Warranting Physical Assets Reliability through Criticality Optimization

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

Ignatio Madanhire

Department of Mechanical Engineering
University of Zimbabwe, P.O Box MP167
Harare, Zimbabwe
imadanhire@eng.uz.ac.zw

Abstract

Criticality optimization for physical assets maintenance is meant to warrant high plant reliability for the processing plant. This is a vivacious trait that a bulk of industrial establishments discount and calamitous effects are typically encountered such as lessened reliability of installed equipment owing to wrong maintenance priorities. Equipment criticality ranking constructed on diverse impacts of equipment failure(s) on the businesses need to be carried out so that the businesses do not take a blanket approach to applying the same maintenance strategies and allocating resources unrestrained on all processing physical assets. Maintenance resources allocations need to be apportioned and prioritized as per equipment criticality ranking, and the various facets to consider encompass safety, environment, operations, financial, customer service and quality focused elements, and this is vital for securing cost-effectiveness in maintenance and high reliability in physical assets. Derivation of the processing plant's physical assets spares is consequential to assets criticality analysis and the related parts are managed according to their impacts on the businesses according to the laid-down criteria. This research was carried out to establish the priorities that businesses take at physical asset maintenance level to warrant equipment reliability.

Keywords

Criticality, ranking, optimization, reliability

1. Introduction

Various factors that incorporate focus on strategic resources, resources constraints and management styles have spurred asset intensive enterprises to embark on diverse means of prioritizing and ranking their assets. This consequently drives resources allocation and time investments per physical asset. In some instances, even inventory holding strategies are directly derived from the physical assets criticality ranking and prioritization scheme. Most processing plants establish priorities that are prescribed in such ways that even the intensity of maintenance activities rendered to a particular asset is proportionately concomitant with the projected performance from it, and hence, it is anticipated that the highly critical assets will perform at the highest level conceivable (Go´mez de Leo´n Hijes and Cartagena, 2006:444). With scarcity of resources constraining most firms, and the advent of complex manufacturing systems, assets criticality optimization and prioritizing are presently regarded as tools to tackle the challenges that are prevalent in the management of physical assets (Pascual, et al., 2011:1396). The scarcity of resources enable that the requisite maneuvers are undertaken to express how the resources are apportioned, to warrant that no critical asset is sidelined while more resources are channeled towards non-critical assets, it becomes therefore incumbent upon organizations to classify their assets in a systematic approach to depict their criticality (Go´mez de Leo´n Hijes and Cartagena, 2006:444). During the foregone eras, Pareto-analysis has been utilized to classify the highly critical assets and their linked failure patterns, but the distinctive drawback of this approach was found as the fact that it imposes pre-selection of a specific state to present criticalities (Pascual, et al., 2009:1308).

To satisfy the ever piling strains of the prevailing industrial scenario, institutions are propelled to consistently enhance their aptitude to upsurge value and progress the cost-effectiveness of their decision criterion (Pascual, et al., 2009:1308). The decision criteria incorporate a mix of approaches and tasks that can present the optimized savings, coupled with their associated strategic outcomes, with these decision criteria largely deployed at strategic and tactical stages (Pascual, et al., 2009:1308). The approach taken during criticality optimization need to cater for the consequences emanating from any business impact which maybe financial, operational or legislative when an asset functionally fails (Go´mez de Leo´n Hijes and Cartagena, 2006:444). Therefore the asset maintenance activities are established chiefly to ensure reliable functioning of assets and guaranteeing the utmost attainable asset availability complemented by high safety performance (Go´mez de Leo´n Hijes and Cartagena, 2006:444). Reality dictates that no economic viability is derived for a processing plant when all assets obtain the same maintenance care, and this necessitates that asset care strategic choices are done with full contemplation of the scarcity of resources (Go´mez de Leo´n Hijes and Cartagena, 2006:444). Thus a maintenance scheme is derived from a duteous examination of all the physical assets from an objective point of view that pursues collecting of all pertinent information on assets to endorse and dissect the achievability of every asset care action, or emblematically, to establish optimized criticality ranking that derives the asset care (Go´mez de Leo´n Hijes and Cartagena, 2006:444). That duteous examination starts with a wide-ranging catalogue of assets, comprising their features and operational connections; historic facts of prior failures, the original acquirement value, fundamentals and operational essentials, the type of asset care to be deployed, and any legislative or votive obligations regarding asset care, etc. (Go´mez de Leo´n Hijes and Cartagena, 2006:444). The intention is to inaugurate the criticality of all physical assets according to their ranking in the significance of their functions and, subsequently to the corporate, and this brings about a prioritization criterion for asset care efforts and resources apportionment (Go´mez de Leo´n Hijes and Cartagena, 2006:445).

2. Key Facets of Criticality Optimization

Literature on maintenance systems carry an innumerable number of techniques for criticality optimization related to maintenance decisions that deliberates on safety, technical aspects and business views (Pascual, et al., 2011:1396). Different techniques have been developed to categorize the critical assets of an enterprise, with some dwelling entirely on the functional failure effect on service delivery, while others are framed on risk, like HAZOP, the Analytical Hierarchical Process (AHP), and the multi-criterion classification of critical equipment (MCCE), with these approaches arrogating values that determine the criticality index (Go´mez de Leo´n Hijes and Cartagena, 2006:445). Recently, new methodologies such as the graphical log scatter-mapping technique has been availed and it reveals three elementary performance indicators contemporaneously, which are reliability (MTBF), maintainability (MTTR), and unavailability (D), but it doesn’t incorporate economic bearings (Pascual, et al., 2009:1308). The format of asset criticality optimization which is applied to an operational asset and meant for asset care decisions differs to the criticality optimization that is applied during the design phase of an asset, with the design phase objectivity being more inclined towards ascertaining critical dimensions to enable contradictory designs to achieve distinct performance goals that can be augmented and paralleled (Marquez, et al., 2016:513). The greater part of the modern-day quantifiable contexts of assets criticality optimization apply weighted-scoring methods well-defined as deviations of the RPN approach and these methods may appear simple, but to safeguard genuineness of examination outcomes, a distinct technique ought to be used when instituting facets and computed grades and connected algorithms (Marquez, et al., 2016:514).

3. Utilizing Criticality Optimization to Drive Physical Assets Reliability

Assets Criticality Optimization when it is applied to maintenance activities directed towards physical assets is preordained to warrant reliability when the asset is installed in the industrial factory (Upadhyay et al., 2013:17). This is a crucial trait that various manufacturing firms disrespect and cataclysmic outcomes are normally incurred like suppressed reliability of physical assets (Upadhyay et al., 2013:17). The objective of Assets criticality optimization is to develop a system that culminates in optimised maintenance activities in the business, and therefore offering value added maintenance (Burnett and Vlok, 2014:165). The prioritization rating analysis that is applied considers assets by their uses or by applying a criteria-based rating arrangement which computes significance relative to allotted criteria-weights (Burnett and Vlok, 2014:166). The decision miscellany embodies the priorities averred to assets, with the objectivity being to pinpoint those assets that are highly crucial to operations and necessitate close asset care attention, ranking the failure types of every critical asset so as to counteract the impression, and selecting the utmost fitting asset care strategy for every defined failure mode (Burnett and Vlok, 2014:167). Thus in essence, the asset criticality optimization model follows the three phases of identification, prioritization and asset care, as depicted in figure 1 below.

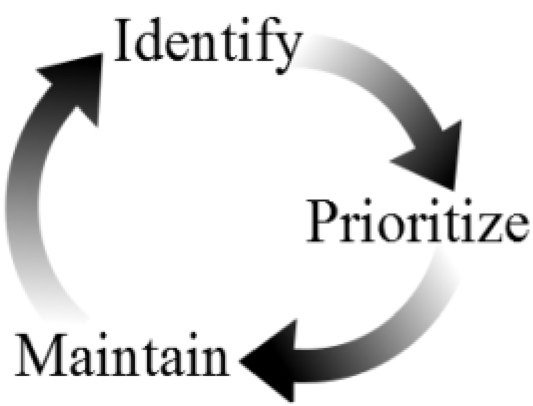


Figure 1: Broad scheme of asset criticality optimization (Burnett and Vlok, 2014:167)**.**

.

Various techniques have been developed and applied for the sake of equipment identification, analysis and prescription of consequential maintenance strategies, and some of the widely applied techniques are specified below.

- The tactical-analytical-hierarchal-process-for-prioritization (TAHPP), which is a derivative of the analytical- hierarchal-process (AHP) whose objective is to address the privation of decision making approaches that are comprehensible and implementable to allow for complexity handling. This technique translates qualitative annotations to figurative outcomes which can be ranked. TAHPP aims to quantify comparative significances for a specified establishment of options, comparing the alternatives on a ratio-scale ranging from 1 to 9, and the dependability of the decision-maker is also verified, ascertaining the accuracy of the results (Burnett and Vlok, 2014:167)**.** The figure below illustrates a typical TAHPP approach as applied to an industrial setup.

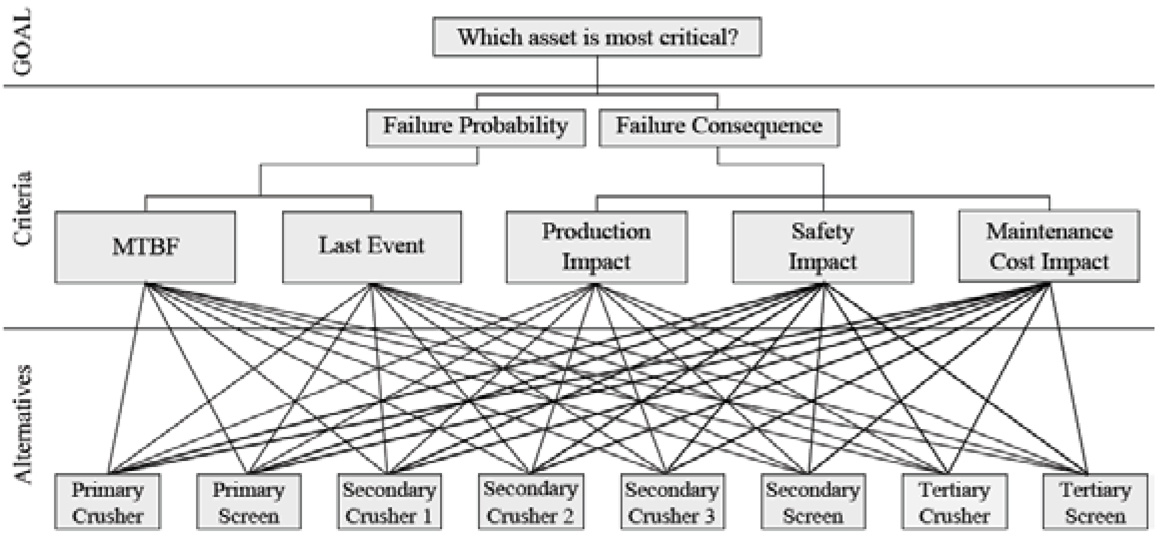


Figure 2: The TAHPP illustrative structural approach (Burnett and Vlok, 2014:170).

- The Simple-multi-attribute-rating-technique (SMART), which is structured and formulated to manipulate the trade-offs amongst various intents, and is considered one of the modest approaches used for multi-criteria decision-making (MCDM). SMART is somewhat a swift and uncomplicated examination that delivers expressive results, it is designated for the failure-mode prioritization stage. SMART addresses the notion that a multiplicity of failure modes can be attributed to a single asset, so in the event an asset is identified as critical, all of its failure modes must be evaluated to attain precise prioritization. SMART follows a structural approach premeditated to leverage the tradeoffs amongst various intentions, and is an easy method utilized for multi criteria decision making (MCDM). With SMART, each alternative is specified a directly rated value relative to every separate criteria. This rated value depicts the satisfaction each alternative fulfills the criteria. Typically, the ratings alternate between either 0 or 1, with 0 depicting the worst-case situation and 1 representing the best-scenario. The multiplication of the alternative rates, r_{ij}, by the criteria weights, w_i, and then summarizing them, give an outcome which is the evaluation value, *V(Aj),* which is computed in accordance with the equation below:

$$V(A_j) = \sum_{j=1}^{n} w_i r_{ij} \tag{1}$$

(Burnett and Vlok, 2014:167).

- The Technique-for-order-of-preference-by-similarity-to-ideal-solution (TOPSIS) is labelled as a decision making technique that discovers an outcome that is bordering on the ideal and furthermost from the undesirable ideal – to a multi-criteria issue. The undesirable ideal result is taken to be the foulest alternative. TOPSIS only requires imperfect subjective contribution from the decision-maker, and then weigh the alternatives against the specified criteria. TOPSIS is an easy technique and is highly applicable for existent multi-criteria problem-solving, affording the decision-makers with the greatest alternatives and it's a swift, easy-rating technique that applies matrix normalization and cross-multiplication to ascertain the alternative outcome that is bordering the ideal and furthermost from the negative ideal. Application of TOPSIS leads to selecting the preeminent asset care strategy for every failure mode. Figure 3 below depicts the various stages in which the various techniques are applied (Burnett and Vlok, 2014:168).

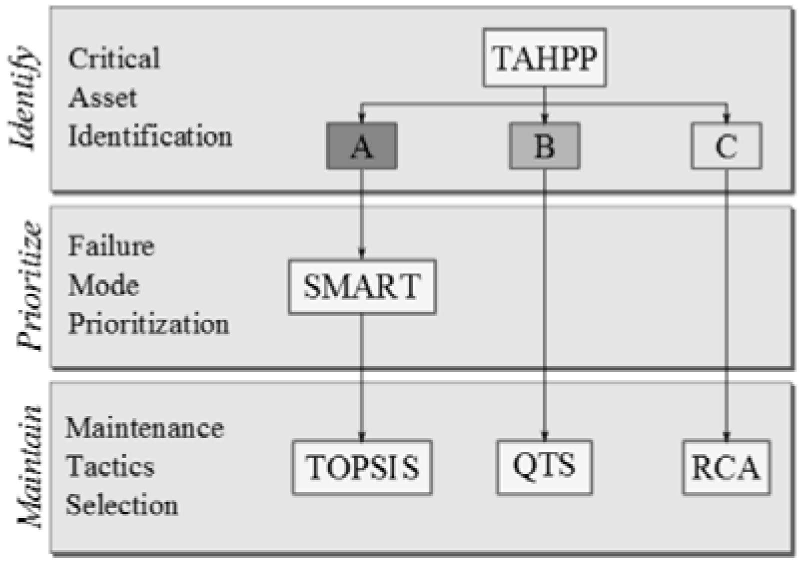


Figure 3: Criticality Optimization phases and techniques application (Burnett and Vlok, 2014:168)**.**

- The simplified-numerical-decision-making-methodology (SMDM) is another technique that have the criticality of the assets plotted on a grid to display the criticality graphically, whereby selected asset care tactics are deployed to further analyze failure modes, and then Pareto analysis is applied to regulate the urgency of the requisite activities (Burnett and Vlok, 2014:169)**.**

- The Multiple-criteria-decision-making-Fuzzy-analytic-hierarchy process as an asset prioritization technique holds the fact that a crispy decision making scheme as the conventional AHP is not adequate as the bulk of asset care goals availed as criteria are not monetary and therefore not easy to quantify. Fuzzy-inference theory and fuzzy-multiple-criteria-decision- making (MCDM) are applied on the ensuing maintenance strategies utilizing the evaluation system. The utilization of the fuzzy theory for the asset criticality optimization technique has proven to be a worthy key. (Wang et al., 2007:152). It is a populous technique for MCDM as it structures an intricate decision problem hierarchically at multiple dissimilar echelons. It embraces: (1) establishing the problem(s) hierarchically being structurally configured as a hierarchical tree, with the peak level being the inclusive objectives of the problem, and the alternatives being located at the lowermost level, and being separated by the criteria and sub-criteria. (2) Construction of decision matrices by pair-wise assessments: The decision-matrices of the criteria/alternatives are well-defined from the common associations of criteria at given levels or for every conceivable alternative. Pairwise associations are centered on a standardized assessment arrangements (1 = equivalent significance; 3 = weak significance; 5 = solid significance; 7 = established significance; 9 = complete significance). (3) Computing localized priorities from decision matrices: multiple approaches for establishing localized priorities (i.e. the localized-weights of criteria and the localized-scores of alternatives) from decision matrices have to be formulated, of which the examples of methods include the eigenvector (EV), the logarithmic-least-squares (LLS), the weighted-least-squares (WLS), the goal-programming (GP) and the fuzzy-programming (FP). The consistency of decisions check is incorporated for each decision matrix. (4) Ranking the alternatives: The concluding stage entails obtaining global-priorities (including global-weights and global-scores) by computing the aggregates of all localized priorities through the means of applying simple-weighted sum, and ultimately the absolute classification of the alternatives is constructed on the premise of the global priorities. (Wang et al., 2007:155).

It is possible to use a combination of selected techniques for assets criticality optimization and eventually prescribing maintenance actions for ensuring their functional reliability. The figure below demonstrates a combinative approach to the asset criticality optimization process.

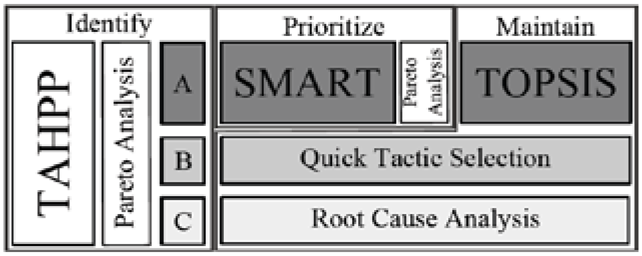


Figure 4: A combinative technique approach to Asset Criticality Optimization (Burnett and Vlok, 2014:169).

During the selection of the appropriate maintenance strategies for diverse physical assets in manufacturing businesses, several maintenance objectives or comparative criteria ought to be considered, and aspects such as impacts on operations, health & safety, environment and cost are common considerations (Wang et al., 2007:153). Therefore, the Asset Criticality Optimization modelling should be used for ultimately selecting the maintenance strategies for the business' physical assets and ensuring that they operate with high reliability (Wang et al., 2007:153). Essential controlling and storage of spares inventory for critical assets follow the criticality optimization process and the ensuing measures of storage of the spares in dust-free, moisture-less, sanitary and clean thermosphere, are the necessary steps taken for guaranteeing assets reliability (Kamani, (2014:5), Knotek, (2016: 81)). It is imperative that these rule-based decision-making systems have conflict resolution mechanisms embedded in them, as the rule-based reasoning systems, can have a tendency to create clash or obscurity when retrieving and comparing sub goals and rules (Lai and Xiong, 2014:677).

4. Case Study – Using Criticality Optimization to Prioritize Reliability Improvement

4.1 The TDPC approach to physical assets Prioritization

A manufacturing organization in Johannesburg, South Africa, whose main products were meant for the construction industry, did embark on an asset criticality optimization process, as they intended to classify all their physical assets, and ultimately formulate maintenance strategies to improve reliability according to the guidance afforded by the resultant classification from the criticality optimization process.
As a first step, a vision was formulated, and they defined it as the necessary steps taken to prioritize all manufacturing physical assets according to their classification of AA, A, B and C. The formulation of the vision was closely followed with the objectives setting, of which they had 2 key objectives which addressed the issue of having all their equipment classified as per specific methodology, and secondly, targeting the high criticality machines to have a high maintenance and reliability status. The table below depicts an objectives table as was developed and tracked in the year 2016 by the company.

Table 1: Criticality Optimization objectives (Muganyi, 2017).

Number	Workshop	Objective	Target	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	YTD
1	PLANT	Number of machines not classified	0					37	25	22						22
2		Number of machines updated to PM Step 3	3					1	2	5						5
3																
4																
5																
6																
7																
8																

The objectives were being tracked to ensure that the set targets were attained as was determined by the leadership and team that were involved in the exercise.

In order to derive the assets criticality ranking, a defined methodology was followed and it was guided by the measures detailed in the table below that specified the rules to be adhered to during the process of assigning ranking values for each and every aspect considered. The aspects that were considered for coming up with the overall criticality ranking included the following four main categories that were further subdivided into finer measures:

- ❖ Time to Repair (T)
- ❖ Degree of Influence (D)
- ❖ Probability of Failure (P) and
- ❖ Criticality of Equipment (C)

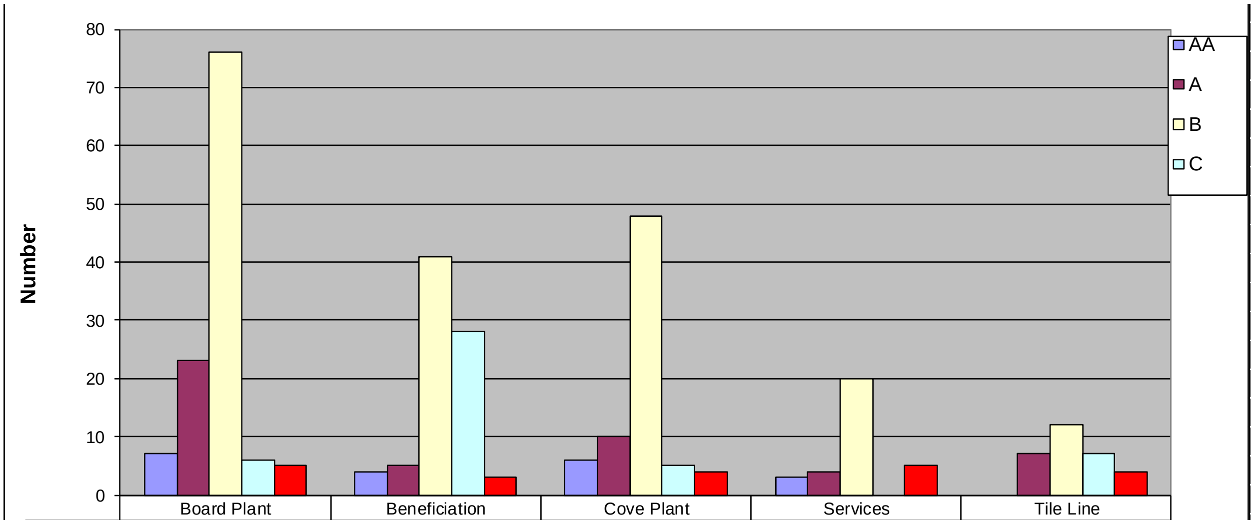
This methodology is known with the acronym TDPC, and it was followed methodically to come up with the criticality optimization of the Johannesburg manufacturing firm's physical assets.

Table 2: TDPC methodology for physical assets criticality optimization (Muganyi, 2017).

Classification	No	Item	Guidelines for Scoring
Time to Repair (T)	1	Average downtime MTTR	>11 hours = 35, <0.12 hours = 5
Degree of Influence (D)	2	Loading of Machine	>100% = 5 <60% = 1
	3	Effect on product quality (Quality Index)	Effect on Quality Index > 10% = 5, no effect = 1
	4	Cost of quality failure (Customer Claims)	>ZAR25,000 = 5, ZAR2,500 = 1
	5	Energy Loss	>ZAR40,000 = 5, ZAR2,500 = 1
	6	Impact on Yield	0.1% of Line Yield Loss = 5 < 0.01% of Line Yield Loss =1
	7	Failure affects people safety	High risk to personnel = 5, no risk = 1
	8	Failure affects environment	High effect on environment = 5, little effect =
Probability of Failure (P)	9	Frequency of stoppage MTBF	>77 HRS = 35, <30000 HRS = 5
Criticality of Equipment (C)	10	Criticality of equipment with respect to line(s) stoppage	20 - Does not impact line / process 40 - Impact to line < 24hrs 60 - Impact to line > 24hrs 80 - Impact to more than one line < 24hrs 100 - Impact to more than one line > 24hrs

4.2 The results of TDPC methodology implementation

The TDPC process resulted in the following equipment classifications for the Johannesburg manufacturing company. Their two manufacturing facilities yielded the results displayed in figures 5 and 6 as shown graphically.



	Board Plant	Beneficiation	Cove Plant	Services	Tile Line
AA	7	4	6	3	0
A	23	5	10	4	7
B	76	41	48	20	12
C	6	28	5	0	7
Unknown	5	3	4	5	4

Figure 5: TDPC analysis results for manufacturing facility #1 (Muganyi, 2017).

The figure below shows the TDPC categorization derived from the second manufacturing facility.

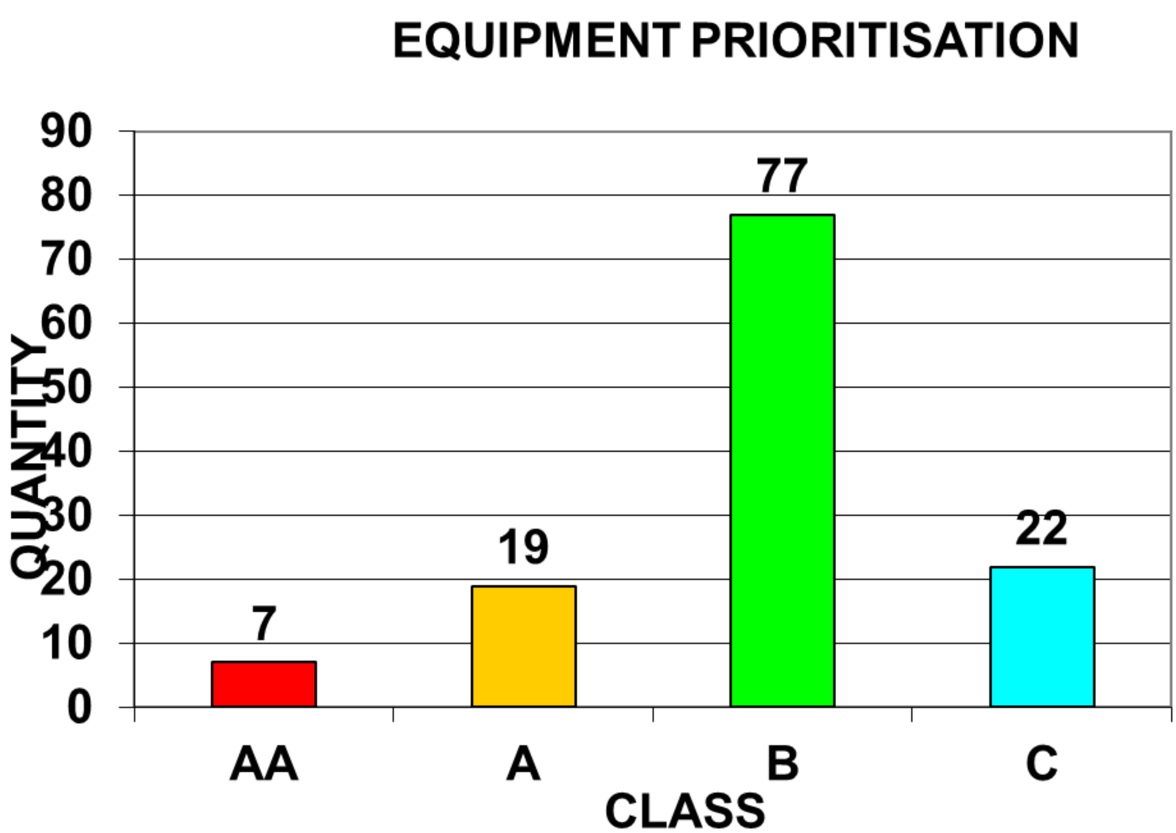


Figure 6: TDPC analysis results for manufacturing facility #2 (Muganyi, 2017).

The results of the classification process according to the TDPC process is illustrated as per the extract from the analysis register which is shown below.

Table 3: Criticality optimization analysis results as extrated from the results register of TDPC (Muganyi, 2017).

	A	B	C	E	F	G	H	I	J	K	L	M	N	O	P	Q
1				Average Downtime	Loading of Machine	Effect on Quality	Cost of Failure	Energy Loss	Impact on Yield	Safety Impact	Environment	MTBF	Criticality			
2	NUMBER	MACHINE DESCRIPTION	WORKSHOP	TI	DE	RE	O	NE	UE	CE		PR	CR	TOTA	RANKIN	Comments
3	TUBE MILL	Tube mill	Tubing Plant	35	1	5	5	5	5	2	3	35	100	196	AA	
4	HP PUMP1	Hot Pit submersible pump	Calcining Plant	35	5	5	5	5	5	2	3	5	100	170	AA	
5	KETTLE	Calcine kettle	Calcining Plant	35	5	5	5	5	5	2	3	5	100	170	AA	
6	110.1	TRANSFORMER #1	Services	35	5	3	5	2	5	5	3	5	100	168	AA	
7	Screw 8	Jetstream discharege screw	Calcining Plant	35	5	5	5	1	5	5	1	5	100	167	AA	
8	110.2	TRANSFORMER #2	Services	35	5	3	5	2	5	5	2	5	100	167	AA	
9	110.3	TRANSFORMER #3	Services	35	5	3	5	2	5	5	2	5	100	167	AA	
10	SUB 1	Sub Station 1	Services	35	5	3	5	2	5	5	1	5	100	166	A	
11	CAL-DB	Calcine Plant Distribution Box	Services	35	5	3	5	2	5	5	1	5	100	166	A	
12	22.1	COMPRESSOR #1	Services	35	5	5	5	1	5	2	2	5	100	165	A	
13	22.2	COMPRESSOR #2	Services	35	5	5	5	1	5	2	2	5	100	165	A	
14	E2	Elevator #2	Mixing & Bagging	30	5	4	4	1	5	2	2	10	100	163	A	
15	HOT PIT	Hot pit	Calcining Plant	35	5	1	1	5	5	3	2	5	100	162	A	
16	E3	Elevator #3	Calcining Plant	35	5	1	5	1	5	2	2	5	100	161	A	

The resultant classification was then used to embark on reliability improvement projects that were targeted firstly on AA category machines to begin with. The major tenets of the reliability improvement projects entailed analysis of all previous equipment failures, identification of major assemblies and components, identification of wear components, identifying hard to access areas and designing them out, and finally, formulating maintenance actions to prevent failure. The improvement projects followed a 7 steps structured methodology of improving physical assets reliability under the auspices of the Professional Maintenance pillar of World Class Manufacturing system. The tracking of failure results for a monthly interval was carried out and the results of the analysis is shown in the figure below.

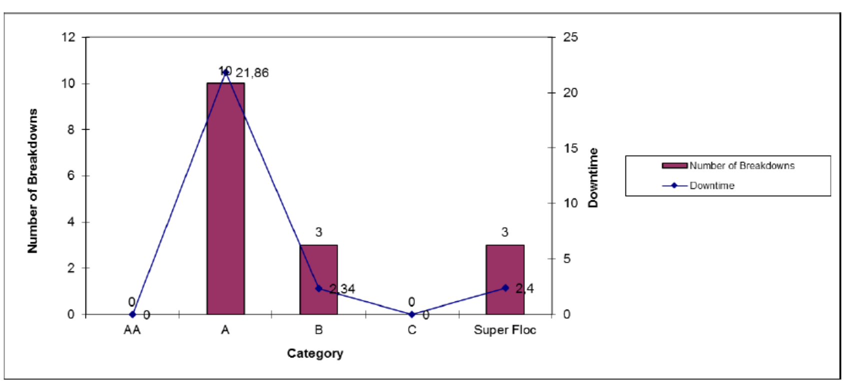


Figure 7: Number of equipment breakdowns per criticality category during a monthly interval (Muganyi, 2017).

The AA category machines which had reliability improvements projects undertaken on, showed that they had experienced zero downtime during the month under consideration and there was minimal impact on the business operations and other critical decision factors like safety and environment. The criticality optimization process was highly regarded as successful for a cost effective reliability improvement programme for the manufacturing assets.

5. Conclusion

The results of the case study shows that though there are variants of physical assets criticality optimization models that various businesses can apply, it is feasible to apply a specific model that can give consistent results when a systematic approach has been undertaken. Even though the use of the numerical decision-making techniques had some limitations in the absence of the likes of fuzzy based AHP decision making systems, it was shown that the key aim of every asset criticality optimization model is to cost-effectively maintain physical assets to upsurge their reliability in an economically optimum manner.

The criticality optimization model, whichever is selected, for instance, TAHPP, should ultimately create a priority hierarchy of assets constructed on specific applicable criteria. The quality of input data is crucial to prevent ambiguity of the decision process, and this is key to the ensuing processes as maintenance resources can be eventually wasted on non-critical assets as a result. The consequence or impact of equipment failures is a critical aspect that always needs to be considered during the criticality optimization process, and aspects such as impact on maintenance and operational costs, impact on health, safety and environment are paramount.

At the end of the day, the criticality optimization model computes the significance of physical assets according to assigned criteria weights, and the resultant priority rankings are utilized to formulate asset care strategies for physical assets to mitigate the overall impact on the business as a whole. The overall business impact or performance is ameliorated when the physical assets attain high reliability in the operational environment, thus heightening assets availability for operational viability.

References

Burnett, S. and Vlok, P.J., A Simplified Numerical Decision-Making Methodology for Physical Asset Management Decisions, *South African Journal of Industrial Engineering*, Vol 25., No. 1, pp.162-175, 2014.

Go´mez de Leo´n Hijes, F. C. and Cartagena, J. J. R., Maintenance strategy based on a multicriterion classification of equipments, *Reliability Engineering and System Safety*, vol. 91, pp. 444–451, 2006.

Kamani, P.K., Forms of corrosion: Erosion-corrosion - Part 9, *www.paintindia.com*, vol. 101, 2014

Knotek, R.R., How to diagnose bearing failures: Take a 'CSI' approach to find the root cause of bearing failures *www.plantengineering.com*, pp. 77 – 81, 2016.

Lai, Y. and Xiong, Y., Hierarchical Storage Model and Priority Ranking of Rules in Rule-based Reasoning System, *International Journal of Computational Intelligence Systems*, Vol. 7, No. 4, pp. 676-685, 2014.

Márquez, A. C., Moreu de León, P., Rosique, A. S. and Gómez Fernández, J. F., Criticality Analysis for Maintenance Purposes: A Study for Complex In-service Engineering Assets, *Quality and Reliability Engineering International*, vol. 32, pp. 519–533, 2016.

Pascual, R. Del Castillo, G., Louit, D. and Knights, P., Business-oriented prioritization: A novel graphical technique, *Reliability Engineering and System Safety*, vol. 94, pp. 1308–1313, 2009.

Pascual, R., Godoy, D. and Louit, D.M., Throughput centered prioritization of machines in transfer lines, *Reliability Engineering and System Safety*, vol. 96, pp. 1396–1401, 2011.

Upadhyay, R.K., Kumaraswamidhas, L.A. and Sikandar Azam, Md., Rolling element bearing failure analysis: A case study, *Case Studies in Engineering Failure Analysis*, vol. 1, pp. 15–17, 2013.

Wang, L., Chu, J. and Wu, J., Selection of optimum maintenance strategies based on a fuzzy analytic hierarchy process, *International Journal of Production Economics*, vol. 107, pp. 151–163, 2007.

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.

Ignatio Madanhire graduated with a PhD in Engineering Management at the University of Johannesburg, South Africa, he is also a Senior Research Associate. He is also a lecturer with the Department of Mechanical Engineering at the University of Zimbabwe. He has research interests in engineering management and has published works on cleaner production in renowned journals.