans and controls the asset-related activities and their relationships to ensure the asset performance that meets the intended competitive strategy of the organization” (El-Akruti 2012). This definition provides an integrated view of the AM system within the whole organization’s management system. As a control system AM involves a set of planning and control activities at different organizational levels.

It is proposed that the role of LCC analysis in AM system is focused on defining decision criteria for the lifecycle management of physical assets as a holistic approach to control the life cycle activities of assets in order to achieve the organization’s objectives.

The activities of concern in asset management in relation to LCC analysis during each stage of the asset life are shown in Figure 1. For example, at the preliminary system design stage, the AM system activities that require LCC analysis may include system definition, system analysis, and evaluation of alternatives or trade-offs. The challenge in managing the entire asset life effectively lies in integrating the fragmented activities through the various stages (Charles & Alan 2005). This leads to integrating the need-identification, alternative analysis, and project selection to the business management focus (ISO/IEC 15288 2008).

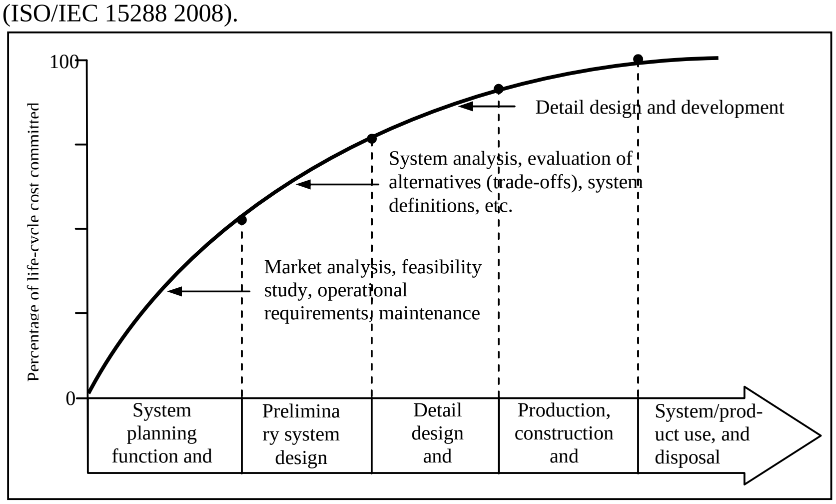

Figure 1: Life cycle processes and cost committed (Blanchard & Fabryky 2011)

Value creation is a concept that is related to organizational activities and LCC (Porter 1985). Relationship between value activities and AM system is not clear but performance attributes reflect the LCC-value relationships between activities.

El-Akruti (2012) argues that the AM system controls LCC of assets. He states, that it also incorporates coordination activities to maintain relationships between these life cycle activities such as those related to:

a. Procurement, finance and accounting which are important for establishing the LCC requirements to enable investment, funding and budgeting, cost analysis and decision making.
b. The information technology to establish the required information flow to facilitate a data base for LCC. For example, a published case study (Holland et al 2005) reports that “BP connects its business processes with over 1500 suppliers to co-ordinate the maintenance, operation and repair of specialized exploration and production equipment.
c. External suppliers to establish their impact on asset’s LCC and maintain value added relationships with suppliers and to make outsource verses in-house decision and maintain both-side-benefit relationship.
d. Technical support and development to establish the required development in assets or asset-related processes and the suitable technology or any new developments in technology for use in enhancing performance.
e. Human resources, inventory, quality and safety systems for better performance, less risks and safe environment.

The AM activities involve the use of LCC analysis in lifecycle management of assets in existing organization (Charles & Alan 2005; Amelsberg 2002). Any decision concerning the portfolio of assets is built on the accumulated information of managing the utilisation stage. A major portion of such information would be related to cost of activities at different stages of asset life (Blanchard & Fabryky 2011). At any time it may be determined for example that the current design of one or more assets is not capable of achieving the required performance given the current or projected future environment (Dwight & El-Akruti 2009). Concurrently, organizations must identify the business needs, and make decisions to launch any change or project to enhance assets, their design, operation, maintenance or logistic support (Charles & Alan 2005; Du Preez & Louw 2008; Narayanamurthy & Arora 2008). AM projects may involve decision regarding, upgrading, expansion, support system, redesign, replacement or retirements of assets. These decisions require the LCC analysis to choose the right assets, use or maintain them appropriately, and balancing short-term performance against long-term sustainability.

The literature on this topic is extensive. Examples on the use of LCC in asset management decisions are numerous but each example may be unique due to the nature of different assets in different industries. Table 1 is a summary of some of the reviewed literature on the use of LCC in engineering asset management decisions. These decisions highlight the need for LCC analysis as a holistic approach to AM system activities in relation to achieving an organization’s objectives. For example, Pinjala, et al. (2006) discuss relationship between business and some of the asset-related activities such as maintenance.

Table 1 Use of LCC in engineering asset management decisions

Use of LCC in AM Decisions	Sample References
To develop value-orientated decision support systems for maintenance and replacement or rehabilitation: this may include optimization or performance improvement, setting policies or developing strategies	Scarf et al. (2006); Taylor, (2012); Tähkämö, et al. (2011); Shahata, and Zayed, (2008); Schuman and Brent (2005); Khan (2001); Mahapatra. (2008); Garcia et al. (2008); Hartman (2004); Eginhard (1977); Jardaine (1970), White (1985) & Herbert and Gordon (1979); Wijnia et al. (2007)
To evaluate feasibility and/or requirements of existing & new asset or asset-related projects	Goralczyk & Kulczycka (2003); Wubbenhorst (1986); Buys et al. (2011); Vorarat & Al-Hajj (2004)
To develop value-orientated decision support systems to improve asset design/selection, installation, use & maintenance and retirement or trade-off between alternatives to an asset	Girsch et. Al. (2005); Barringer (1998); Janz and Westkamper (2008); Liu (2012); Farran & Zayed (2009); Jun and Kim (2007)
To assess or assert trade-offs for environmental impact and sustainability	Nyuk (2002); Sullivan & Young (1995); Norris (2001); Mahapatra (2008); Castella et al. (2009)
To provide a decision tool (e.g. cost-benefit analysis) for estimating project requirements or investment, identify cost drivers and highlight need for change or for selecting assets	Kim et al. (2009); Patra & Kumar (2009); Ge & Wei (2011); Yu-Rong et al. (2009); Woodward (1997); Jeromin et al. (2009); Esveld (2001); Thoft-Christensen (2012); Uppal (2009)

A strategic approach to maintenance as an asset-related activity has been recognized especially in capital-intensive industries (Pinjala, et al. 2006; Tsang 2002; Muchiri & Pintelon 2007).

As presented by Blanchard's model (Blanchard & Fabryky 2011), integration of LCC models into asset management decision process involves 12 steps:

1. Define system requirements and TPMs.
2. Specify the system life-cycle and identify activities by phase.
3. Develop a cost breakdown structure.
4. Identify input data requirements.
5. Establish costs for each category in the CBS.
6. Select a cost model for analysis and evaluation.
7. Develop a cost profile and summary.
8. Identify high-cost contributors and cause-effect relationships.
9. Conduct a sensitivity analysis.
10. Identify priorities for problem resolution.
11. Identify additional alternatives.
12. Evaluate feasible alternatives and select a preferred approach.

Decisions may involve issues such as:

- Establishing the remaining costs (given you are in the use phase), which raises the issue about replacement cost as a function of behaviour of the current system.

- Repair/replace decision logic which may give rise to economic or optimum repair frequency and replacement period.
- Prediction and estimation decisions which require CBS breadth and depth for visibility.
- Projection decisions which involve investment, system operation and support costs. These are based on the projected activities throughout the operational use and support phase and are usually the most difficult to estimate.
- Trade-off decisions which may involve capital vs. running costs, labour & materials vs. reduced services and reduced safety.
- Alternative options decisions which comparing LCC of alternative asset e.g. pieces of equipment or maintenance strategies or methods and balancing the cost of a new item against the cost of maintaining efficiency on the old one and/or that due to the loss of efficiency.

2 LCC Criteria for AM Control Models and Performance

It is necessary at this stage to stress that the purpose of a LCC model is so that it can formally be manipulated to determine relationships between AM control decisions and levels of performance. LCC models are essential for AM control to aim at improving performance, either in terms of improved benefits for the same cost, or reduce cost for the same benefit, or in terms of cost / benefit mixtures. For example for obtaining optimum LCC, control of replacement and/or repair frequencies is needed. AM control is meaningless unless there is a criterion to tell when control is good or bad. Such criteria do not exist, and involve a search for it in the context of the demand for the asset and in the effectiveness of the functions in meeting this demand. It is therefore a two way interaction e.g. replacement and/or repair functions as shown in Figure 2, and the demand pattern has to be decided in the light of economic or optimum LCC.

As shown in Figure 3, there are two aspects to this; firstly determination of how to measure performance and secondly identification of the decision criteria (control variables) to be manipulated by the replacement function in order to set a decision or policy. Measures of performance depend on the availability and performance of the asset required by production over some time span. If they are laid down clearly and can be met, then performance can be judged in terms of cost of providing this service.

Figure 2: Demand *vs*. replacement and repair

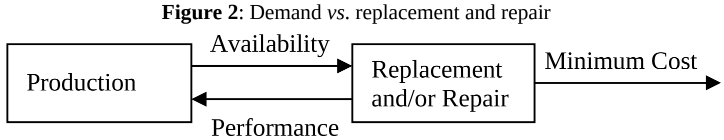

Figure 3: Demand *vs*. replacement and repair

Even if availability and performance are specified, one can question the true financial production effects of each service level. Thus what are the financial effects of lost production time and of poor quality? What are the financial effects of delaying production, resulting from not having equipment available? This gives rise to the need of combining both functions; minimizing LCC to achieve various service levels and the economic benefits of various service levels. Finally it needs to be remembered that the way in which an asset is used in production programs, will inevitably influence the condition of the equipment. Meeting demand is usually a priority but some time the choice between delaying production and using asset with risky condition has to be made depending on deterioration rate which may be rapidly accelerated and lead to catastrophe.

Regarding LCC decision criteria for AM policies, the decisions which can be taken are numerous, and they occupy different hierarchical levels, e.g. replacement of equipment, repair or overhaul of equipment, replacement of components or inspection of component. The effect of such decisions cannot be separated. Thus it is the combined effect of operation and maintenance that has to be assessed when dealing with AM policies in utilization stage. For example an optimum overhaul frequency of replacement of some components depends on the frequency of other associated components replacement (component may or may not be replaced at times of major overhauls and at time of breakdown). LCC is needed for replacement decision which does not have to be in the strict sense of the word, but perhaps maintenance decisions such as repair and overhaul may be taken synonymous with replacement provided that it is reasonable to assume that maintenance actions return equipment to as new condition. Therefore it is not a 'one-off' decision, but a serious of decisions. Thus there is a complexity of decision structure that involves LCC.

3 LCC Criteria for AM Control Models and Performance

3.1 Case Study Definition

This case study examines furnaces as the significant assets in steel making industry. In this steel making case study organization, EAFs are the most critical assets for the process availability. The main activities of the EAFs that impact process availability are lining replacement and repair. Therefore, the development of the economical criteria for the control of lining replacement and repair of EAFs provides a good opportunity to increase product unit profit (profit margin).

The policy of lining refractory replacement and/or repair varies greatly from one steel plant to another depending on differences in environmental and operational condition. Hence every plant has to develop its own convenient replacement and/or repair policy.

Furthermore the maintenance strategy of working lining replacement and/or repair controls to a large extent the availability and productivity of the process, resulting in a great effect on the unit cost of liquid steel produced.

The life of the working lining is dependent on the repair practice. Lining repair involves two types; hot repair and cold repair. Hot repair is done by fettling and gunning while EAF is hot. The amount of material used and the time required to do hot repair are the main factors in considering hot repair cost. Cold repair is done by cooling EAF down to fix the damaged spots. It is usually resorted to when deterioration or damage cannot be handled by hot repair. It is time consuming because it requires cooling the EAF down resulting in a great loss of EAF's availability. The time required for cooling EAF and the time required for repairing are the main factors in considering cold repair cost. Working lining replacement is done periodically as required and has direct effect on EAF availability.

Hence it can be concluded that, working lining replacement is directly related to the overall cost of replacement and repair, and lost production cost due to unavailability. Consequently an assessment of working lining replacement costs in terms of lining material and replacement stoppage is required to base decision on the LCC.

Hot repair is done as required and involves consumption of material and relatively short time. Cold repair is done when hot repair is not sufficient and the time is too early for replacement, or most of the lining is still in a good condition. Cold repair is considered as a partial replacement where the EAF has to be cooled down. It involves the use of used bricks and its duration may be as long as that of the replacement or even more.

Hence it can be concluded that, hot and cold repair are as relevant aspects as working lining replacement because they are directly related to LCC involving replacement and repair, and lost production cost due to unavailability. Consequently an assessment of repair costs in terms of hot and cold repair material and hot and cold repair stoppages is required to base decision on the LCC.

3.2 AM Decision Models and LCC Criteria of the Case Study

In this case study, the AM control focuses on providing a maintenance policy that guaranties and outlines the economical decision bases for replacement, repair practice and refractory procurement policy.

For AM control, the main concerns are the working lining life, the required repair amount, frequency and the required repair type. Since the consumption rate of hot repair material and time making hot repair increases with longer life of EAF's lining, there must be a point where it is not worthwhile to use hot repair and replacement is more economical. Furthermore, is it worthwhile to use cold repair at all? Also, what lining supplier's set of refractory materials is more economical?

It is the aim of this paper to demonstrate and establish the modelling procedure using the LCC to set an AM policy that economically control the replacement and repair practice of refractory working lining in EAFs. The policy of determining the maintenance economical decision bases, involves modelling for the replacement and the repair criteria of lining such that the LCC of lining is reduced for each unit produced. The question then becomes how to optimize LCC while maintaining the same high level of availability, quality and productivity.

As a result, this case study involves answering these questions:

1. What lining type (supplier) is better?
2. When to replace lining in a cyclic manner?
3. At what sequence is hot repair required relative to lining life?
4. Whether to use cold repair in between replacements and determine the repair limit for use?

3.3 Cost Structure Breakdown and Evaluation for Modelling

As the decision criteria are based on cost data, the various types of costs that might be involved in lining repair and replacement must be outlined. These costs are structurally related as shown in Figure 4. As will be noticed only some costs will be used for the development of the model, where others would not be used either because they have no effect on the replacement and repair practice or they do not change with respect to time or replacement and repair events.

The main cost variables evaluation includes:

1. Working lining cost: which is composed of material cost and stoppage loss and it may be defined as; (Cw = Cwm + Cws). Where Cwm represents the material cost and Cws represent the stoppage loss.

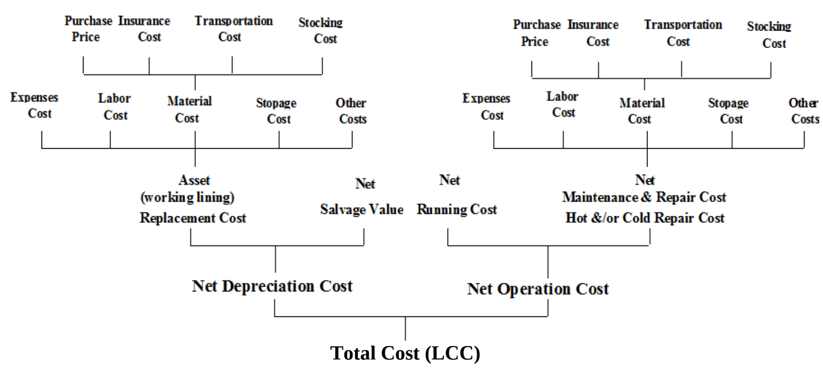

Figure 4: Model's cost structure breakdown

2. Working Lining Replacement Stoppage Cost (Cws): which is a loss of time that could have been utilized for production resulting in two effects one is the loss of operation while incurring ongoing payment of fixed cost. The second is the loss of products that could have been sold and therefore a possible result of lost benefit. These effects are dependent on many economical policies imposed by strategies of the overall economy. For instance at one extreme, the policy may be purely economical benefit where product value is equal to sales price. On the other extreme the policy may be anything but not economical benefit where product value is equal to product

unit cost. For nature of demand in markets associated with this case study it is assumed that stoppage cost is only due to the contribution of "no operation cost" which is incurred ongoing payment of fixed cost.

3. Cold repair cost which is composed of material cost and stoppage loss and is defined as; Cc = Ccm + Ccs. Where Ccm represent the material cost and Ccs represent the stoppage losses. Ccm is the cost made up of the various material used which may be brick or mixes or binding material. Cold repair stoppage cost may be define as:
   Stoppage cost = stoppage duration * productivity * availability * fixed unit cost (Cws = Dcs * Pr * A * NOCu)
   Where, Dcs**,** Pr and A values are to be evaluated statistically from operation records as an input to the model and the NOCu is based on accounting records (Omar et al 1996).
4. Hot repair cost which is composed of material and stoppage cost (Ch = Chm +Chs). Where hot repair is defined in terms of gunning and fettling (Chm = Cf +Cg) and the hot repair stoppage cost is define similar to cold repair stoppage cost as: Stoppage cost = stoppage duration * productivity * fixed unit cost (Chs = S * Pr * NOCu).

3.4 Model Development, Result and Application

3.4.1 Model Development

The model is developed based on LCC structure to achieve the research objectives. It is intended to contribute a significant saving in refractory consumption by proper application of the developed model to set the policy for the economical criteria. It is also intended that such application of the model is made such that it does not impose any changes in the actual practice and provides the required information for decision makers to base their decisions on the economical aspects of LCC optimization while increasing productivity and maintaining the required quality. As such those objectives shall be achieved through obtaining an optimum replacement model and a repair limit model.

These models are developed as a decision support system to enhance optimum life decision, suppliers’ refractory lining selection decision based on the most economical supplier’s lining (refractory set), decision regarding amount and sequence of using hot repair and cold repair limit. The models are developed to define the appropriate action in terms of hot repair, cold repair or replacement. The two types of repair stand as preventive means to failure and as a substitute for replacement until they become uneconomical. Hot repair is to be carried out as a preventive treatment against failure until optimum life is reached based on minimum LCC per heat. If hot repair fails as a preventive treatment, then cold repair is applied only if it is more economical than replacement. This comparison is done on the basis of the remaining age value of the lining as a repair limit. Cold repair is carried out as long as its estimate at any specified age does not exceed the repair limit.

3.4.2 Model Results

A graphical presentation of the results for one supplier's material type is presented in Figure 5 and 6. They show the analysis that determined the criteria for optimising replacement and frequency of hot repair for one lining supplier. These solutions represent the evaluation and analysis that provided a view on the economics of repair and replacement for decision making based on the LCC per heat, repair costs per heat and the gunning consumption per period. The output values for application decision variables are summarized in Table 2 for each supplier's material type.

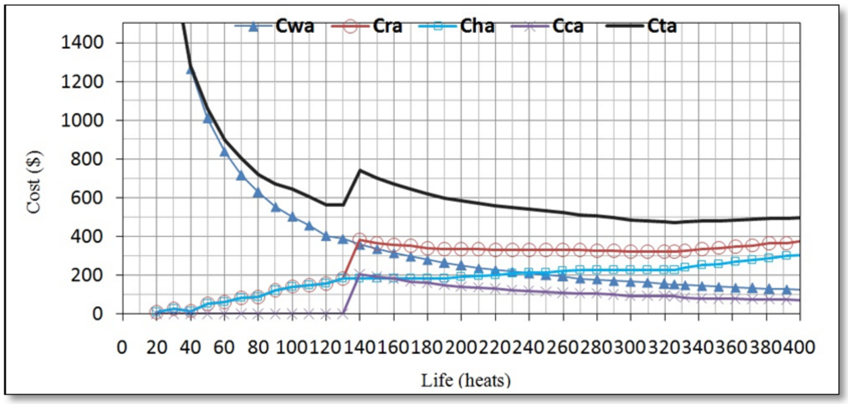

Figure 5: Determining the optimal replacement

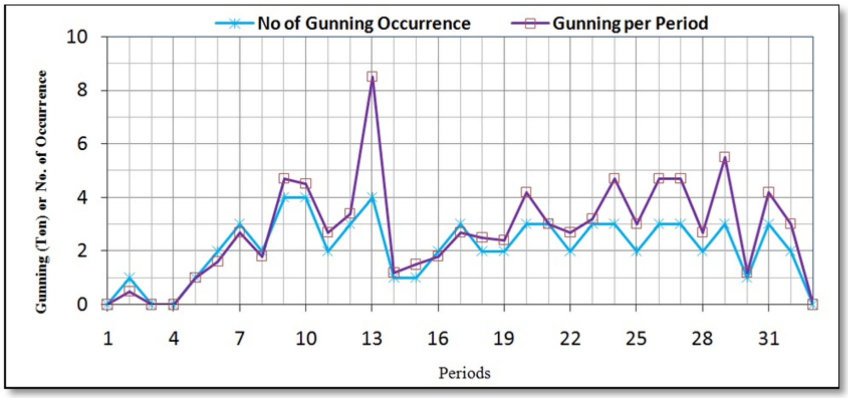

Figure 6: Gunning consumption for hot repair sequence

Table 2: Output values of the model for decision criteria and optimum status

Parameter	Unit	Material Suppliers		
		Supplier-X	Supplier-Y	Supplier-Z
Replacement Cost	$	175,490	161,614	152,613
Cold Repair Cost	$	91,446	91,446	91,446
Maximum Gunning	Ton	5.20	6.0	5.50
Hot Repair Period Length	Heats	10	10	10
Max. Hot Repair Cost per Period	$	13,682	14,007	15,907
Optimal EAF Working Lining Life	Heats	278	319	229
Cold Repair Limit	Heats	120-to-130	110-to-120	80-to-90
Cold Repair Actual Application	---	Not Feasible	Feasible	Feasible
Total Cost per Heat (Cta)	$	1,426	1,544	1,652
Total Cost per Ton of Liquid Steel	$	15.6	16.8	16.8
Priority for Use	---	First	Second	Third
Total Annual Cost based on use of each suppliers material alone	$	5,436,058	5,887,760	6,298,710

3.4.3 Benefit and Recommendation for Application of the Model Results

The application of the results is carried out in terms of the values determined by the model analysis for the decision criteria. Using these values of decision criteria with relation to the total management system of the company, requires fitting these criteria within the existing procedure for the decision making process at the different existing decision levels. The integration of these models is presented in Figure 7, where all decision criteria and relevant points needed for decision making were indicated. Therefore the model is made so that, the application procedure can fit easily within the operation practice and allows for taking advantage of any production stoppage or any furnace in a non utilization case when more than one furnace exist for production.

The application of the model for the optimum policy would result in cost reduction for the company:

- From 10% to 15% annual saving in the annual refractory cost ($1,900,000) is expected when managerial decision for material type selection is based on the model output criterion.
- From 2% to 6% annual saving in refractory cost is expected when operational decisions are based on the model output criteria.

Therefore it is an attractive proposal for top management to adopt. Furthermore the application is very simple since it only requires the use of the model findings for the economics of the decision making process with a very simple procedure that would not impose any change in the actual operation or managerial practice. The recommendation for application includes:

- Operational recommendation
  1. Always replace lining at optimum life or as close to it as possible.

2. Observe gunning amount for every sequence of 10 heats Cold repair should not be applied if its cost exceeds the limit. Start hot repair approximately after the 20th heat For lining life less than 100 heats hot repair should be applied with a frequency ranging from every 5th to every 4th.
3. For lining life beyond 100 heats hot repair frequency should not be less than every 3rd heat.

- Managerial recommendation
  1. When purchasing lining material, the decision of supplier selection should be based on the criterion of minimum LCC per unit production.
  2. The model should be updated in case of any future development, changing conditions or including new suppliers.

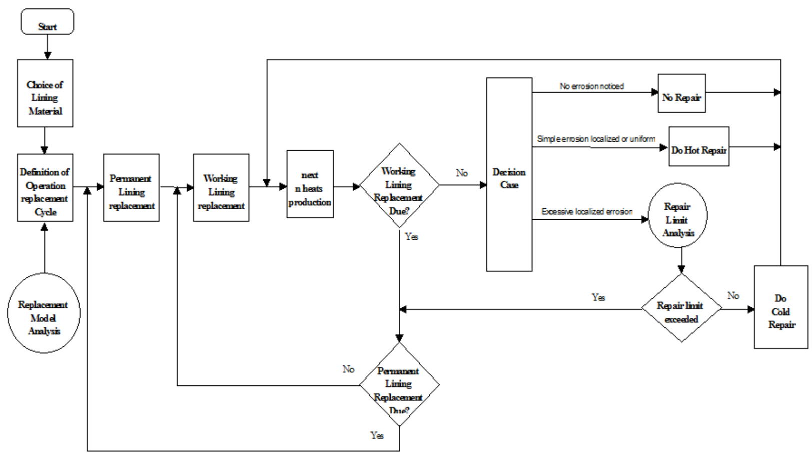

Figure 7: Operational procedure & decision criteria

4 Conclusion

LCC is a tool to develop value-orientated decision support systems in various AM-related industries. LCC has a critical and essential role to play in asset management decision making processes.

The main results of the case study present an illustrated simple example of how LCC plays an essential role in asset management decision making; in particular replacement optimization and maintenance policy and its impact on the procurement policy. Those decision criteria in the case study are shown to be supported by the LCC-based model developed at the operational and strategic levels within the direct and support functions of the company.

Therefore, the developed LCC-based model provides a decision support system within this case study company and implies that LCC has a great potential for decision making support for asset management.

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