Perfect Repair Tenability Drawbacks in Manufacturing firms – A Case Study

Peter Muganyi

Department of Engineering Management
University of Johannesburg
Johannesburg, South Africa
peter777.muganyi@gmail.com

Charles Mbohwa

Faculty of Engineering and the Built Environment
University of Johannesburg
Johannesburg, South Africa
cmbohwa@uj.ac.za

Abstract

Every organization's desire is to realize perfect processes, systems, physical assets and ultimately the perfect goods generated as a result of all the perfect input resources. However, in practice, this is not always tenable, as there are militating factors that deduct the aspects that drive a system or product to perfection. Perfect repair of physical assets is the ultimate aim of maintenance service provision by the maintenance function in various manufacturing firms, but the reality on the ground is far from perfect. A study was conducted to understand the drawbacks that derail the maintenance function from attaining perfect repair of their physical assets, and the acceptable actions that the maintenance function need to embark on to draw their physical assets to near perfectly maintained or repaired.

Keywords
Perfect repair, drawbacks, negating factors, maintenance provision

1. Introduction

There are numerous prevailing reliability strategies for repairable arrangements and they range from minimal to perfect repair arrangements (Yang et al., 2013:490). The reliability modeling of rotable/repairable equipment absolutely applies two (2) forms of restoration, and these are categorized as perfect and minimal repairs (Finkelstein and Shafiee (2917:101), Dijoux et al. (2016:84)). Perfect repairs gets the component back to a "as good as new" status whilst minimal repairs, contrarily, brings a component that had failed to the status prevailing proximately prior to the failure (Finkelstein and Shafiee, 2917:101). A majority of functional failures are triggered by various dynamics such as usage time, degradation, wear and absence of appropriate and well-timed maintenance actions (Hajeeh, 2015:64). However, the choice of a particular repair preference is reliant on the needs of the decision-maker and the competence of the maintenance artisans and how well-equipped the facilities are (Hajeeh, 2015:64).
The establishment of perfect repair models for multi-component configurations still remains a mammoth task for many industrial establishments in view of the reliance on part functional failures, and this leaves many maintenance practitioners confining themselves to limited or partially-perfect repair status whereby merely the failed part is restored to as good-as-new-condition (Yang et al., 2013:490). Manufacturing firms are progressively emphasizing on heightened physical assets reliability and durability, with these two aspects becoming crucial facets of industrial dynamics (Liao, 2016:1129). This entails that when manufacturing components encounter functional failure, perfect repairs and inspections are conducted to counteract imminent failure (Liao, 2016:1129). Every corrective maintenance action that is performed in reaction to a functional failure occurrence is generally regarded to be

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imperfect unless considerable effort was taken to restore the physical asset to an “as-good-as new” status (Dijoux et al., 2016:84). For deteriorating manufacturing equipment, the time limitation to effect perfect repairs in constrained by production requirements and other business priorities, and this leaves room for satisfactory equipment repairs to take place in order to keep the business running (Liao, 2016:1129). Maintenance actions comprise of broadly preventive and corrective maintenance that is applied to preserve an equipment in or to restore it to a functional status (Do et al. (2015:22), Dijoux et al. (2016:84)). The reliability of repairable components is dependable on the subjective degradation progression and the resultant repair actions rendered to the equipment (Doyen et al., 2017:40).

2. The drivers for circumventing Perfect Repair

The downside of perfect maintenance is the related high repair costs and the prolonged production time consumed while the machines are being repaired (Do et al., 2015:22). The practical application of maintenance policies entail optimization models that focus on providing optimal systems reliability/availability and safety performance at optimum maintenance expenditures, and this does not warrant that manufacturing firms will always pursue perfect maintenance options (Do et al., 2015:22). The impact of recurrent equipment failures drives maintenance practitioners to focus their efforts on the reliability of individual repairable components instead of collectives, as a means to tailor the maintenance requirements to the essentials of the respective (Navas et al., 2017:1373). The practical reality in manufacturing firms alludes to the fact that limited/imperfect maintenance can ascribe to the majority of types of maintenance actions that are realistically happening in manufacturing firms (Do et al., 2015:22). The limited maintenance is regarded as emanating from two chief causes and these are:

- the unplanned imperfect maintenance action that was initially intended to be a perfect maintenance action through for instance, human error emanating from stress, deficiency of skills or failure to pay attention to the task at hand; shortage of correct spare parts; and repair time constraints (Do et al., 2015:22).
- A deliberate maintenance policy shift towards working on lessening maintenance costs through strategic implementations such as contractuallization of maintenance activities may lead to economical labour rates, optimal spares inventory and maintenance logistics costs (Do et al., 2015:22).

In fact, imperfect maintenance can be adopted as a cost-effective maintenance strategic drive which is intentionally implemented as an acceptable norm, and can only be revised when the equipment deterioration status renders it uneconomical to pursue such traits, and the default option then becomes to opt for perfect maintenance (Do et al., 2015:22). The process to ameliorate the performance of any factory, reducing maintenance costs and the failure probability of equipment encompasses suitable inspections and repair resolutions (Ossai et al., (2016:40). Some researchers have even gone on to develop maintenance optimization models that are meant to minimize the overall costs of maintenance by incorporating imperfect degradation-based repairs with condition monitoring techniques to prevent the complete functional failure of components (Wu et al., 2015:234). These maintenance models have decision systems that couple the functional correlation between the projected degradation decline and the costs associated with preventive maintenance repair actions (Wu et al., 2015:234). An optimal perfect maintenance strategic attribute was suggested by some researchers for a multi-state arrangement that incorporates limited maintenance to define the optimum number of failures before the complete replacement of the complete system is undertaken (Wu et al., 2015:234). Extra consideration has been given to limited degradation based maintenance in the modern era, where some researchers suggested a maintenance activities planning approach centred on augmented cumulative maintenance costs for an arrangement that is subjected to deterioration under operation (Wu et al., 2015:235). Below, is shown an example of erosion deterioration.

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Fig. 1: Illustrations of erosion deterioration failures (Rezaei, 2013:154).

The maintenance budgetary constraints forces manufacturing firms to optimize the physical assets reliability/availability by conjointly deriving perfect maintenance opportunities and limited maintenance repairs for systems subjected to degradation (Wu et al., 2015:235). Some researchers have developed models that take into consideration the aspect that imperfect maintenance might alter the rate of component deterioration instead of the level of deterioration (Wu et al., 2015:235). The degradation modelling can be depicted in the form of an equation by letting *D(t)* designate the accumulative degradation during the period *t*. The accumulative degradation is then expressed according to the following exponential formula.

$D(t_i)= \Phi+ \theta e^{\beta t_i + \varepsilon(t_i)}$ Where I = 1; 2;…; 0=< t_1 =< t_2 =<…   (1) (Wu et al., 2015:235).

An equipment is either in functional or in non-functional status at any moment t, and the instantaneous availability at the time t can be stated as:
$A(t) = P(Xt = 1)$ (2).
The objectivity of the repair(s) is to revive the functionality of the failed component or equipment, and from a reliability point of view, a perfect repair is the preferred option to revive the equipment functionality, but operational circumstances may derail the option otherwise (Yang et al., 2013:1).
The maintenance management of industrial equipment necessitates the utmost application of maintenance data pertaining to the previous failures and repairs, and in most industrial set-ups the perfect record keeping is non-existent and this renders an impossible scenario for rolling out perfect maintenance for degrading systems (Dijoux et al., 2016:84). Thus perfect maintenance is generally not attainable in most industrial scenarios as there are limiting factors that militate against its effective deployment in manufacturing firms.
It has been numerically proven that the maintenance philosophies that adhere to carrying out minimal repairs in planned intervals have shown improvements in the reliability and some cost savings due to minimized overall operational expenditures (Huynh et al., 2012:140). More so, the evaluation of optimal maintenance costs incurred by various maintenance philosophies with minimal repair have yielded to the justification of the appropriate conditionality of time-based minimal repair approach and condition-based minimal approach (Huynh et al., 2012:140). The figures below display two varying scenarios of components subjected to scheduled minimal repairs.

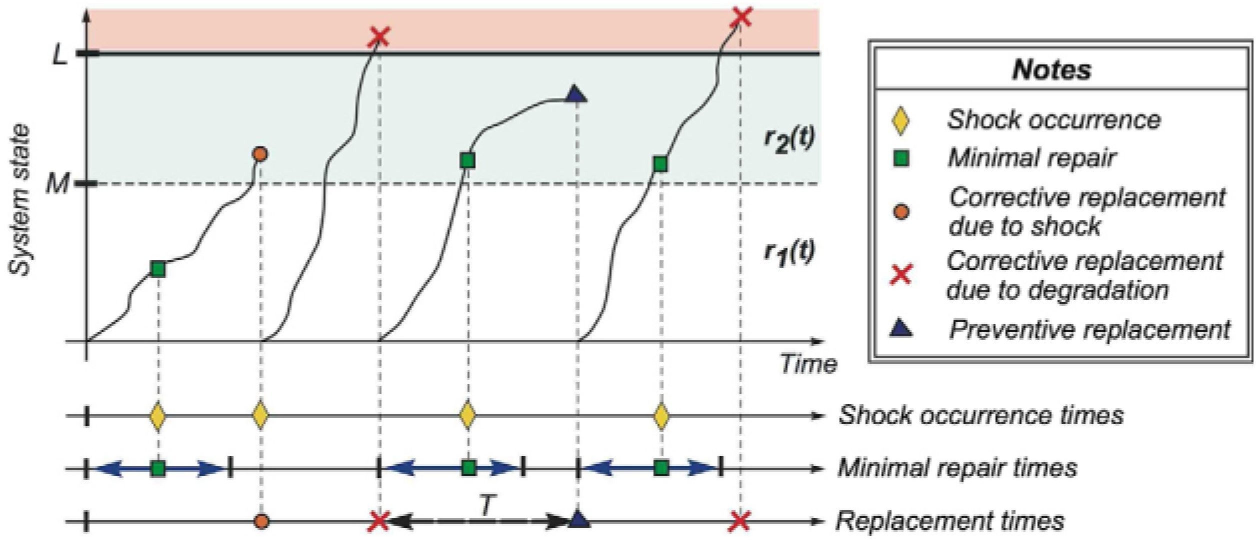

Fig. 2: A system maintained under the interval based policy (Huynh et al., 2012:144).

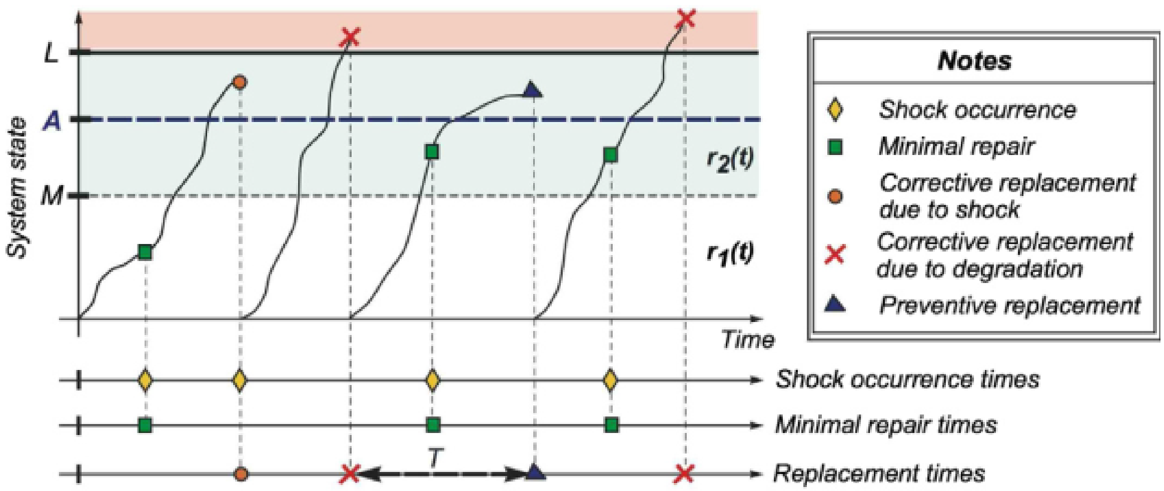

Fig. 3: Behavior of system maintained under the alternating replacement paradigm (Huynh et al., 2012:146).

3. Downside of Imperfect Maintenance Actions

Maintenance action selection is determined by the degree to which the component can be repaired or refurbished (Tanwar et al. 2014:24). Every imperfect preventative maintenance activity affects the velocity of the component degradation process (Do et al., 2015:26). This is evident if for instance a welding repair operation is undertaken to curtail a crack, but in the end it varies the physical characteristics of the material, or when various parts of a machine are dismantled for preventative maintenance and accelerating the degradation of other components (Do et al., 2015:26).

4. Correlation between Repair decisions and other Maintenance Tactics

The purpose of carrying out repair actions is for the preservation of a machinery system or to refurbish it to a projected status, and the two basic maintenance types to be considered are corrective and preventative maintenance that is executed in a time interval or age based interval (Tanwar et al. 2014:24). An inspection regime is one of the prominent tactics to identify and resolve functional failures in repairable physical assets (Rezaei, 2017:148). The optimal planning of inspection interims has a crucial part in determining maintenance costs and the reliability dispensation of factory equipment (Rezaei, 2017:148). After a machine part has failed in operation, the noble thing to do is to either replace it or to repair it, and this gives rise to either a perfect repair or imperfect repair (Rezaei, 2017:148). Thereafter, in order to preserve the functionality of the installed or repaired component, inspection regimes have to be ascribed and adhered to.

A system with a variety of components renders a dependency inclination among the diverse components, and the types of dependencies vary in one or more ways, such as:

1. Economic-dependence – whereby the maintenance costs and the part replacement decision produces dependency amongst the equipment parts, as sometimes a collective replacement of parts may prove cost-effective and efficient than the replacement of only one component.
2. Structural-dependence – whereby the accessibility of a component to be replaced requires the concurrent replacing or disassembling of other equipment parts
3. Stochastic-dependence – whereby the condition of a part, such as environmental stress, distresses the useful life performance of adjoining components, as its failure directly interacts with other components. (Rezaei, 2017:148).

The dependency of components have led to other repair options such as the partially-perfect repair, which is applied for repairable parts with dependent component failure, during which only the failed part is replaced with a new spare and the other adjoining and affected ones are not replaced (Yang, 2013:490). The functional connection between the projected degradation lessening and the cost of preventative repair actions need to be managed under a philosophy of rendering repairs when there is imminent indication of looming failure, and this is when the degradation-based maintenance (DBM) philosophy comes in handy (Wu et al., 2015:234). DBM focuses on the checking and assessment of degradation data such as fatigue stress cracking, vibration topographies, temperature fluctuations, and oil deterioration as indicative of real time degradation state of the components (Wu et al., 2015:234).

The perfect and imperfect maintenance actions are best planned for at predetermined intervals instead of waiting for equipment breakdowns to occur and then instituting repair actions. Before a preventative repair is carried out, the system component is prone to unforeseen failure and the failure trend takes the shape as displayed below.

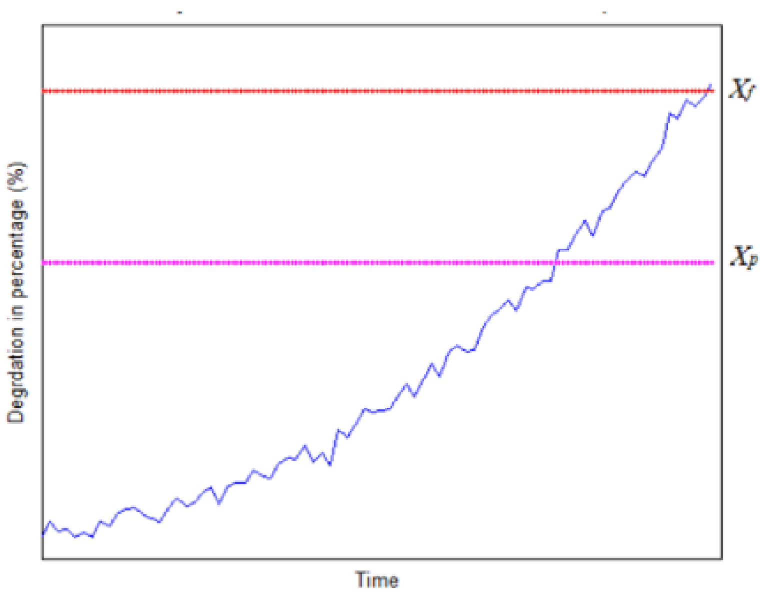

Fig. 4: Malfunctional occurrence before preventative repair (Wu et al. 2015:236).

After instituting preventative repair maintenance actions, the failure trend assumes a profile as depicted below.

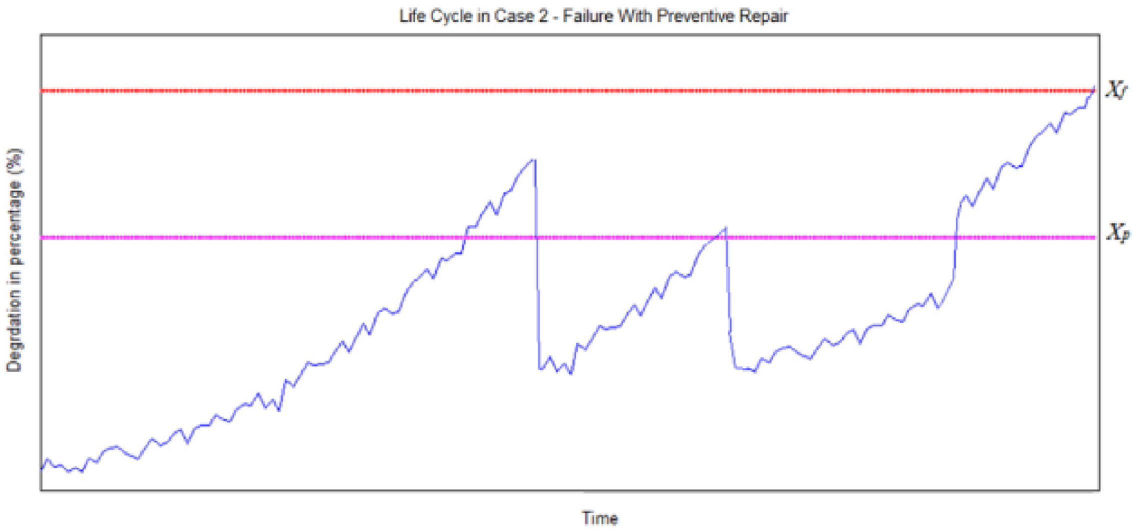

Fig. 5: Failure occurrence trend after applying preventative repair actions (Wu et al. 2015:237).

The effectiveness of repair actions is more over enhanced when there is a compendium of inspection activities and scheduled repair actions, and this applies to whether the repairs are perfect or imperfect. The planned inspections and repairs prolong the failure intervals of a component that is subjected to degradation. Likewise the overall cost of maintenance tend to decline as a consequence of planned inspections and repairs, see figure below.

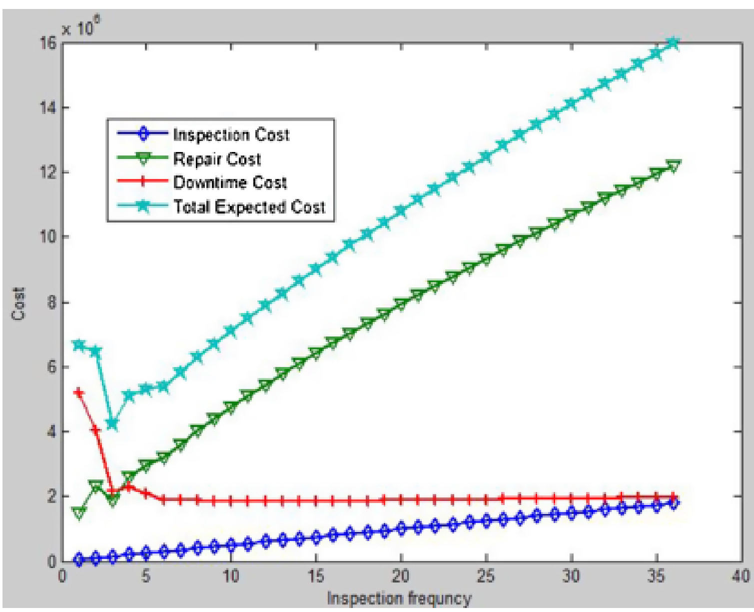

Fig. 6: The corresponding cost trend as a result of planned repairs and inspections (Rezaei, 2013:154).

Separate maintenance modelling has been developed for repair actions that incorporate perfect, imperfect, and minimal repair in conjunction with condition-based opportunistic maintenance. (Varghese and Kumar, 2014:57). This signifies that utmost effectiveness of any repair action mode is dependent on the total scheme of maintenance tactics that is applied. The essence is to develop an optimal maintenance paradigm with minimal overall system costs at the projected level of reliability, and as the systems become more complex, advanced modelling techniques are reminiscent to render the fitting configuration and performance dynamics (Hajeeh, 2015:1). When a repair action is instituted, the objectivity is the reduction of the failure rate of the component/system and to prolong the related useful-life time, and it is a more effective dispensation when the maintenance practice takes into cognizance both the intrinsic aging of the component and the repair efficacy (Nguyen et al. 2017: 439). The age assumption modelling have been applied recently in literature according to the likes of Kijima (1989) proposals of two extensive categorizations of virtual age suppositions – which purports that the Kijima Type I conjecture relates to a repair rejuvenating the virtual age of a proportionate aggregate of the preceding inter-failure interval, and the Kijima Type II conjecture presuming that the rejuvenated aggregate is proportionate to the virtual age immediately before the repair(s) (Nguyen et al. 2017: 439).

5. Repair of a Bucket Elevator – Case Study

Within the country of South Africa, in the Johannesburg industrial area, a bucket elevator at a construction products manufacturing company failed according to the following mode:

- The bucket elevator's main drive was tripping on overload electric current.

The failed components of the bucket elevator are shown in the figure below.

(a) (b)

Fig. 7: (a) Aerial view of elevator chain, (b) stuck bushes on shaft

On further investigation, the following causes of the malfunction were identified as per the table appended below.

Table 1: Bucket Failure root causes and countermeasures

Root Cause / s Identified			
1. Identified elevator chain stuck and not moving.			
2. Worn-out support bushes on counterweight.			
3. No PM Schedule/Frequency for replacement of Bushes.			
4. No spare kept in Engineering stores for worn-out bushes. 5. Accelerated wear of bushes due to dry running of elevator caused by frequent stop-starts due to material outage (starvation from upstream process). 6. Localized metal welding during dry run periods			
Permanent Countermeasure/s	Who?	When?	Done?

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1. Introduce PM01 for Annual Replacement of counterweight bushes.	Maintenance Planner	1 week	N
2. Replace worn-out counter weight bushes with phosphor bronze bushes.	Maintenance Foreman	1 day	Yes
3. Keep Spare of phosphor bronze support bushes in Stores minimum Qty 2 units.	Stores person	1 week	N
4. Address process balance issue from upstream processes to ensure material lubrication on bushes and prevent dry run	Process Engineer	2 weeks	N

The ensuing repair actions entailed the replacement of the worn out phosphor bronze bushes, but the counterweight shaft was not replaced during the same time. The reasons for not replacing the shaft concurrently emanated from the unavailability of the spare shaft in stock and the time it would take to machine a new shaft. The estimated maintenance delay was estimated at seven hours as a contractor company was going to source the shaft material and then machine the shaft, and the failure had occurred during a weekend when most suppliers of steel shafts are closed. The time constraint and the operational losses associated with the maintenance delay was the main push to go for limited maintenance rather than a perfect complete repair of the system.
There was also a screw conveyor that failed at the Johannesburg manufacturing company, but the opted repair type was limited repairs due to more or less the same reasons on the above. The crucial findings were that most repairs instated during breakdowns resulted in imperfect repairs. Over 90% of planned repairs were also found to be imperfect and with only less than 10% of the repairs being perfect.

6. Discussion on Findings

There are several militating factors that prevent perfect maintenance repair actions to be deployed within the industrial setups.

- Firstly cost is the major thrust that determines the choice of a maintenance action being perfect or limited. The overall operational cost is generally considered versus the cost of maintenance, and in most instances, the operational loss far exceed the cost of maintenance, and therefore if a perfect maintenance decision costs are unbearable to the business, a decision is made to opt for an imperfect repair process that minimizes the overall costs
- The availability of skilled resources for the maintenance actions determines whether the resultant repair is going to be perfect or imperfect. For example if specialized welding that requires a competent coded welder needs to be done and the only available resource is a boilermaker without coded welding proficiency, then the resultant repair is imperfect.
- The availability of appropriate maintenance tools and equipment for executing a perfect repair action will affect the repair outcome. If the appropriate tools and equipment are available coupled with the right skillset and operational time constraints, then a perfect repair is feasible, otherwise the option will be to go for a limited repair.
- The availability of appropriate spares and materials required for the repair actions confirms whether the resultant repair is perfect or imperfect.
- The perceived cost-effective maintenance paradigm to be adopted by the organization, e.g. degradation based maintenance with perfect or imperfect repair actions

7. Conclusion

The majority of research findings focusing on age replacement philosophies, relate to the aspect that component failures prior to scheduled replacement time can be either subjected to limited repair or perfect repair centered on the nature of the failure(s), costs for repairing and time availability (Lim et al., 2016:24). The maintenance costs effect of repairs is increasingly becoming an issue of consideration within the maintenance arena, and the cost effect need

to be managed effectively in relation to systems subjected to degradation (Lee et al., 2013:43). Appropriate repair policies are essential in industrial setups because a suitably planned maintenance strategy with defined repair selections can save the business a lot of money and keep physical assets running longer and reliably (Tsai et al., 2011:744). The decision to go for perfect or imperfect repair should be deliberately adopted by the business in full consideration of the costs and reliability impact of the repairs. This has resulted in many industrial parties opting for imperfect repairs instead of perfect repairs in the bid to chase cost effectiveness of the entire business operations. In essence, the business objectives should drive the direction to be taken by the organization when it comes to pursue scheduled perfect or imperfect repairs. The full impact of the repair actions need to be evaluated beforehand before a strategic position is adopted on whether to opt for perfect or imperfect repairs.
The industrial arena is predominantly stashed with imperfect maintenance actions, and the application of perfect repair actions is lagging behind. This is because most business decisions favour imperfect maintenance actions over perfect maintenance actions. The modelling of cost effective perfect maintenance systems is the only way to counteract this deficit, as most business models are financially driven. Future studies should focus on cost-effective repair modelling which presumably emanate from design for cost efficient perfect repair concepts.

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Biographies

Peter Muganyi is a doctoral candidate in Engineering Management at the University of Johannesburg, South Africa and he is an Engineering Manager at Gyproc. His research interest covers the areas of Lean Six Sigma effectiveness, Strategic Maintenance Systems deployment and Business Process Modelling.

Professor Charles Mbohwa is the Vice-Dean Postgraduate Studies, Research and Innovation at the University of Johannesburg's (UJ) Faculty of Engineering and the Built Environment (FEBE). As an established researcher and professor in the field of sustainability engineering and energy, his specializations include sustainable engineering, energy systems, life cycle assessment and bio-energy/fuel feasibility and sustainability with general research interests in renewable energies and sustainability issues.