Development Of An Asset Criticality Assessment Tool, The Case Of A Fertiliser Manufacturing Company

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Abstract
The adaptability of asset management plan to changes in production models is needed to improve competitiveness. This research outline a design of a criticality assessment tool with particular emphasis to a Fertiliser Manufacturing Company. The criticality assessment tool was developed as a framework based on the Analytical Hierarchical Process (AHP) which was used in the design of a computer application. The assessment tool was applied at the Company producing criticality scores and ranking for assets which had been presented in two hierarchical levels namely system and sub-system 12 System level assets and 142 sub system level assets). The results produced by the assessment tool where consistent with the perceived top 10 critical assets as determined by 24 subject matter experts (SME) within the organization. The results allowed the Company to priorities its critical assets and come up with strategies for each asset which was previously difficult to achieve. The tool enable the prioritization of assets in line with the business objective as stipulated in the asset management system standard (ISO 55001).

Keywords
Asset Criticality, Analytical Hierarchical Process (AHP), ISO 55001, Asset Management

1 Introduction
The current global trend where energy deficiency and dynamic trade policies affect business, provides a platform were business strategies change rapidly thus affecting production models which in turn affect asset management (in this paper asset management refers to physical assets). It becomes important for asset management decision makers to be in-sync with the business strategy. Thus "changing business dynamics has made it imperative on a decision maker to have a quantified decision" (Singh & Kulkarni, 2013). Asset criticality basically changes when business models change since certain systems will be discontinued while other systems are installed or enhanced. This is the case with most Company in Zimbabwe where a fertilizer manufacturing company can be cited as an example that has changed the operational model resulting in three production systems being discontinued, Figure 1 shows the installed plant configuration while Figure 2 shows the revised model. The systems seized to be critical thus affecting, service level agreements, spares management and personnel utilisation. Obviously it becomes important to know the assets that need to be prioritized to complement the new business model.

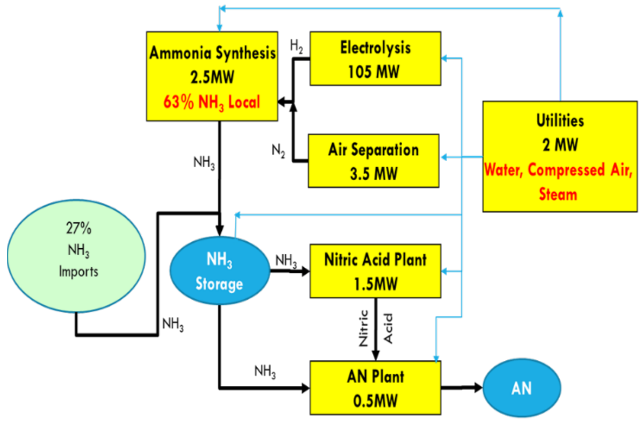

Figure 1: Installed plant configuration

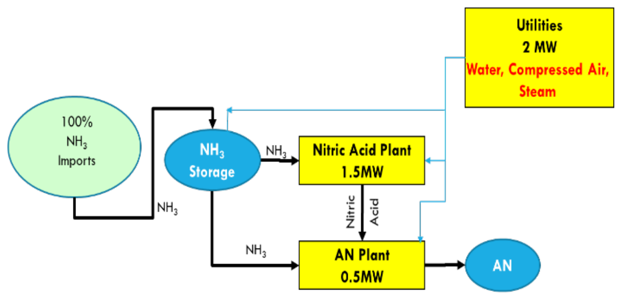

Figure 2: Revised plant configuration

According to ISO 55001:2014 to achieve Asset Management (AM) objectives (6.2.2a) it is a requirement to have a method and criteria for decision making and prioritizing activities and resources. As part of guidelines to application of ISO 55001:2014, the standard states that a risk ranking process can determine which assets have a significant potential to impact on the achievements of the asset management objectives i.e. which are the critical assets. This presents the need for criticality analysis within the asset management framework.

Considering the latter statements it become pertinent for organisations to have an interest in ensuring that the most critical equipment for a given production model are known. A case in point is for a Fertiliser manufacturing company. This paper outline the development and practical application of an asset criticality assessment tool at a Fertiliser Manufacturing Company.

2 Literature review

The literature review focuses on physical asset management and asset criticality determination, implementation, and influential decision making techniques. Alignment of the asset management strategy to the business strategic objectives is important to organisational growth and survival, hence the development of asset management standards such as ISO 55001:2014. ISO 55000:2014 para 2.4.1 states that "asset management is the coordinated activity of a company to realise value from assets which involves the balancing of costs, opportunities and risks against the desired performance of assets, to achieve the organisational objectives". Given the resource constraints in the business environment it is very important to utilise resources were they generate the most impact, it becomes prudent to prioritise assets based on how critical they are to the current business model. Prior to the development of ISO 55001:2014 different institutions had frameworks that related to asset management. According to Jafari et al (2014) the United States Environmental Protection Agency (EPA) methodology has been one of the prominent frameworks. Figure 3 below shows the EPA Ten step Asset Management Methodology. The methodology shows that at step six the organization should identify the assets that are highly critical to its operation hence focus should be placed on assets that matter the most. Therefore asset criticality assessment is precedent to optimization of Operations and Maintenance (O&M) Investment as well as a Capital Investment Plan (CIP). The criticality level of each equipment determines its impact on the operating system and the direction of maintenance improvement (Hartini, Dibyo, & Pujiarta, 2018).

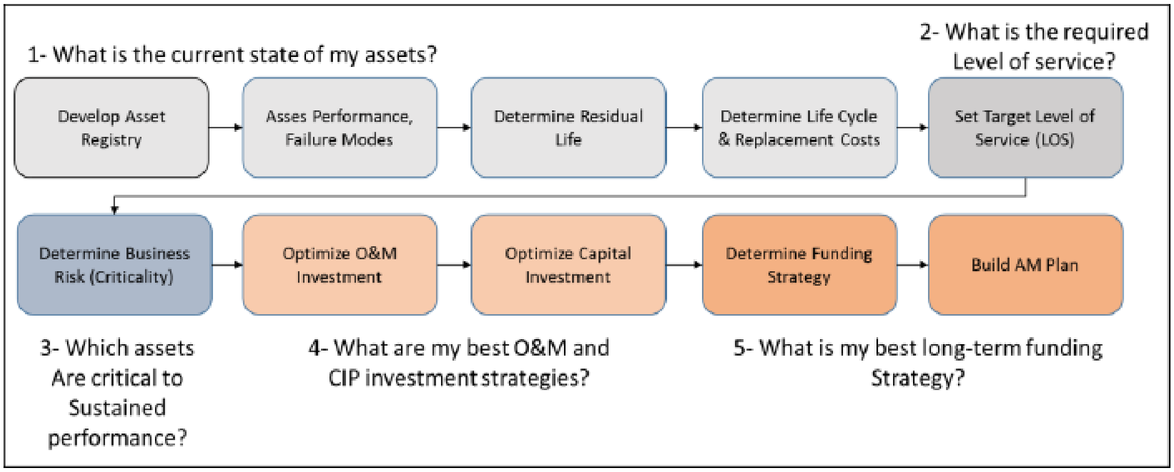

Figure 3: Ten step EPA asset management methodology

2.1 Asset Criticality

Adams et al 2016 proposed the application of dynamic criticality (using system dynamic approach) premised on, one crucial question that must be answered by asset intensive organisations: "Do we understand the risk profile associated with our asset portfolio and how this will change over time?" For one to understand criticality one has to be clear on what criteria influences criticality.

The three main step in asset criticality analysis are;

- Asset identification which involves a method of identifying existing assets, this can be done by establishing an asset hierarchy, assigning assets into specific asset categories, and collecting all the required information regarding each asset.
- Criteria determination involves coming up with asset criticality decision elements. This enable the decomposition of criticality into various meaningful facets.
- Scoring involves giving a relative measure of individual asset criticality based on the criticality criteria which in essence are decision elements.

A literature review focusing on identifying criterion used by different scholars revealed that Operational impact, Safety impact and maintenance cost are common criteria used for asset criticality. Table 1 below shows the commonality of criteria after aggregating identified works by different scholars.

Table 1: Asset criticality criteria

Item	**Asset Criticality Criteria**	**Scholars**						
No	**Title**	(Jaderi, sa'idi, Anvaripour, & Nabhani, 2012)	(Singh & Kulkarni, 2013)	(Suryadi & Setyanta, 2007)	(Hartini, Dibyo, & Pujiarta, 2018)	(Melani, Murad, Netto, Souza, & Nabeta, 2018)	(Jaderi, Ibrahim, & Zahiri, 2019)	**Occurrence**
1	Operational impact	**X**		**X**	**X**	**X**	**X**	**5**
2	Product/Service Quality Impact	**X**	**X**		**X**			**3**
3	Safety Impact	**X**		**X**	**X**	**X**	**X**	**5**
4	Environment Impact	**X**	**X**			**X**	**X**	**4**
5	Presence of redundancy			**X**			**X**	**2**
6	Maintenance Cost	**X**	**X**		**X**	**X**	**X**	**5**
7	Reliability (MTBF)	**X**		**X**		**X**		**3**
8	Probability of Failure	**X**		**X**				**2**

2.2 Decision making

The decision making process provides the baseline for any assessment/analysis or ranking tool. Dodangeh et al (2011) stated that people generally use one of the two methods for making decisions:

a) Trial and error method. In the trial and error method, the decision maker faces reality, so he chooses one of the alternatives and witnesses the results. If decision errors are great and if they cause some problems, he changes the decision and selects other alternatives.
b) Modelling method. In the modelling method, the decision maker models the real problem and specifies elements and their effect on each other and gets through the model analysis and prediction of a real problem. Multi-criteria decision making (MCDM) addresses decision making with regards to multiple and conflicting criteria. In fact, there are two types of criteria: objectives and attributes.

MADM is applied in the evaluation facet, which is usually associated with a limited number of predetermined alternatives and discrete preference ratings. MODM is especially suitable for the design/planning facet, which aims to achieve the optimal or aspired goals by considering the various interactions within the given constraints (Tzeng & Huang, 2011). It is clear that asset criticality assessment/ranking can be defined as an MADM problem.

2.3 Multi Attribute Methods (MA) in Asset criticality

Study by Price et al 2017 validates an existing methodology for analysing cyber asset criticality to determine key cyber terrain in the context of a non-trivial case study accentuates asset criticality analysis using Multi Attribute methods (MA). The study also emphasised that asset criticality is mission-dependent and contextual. In the context of the study, it was found that weighting assets in relative importance to a mission plays a more important role in identifying cyber key terrain than ranking the relative importance of cybersecurity criteria and criteria weights are dramatically less important than family weights (Price, Leyba, Gondree, Staples, & Parker, 2017). MA methods are TOPSIS, VIKOR, ANP, AHP and Weighted Sum (Hodgett, 2013), all these method can be used for asset criticality ranking. AHP is the most prominent of the methods (Hodgett, 2016).

Analytic Hierarchy Process (AHP) is a method for selecting one alternative from a given set of alternatives, where there is multiple decision criteria involved, and to rank available alternatives in a desirability order based on a rational framework of quantitative comparisons (Saaty, 1994). AHP deconstructs decision making into a hierarchical form were the hierarchical order is goal, criteria and alternatives. Figure 4 below shows a representation of AHP.

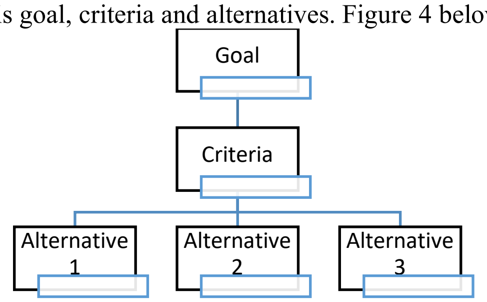

Figure 4: AHP Representation

2.4 Recent Trends in Asset Criticality Determination

Three different approaches mentioned below provide a representation of how asset criticality assessment have been carried out by different scholars as from the year 2017.

a) Drive to standardise Asset criticality assessment

The National Institute of standards and technology (NISTIR) developed their own criticality and prioritisation model to try and standardise Asset management criticality assessment. The model is iterative and can be conducted at increasing level of detail to refine the results and accept additional inputs (Paulsen, Boyens, Bartol, & Winkler, 2018). The model presented involves coming up with a criticality analysis procedure which can be implemented at different asset levels. The model separates equipment by level thus providing a structure approach in conducting asset criticality.

b) System Equipment Reliability and Prioritisation (SERP)

System Equipment Reliability Prioritisation (SERP) comes from a reliability background and can be applied as part of a reliability improvement program. Hartini et al have successfully utilised the SERP methodology on an RSG-GAS safety system. The result of the SERP process is the maintenance priority index (MPI) in the form of ranking equipment (system or component) based on certain criteria that determine the criticality level of equipment based on total data and frequency of damage. The output of the SERP process is the MPI (maintenance priority index) that serves to focus and prioritize the improvement of an asset (Hartini, Dibyo, & Pujiarta, 2018).

c) Criticality determination using Criticality Based Maintenance

Criticality Based Maintenance has been developed to provide additional techniques to increase efficiency and quality of reliability centered maintenance analysis. (Melani, Murad, Netto, Souza, & Nabeta, 2018) proposed a three step method and applied it on the Flue Gas Desulfurization System of a Coal-Fired Power Plant under the auspices of Criticality Based Maintenance. The method utilized the widely accepted techniques of HAZOP, FTA, FMECA with critical component screening using ANP.

d) Criticality based Maintenance Method

The method produced results that were in line with the engineering team's perception of the critical assets hence the method was acceptable. Since the method uses ANP with the ranked equipment as one cluster its limitation is applicability of the method on systems that have a huge number of assets. This method relates well with the objective of this research although it needs to be streamlined and simplified.

2.5 Asset criticality determination trend

Multi Attribute (MA) based criticality ranking tool which incorporates management of risks associated with asset failure have potential for practical application within organizations.
Multi attribute methods MA has been applied by scholars such as;

a) Criticality Analysis of Power-Plant Equipment (Singh & Kulkarni, 2013)
b) Criticality Analysis for Assets Priority Setting of Abadan Oil Refinery (Jaderi, sa'idi, Anvaripour, & Nabhani, 2012)
c) Criticality-based maintenance of a coal-fired power plant. The method utilized the widely accepted techniques of HAZOP, FTA, FMECA with critical component screening using ANP (Melani, Murad, Netto, Souza, & Nabeta, 2018)

3 Methodology

The philosophical stance for the research was critical realism which basically accepts a realist ontology paired with an anti-realist epistemology, that is to say the ability to know for certain what reality is may not exist without continual research. With regards to the research topic which focuses on asset criticality and the change in business model the critical realism stance enable a line of thinking which opens the mind to a shifting reality which does not aim for an absolute outcome but a reasonable outcome.

3.1 Research approach

For this research a deductive approach was utilised were the general theories relating to asset management and decision making where considered resulting in a specific outcome that is in line with the research objective. The research progressed from general theory to more precise deliberations on the research topic. A literature survey into prior research in asset criticality assessment enable the establishment of decision making theory in particular analytical hierarchical process AHP as an appropriate foundation for assessing asset criticality. The data collection strategies employed complimented the identified theoretical inclination.

3.2 Data collection strategies

From the introduction provided for this paper it is evident that the solution being sort is for a specific case which means that the research is largely a case study. Within the case study a survey was instituted to determine the following;

i. Knowledge, and implementation of ISO 55001 at the Company.
ii. Importance of asset criticality ranking in asset management.
iii. Criteria which relates to asset criticality including their effects.
iv. Criteria to criteria comparison to determine relative importance.

v. The perceived five most critical assets.

An interview of senior management was carried out as a feedback mechanism of the applicability of the assessment tool. The engineering manager was targeted for the interview because he is responsible for the Asset Management function at the case Company.

3.3 Research choice and time horizon

The mixed method utilised both the qualitative and quantitative approaches which enable a more detailed evaluation and analysis of research data. The primary research which is based on survey questionnaires provides for the interaction with respondents. A cross section time horizon was adopted, this was largely influenced by the specific nature of the research which focused on the current situation

3.4 Data sources

The research leveraged on primary data obtained from the targeted population. The target population utilised data from the case study as inference when providing the primary data. This therefore implies that the asset performance data and business operation data of the case study was the secondary data for the research.

3.5 Population, Sampling and Sample size

The target group for the study was skilled personnel, who interact with assets and have access to asset performance and operational information. The personnel included skilled personnel from production, maintenance, engineering and administration divisions. These represents the subject matter experts (SME) by function. The population size of 30 provided for a sample size of 28 according (Daniel, 1999) formula for determining sample size based on table value of chi-square for 1 degree of freedom at the desired confidence level (3.841). Table 2 below provides a detailed overview of the methodology.

Table 2: Methodology Overview

Item No	Step	Details of Tool/ method used
1	Detailed literature review	-Existing tools that provide a criticality assessment, and their applicability and short comings.
2	Development of a criticality assessment matrix/framework	-Use literature to determine the key parameters in coming up with a criticality framework and structure -Use function tree diagram to detail framework requirements -Identify Subject Matter Experts SMEs Establish Sample size of all SMEs at Sable Chemicals -Utilise a structured questionnaire issued to Subject Matter Experts SMEs to determine criticality criteria, perceived most critical equipment and criteria pair wise comparison. Questionnaires to be issued to above 80% of SMEs at Sable Chemicals -Use analytical hierarchy process AHP for developing numerical scoring index
3	Development of computer application	Develop process flow diagrams using framework developed in 2 Carry out programming using a Visual Basic SQL and JAVA
4	Establish the most critical equipment	-Use the developed Criticality assessment framework and tool to carry out a criticality assessment of assets and data at the Fertiliser Company. -Use a Focus Group of 4 technical personnel to determine the criticality scoring. -Detail findings of criticality assessment using bar graphs and pie charts -Carry out interview with selected executive management to confirm sensibility of criticality assessment results
5	Findings	-Based on items 2 and 4. Detail analysis finding which allow for improvement in plant performance
6	Conclusion	-Outline fulfilment of objectives, and identify areas of further research

4 Asset criticality assessment tool

The assessment tool was designed based on AHP thus the goal was Asset Criticality Score while criteria was the asset criticality criteria and the alternatives were the respective assets, this is in line with the diagrammatic representation of AHP shown in figure 4. In its simplest form a framework can be defined through levels that are defined by information flow. One appropriate level set is represented as;

- Input

- Processing
- Output

Figure 5 below show a representation of the framework levels in relation to framework functions. The computer application/system (software) was developed using Microsoft Excel as a platform and Visual Basic as the programing language. Determination the Asset Criticality was carried out entirely using the application.

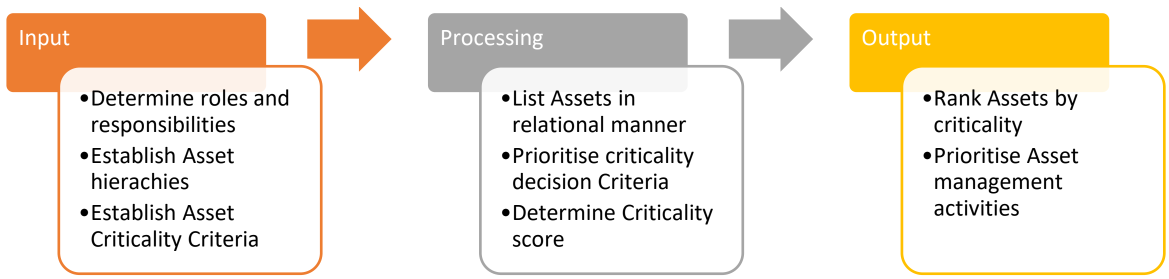

Figure 5: Asset criticality assessment framework levels

5 Application of tool on Case Study

As previously stated in section 2.1 the three main steps of asset criticality analysis are;

- Asset identification
- Criteria determination
- Scoring

The assessment tool developed incorporates the three steps mentioned above in meaningful detail. The steps mentioned above relate well with how the developed assessment tool was applied in the case of the Fertilizer Company.

5.1 Steering Committee and Criticality Assessment Champions

In order to promote accountability the roles and responsibilities pertaining to asset criticality assessment need to be clearly established. Table 3 below show the responsibility of personnel involved in asset criticality assessment.

Table 3: Steering committee and criticality assessment champions

No	Committee	Title	Responsibility
1	Steering Committee	Engineering Manager	Providing resources required
2		Production Manager	Providing resources required
3		General Manager Operations	Providing resources required
4	Champion	Planning Engineer	Coordinating Asset criticality activities
5	Ranking committee for systems	Planning Engineer	Asset criticality scoring
6		Engineering Manager	Asset criticality scoring
7		Plant Mechanical Engineer	Asset criticality scoring
8		Inspection Engineer	Asset criticality scoring
9	Ranking committee for Sub systems	Planning Engineer	Asset criticality scoring
10		Engineering Manager	Asset criticality scoring
11		Plant Mechanical Engineer	Asset criticality scoring
12		Inspection Engineer	Asset criticality scoring

5.2 Asset Identification

The developed assessment tool was applied on the assets of the Fertiliser Company using two hierarchical levels being system/section (level 5 as per ISO 14224) and equipment unit (level 6 as per ISO 14224). Based on the levels mentioned the following assets were assessed;

a) Level 5 12 Assets
b) Level 6 142 Assets

A focus group/ranking committee of 4 engineers (at Middle Management level) carried out scoring against decision criteria which was established through the research instrument mentioned in the methodology. Details of the criteria are mentioned in section 5.3

5.3 Criticality Criteria details determination

Criteria details are described based on definition, scaling and weighting to enable scoring. The pairwise comparison of criteria as outlined in AHP was carried out by 24 respondents since it was part of the research instrument. The criticality criterion had been established from the literature review as detailed in section 2.1.

a) Criteria definitions

The criteria definition were derived from the literature review and presented in the research instrument for confirmation by the subject matter experts detailed in the methodology. Table 4 outline the criteria definitions.

Table 4: Criteria Definition

Criteria	Abbreviation	Description
Operational impact	OI	The extent to which asset failure will affect the ability of the Company to meet its objectives in relation to its mission
Product/Service Quality Impact	QI	The extent to which asset failure can affect product/service quality
Safety Impact	SI	The probable unsafe condition and consequence presented by failure of the asset at point of failure, up to asset restoration
Environment Impact	EI	The probable environmental consequence associated with the equipment failure
Presence of redundancy	PR	The extent to which asset failure can be alleviated. (Isolation of single point failure)
Maintainability	M	The extent to which an asset can be retained to a specified condition and time frame in line with the associated maintenance procedures
Maintenance Cost	MC	The maintenance cost of the asset over a selected period
Reliability (MTBF)	R	The number of historic failures of the asset over a given period
Probability of Failure	PF	The likelihood of the asset failing based on its condition
Spares lead time	SLt	The time it takes to procure spares for the asset
Asset replacement requirements	AR	The resources required in order to replace the existing asset
Planned utilization rate	UR	The extent to which the asset will be used to fulfil the Company objective

b) Criteria Scaling

Table 5 below shows the criteria scaling used for asset scoring, the scale was determined by the ranking committee.

Table 5: Criteria Scaling

Criteria	Category	Abbreviation	Scale				
			1	2	3	4	5
Operational Impact	risk	OI	0-25% loss of capacity	26-50% loss of capacity	51-75% loss of capacity	76-99% loss of capacity	100% loss of capacity
Product/Service Quality Impact	risk	QI	no effect to quality	less than 1% of products	less than 10% of products	more than 10% of products	100% of products
Safety Impact	risk	SI	no risk to personnel	minor injuries, none lost time injuries	less than 2 lost time injuries	multiple lost time injuries	multiple fatalities
Environment Impact	risk	EI	low	moderate impact	severe but reversible within a year	severe but reversible within 5 years	Severe and permanent
Presence of redundancy	risk	PR	Not necessary	Work around possible. Can use alternative system	Hot standby available. Redundant Auto	Cold stand by. Redundant Manual	No redundancy, Reduced capacity, Complete Loss
Maintainability	asset management	M	Serviceability is high and Supportability is available on site	Serviceability is high and Supportability is high	Serviceability or Supportability one is low but not both	Serviceability is low or Supportability is low	Serviceability is low and Supportability is low
Maintenance Cost Full system	asset management	MC	<USD$10000 per year	USD$10000 to USD$50000 per year	USD$50000 to USD$200 000 per year	USD$200 000 to USD$1 000 000 per year	>USD$1 000 000 per year
Maintenance Cost sub system	asset management	MC	<USD$1000 per year	USD$1000 to USD$5000 per year	USD$5000 to USD$20 000 per year	USD$20 000 to USD$100 000 per year	>USD$100 000 per year
Reliability	asset management	R	2 downtime incidents per year	3 downtime incidents per year	4 downtime incidents per year	5 downtime incidents per year	more than 5 downtime incidents per year

Probability of Failure	risk	PF	not likely in more than a year	not likely within a year	not likely between 3 and 12 Months	not likely in 3 months	Imminent
Spares lead time	asset management	SLt	<1week	1 to 6 weeks	6 weeks to 3 Months	3 Months to 6 Months	> 6 Months
Asset replacement requirements full System	asset management	AR	USD$10 000 and less than 2 months	<USD$100 000 and less than 2 months	>USD$100 000 and less than 6 month	USD$200 000 and less than 6 month	>USD$500 000 and more than 6 month
Asset replacement requirements sub system	asset management	AR	USD$100 000 and less than 2 months	<USD$1 000 000 and less than 2 months	>USD$1 000 000 and less than 6 month	USD$2 000 000 and less than 6 month	>USD$5 000 000 and more than 6 month
Planned utilization rate	utilization	UR	20%	40%	60%	80%	100%

c) Criteria Weighting

Table 6 below shows the normalized aggregated pairwise matrix and the consistency test. The objective of the comparison was to come up with respective weighting of the criticality criterion. The matrix was produced using individual pairwise comparisons done by the respondents to the research instrument as detailed in section 3.5.

Table 6: Normalized aggregated pairwise matrix

Criteria	Operational impact	Product/Service Quality Impact	Safety Impact	Environment Impact	Presence of redundancy	Maintainability	Maintenance Cost	Reliability (MTBF)	Probability of Failure	Spares lead time	Asset replacement requirements	Planned utilization rate			
	5.85 %	**6.59 %**	**13.74 %**	**9.60 %**	**5.33 %**	**7.77 %**	**7.55 %**	**10.00 %**	**8.01 %**	**8.94 %**	**9.00 %**	**7.62 %**	**weighted Sum value**	**criteria weight**	**Score**
Operational impact	0.06	0.08	0.07	0.06	0.06	0.04	0.06	0.05	0.06	0.07	0.06	0.05	0.72	**5.85%**	12.32
Product/Service Quality Impact	0.05	0.07	0.04	0.04	0.08	0.06	0.06	0.06	0.07	0.10	0.09	0.09	0.81	**6.59%**	12.33
Safety Impact	0.12	0.21	0.14	0.16	0.10	0.11	0.16	0.14	0.13	0.14	0.13	0.17	1.70	**13.74%**	12.35
Environment Impact	0.09	0.14	0.08	0.10	0.06	0.09	0.11	0.11	0.08	0.12	0.12	0.07	1.18	**9.60%**	12.34
Presence of redundancy	0.05	0.05	0.07	0.08	0.05	0.03	0.04	0.06	0.04	0.09	0.05	0.04	0.65	**5.33%**	12.27
Maintainability	0.11	0.09	0.10	0.08	0.12	0.08	0.04	0.06	0.08	0.08	0.08	0.05	0.95	**7.77%**	12.28
Maintenance Cost	0.07	0.08	0.07	0.07	0.10	0.15	0.08	0.05	0.06	0.07	0.05	0.09	0.94	**7.55%**	12.39
Reliability (MTBF)	0.12	0.10	0.10	0.09	0.09	0.13	0.14	0.10	0.11	0.06	0.10	0.09	1.23	**10.00%**	12.35
Probability of Failure	0.07	0.07	0.08	0.09	0.11	0.08	0.11	0.07	0.08	0.07	0.08	0.07	0.99	**8.01%**	12.33
Spares lead time	0.08	0.06	0.09	0.07	0.06	0.09	0.10	0.14	0.10	0.09	0.09	0.14	1.10	**8.94%**	12.32
Asset replacement requirements	0.09	0.07	0.10	0.07	0.10	0.09	0.12	0.09	0.09	0.09	0.09	0.11	1.11	**9.00%**	12.33
Planned utilization rate	0.08	0.05	0.06	0.10	0.10	0.11	0.07	0.08	0.09	0.05	0.06	0.08	0.94	**7.62%**	12.32
SUM	**λMAX**														**12.3**
	Consistency index (C.I)														**0.03**
	Random index														**1.48**
	Consistency Ratio = (C.I/RI)														**0.02**
	Consistency is passed														**<0.10**

The criteria weights as shown by Table 4 clasify safety impact, reliability and environmental impact had the high weightings.

5.4 Asset Criticality Scoring

Having determined the assets and the necessary criteria it then becomes possible to carry out scoring for each individual asset while utilizing the established criteria scales in Table 5. The Table 7 below show the scoring and ranking for the system level while the sub system level scoring is detailed in Figure 6 where each bubble represents a sub system. The scoring was carried out by the ranking committee detailed in section 5.1. The committee determined score for the 12 system level assets and the 142 sub system level assets.

Table 7: System level scores for assets

ITEM No	Parent	System Name	Operational impact	Product/Service Quality Impact	Safety Impact	Environment Impact	Presence of redundancy	Maintainability	Maintenance Cost	Reliability (MTBF)	Probability of Failure	Spares lead time	Asset replacement requirements	Planned utilization rate
2	Kwekwe Factory	South Nitric Acid Plant	2	5	5	5	4	4	5	4	4	5	5	5
3	Kwekwe Factory	North Nitric Acid Plant	2	5	5	5	4	4	5	4	4	5	5	5
1	kwekwe Factory	AN Plant	5	5	5	5	5	2	4	5	4	2	4	5
7	Kwekwe Factory	Steam Raising Plant	5	5	5	3	5	2	4	5	4	3	4	5
9	Kwekwe Factory	Ammonia transportation	5	4	5	4	2	3	5	4	3	3	5	4
4	Kwekwe Factory	Ammonia Storage Plant	5	1	5	4	5	2	3	1	5	5	5	5
10	Kwekwe Factory	Compressed Air System	5	4	5	1	2	4	4	4	4	4	2	5
6	Kwekwe Factory	Electrical Power Distribution	5	5	4	1	5	2	3	4	3	5	3	5
5	Kwekwe Factory	Bagging Plant	4	5	3	2	2	3	2	5	2	3	2	5
8	Kwekwe Factory	Water Treatment Plant	5	2	3	1	5	2	3	3	3	2	2	5
11	Kwekwe Factory	Air Separation Plant	1	1	1	1	1	3	1	1	1	4	5	1
12	Kwekwe Factory	Electrolysis Plant	1	1	1	1	1	3	1	1	1	4	5	1
13	Kwekwe Factory	Ammonia Synthesis Plant	1	1	1	1	1	3	1	1	1	4	5	1
	Sum		46	44	48	34	42	37	41	42	39	49	52	52

a) System level Ranking

The asset scores were normalized by dividing the asset score with the criteria sum (example using South Acid Plant with an operational impact of 2 and an operational impact criteria sum of 46 yields normalized score of 0.04348). The overall Asset Criticality Score was determined by the sum of the products of the normalized scores and criteria weights. Accordingly Table 8 shows that the Nitric Acid Plants ranks as the most critical system level asset with a score of 0.104 while the decommissioned plants are the least critical with a score of 0.040. The assets have also been classified into categories where the most critical assets are in Class A. In Table 8 Class A assets have a score of above 0.085 are while class B and C range from 0.060 – 0.084 and 0.000 -0.059 respectively.

Table 8: System level assets criticality score

ITEM No	Parent	System Name	Normalised Scoring												Criticality score	Ranking	Clasification
			5.85%	6.59%	13.74%	9.60%	5.33%	7.77%	7.55%	10.00%	8.01%	8.94%	9.00%	7.62%			
			Operational impact	Product/Service Quality Impact	Safety Impact	Environment Impact	Presence of redundancy	Maintainability	Maintenance Cost	Reliability (MTBF)	Probability of Failure	Spares lead time	Asset replacement requirements	Planned utilization rate			
2	Kwekwe Factory	South Nitric Acid Plant	0.04348	0.114	0.10417	0.1471	0.095	0.108	0.122	0.0952	0.1026	0.102	0.096	0.0962	0.104	1	A
3	Kwekwe Factory	North Nitric Acid Plant	0.04348	0.114	0.10417	0.1471	0.095	0.108	0.122	0.0952	0.1026	0.102	0.096	0.0962	0.104	1	A
1	kwekwe Factory	AN Plant	0.1087	0.114	0.10417	0.1471	0.119	0.054	0.0976	0.119	0.1026	0.041	0.077	0.0962	0.098	3	A
7	Kwekwe Factory	Steam Raising Plant	0.1087	0.114	0.10417	0.0882	0.119	0.054	0.0976	0.119	0.1026	0.061	0.077	0.0962	0.094	4	A
9	Kwekwe Factory	Ammonia transportation	0.1087	0.091	0.10417	0.1176	0.048	0.081	0.122	0.0952	0.0769	0.061	0.096	0.0769	0.092	5	A
4	Kwekwe Factory	Ammonia Storage Plant	0.1087	0.023	0.10417	0.1176	0.119	0.054	0.0732	0.0238	0.1282	0.102	0.096	0.0962	0.087	6	A
10	Kwekwe Factory	Compressed Air System	0.1087	0.091	0.10417	0.0294	0.048	0.108	0.0976	0.0952	0.1026	0.082	0.038	0.0962	0.084	7	B
6	Kwekwe Factory	Electrical Power Distribution	0.1087	0.114	0.08333	0.0294	0.119	0.054	0.0732	0.0952	0.0769	0.102	0.058	0.0962	0.082	8	B
5	Kwekwe Factory	Bagging Plant	0.08696	0.114	0.0625	0.0588	0.048	0.081	0.0488	0.119	0.0513	0.061	0.038	0.0962	0.072	9	B
8	Kwekwe Factory	Water Treatment Plant	0.1087	0.045	0.0625	0.0294	0.119	0.054	0.0732	0.0714	0.0769	0.041	0.038	0.0962	0.065	10	B
11	Kwekwe Factory	Air Separation Plant	0.02174	0.023	0.02083	0.0294	0.024	0.081	0.0244	0.0238	0.0256	0.082	0.096	0.0192	0.040	11	C
12	Kwekwe Factory	Electrolysis Plant	0.02174	0.023	0.02083	0.0294	0.024	0.081	0.0244	0.0238	0.0256	0.082	0.096	0.0192	0.040	11	C
13	Kwekwe Factory	Ammonia Synthesis Plant	0.02174	0.023	0.02083	0.0294	0.024	0.081	0.0244	0.0238	0.0256	0.082	0.096	0.0192	0.040	11	C
	Sum		1	1	1	1	1	1	1	1	1	1	1	1	1		

b) Sub System level outcome

For the sub system level the outcome of the assessment is presented in Figure 6 below where all the 142 sub system level assets are represented by a bubble the bubble size is reflective of the asset criticality class with Class A being represented by the largest bubble size as the most critical class. The assets are also presented graphically in relation to their criticality score. According to Figure 6 the five most critical sub system assets are;

i. BBC Compressor (part of the Nitric Acid Compressor Train)
ii. BBC Gas Expander (part of the Nitric Acid Compressor Train)
iii. Nitric Acid waste heat boiler
iv. Ammonium Nitrate Neutralizer
v. Steam raising Cochrane III Boiler

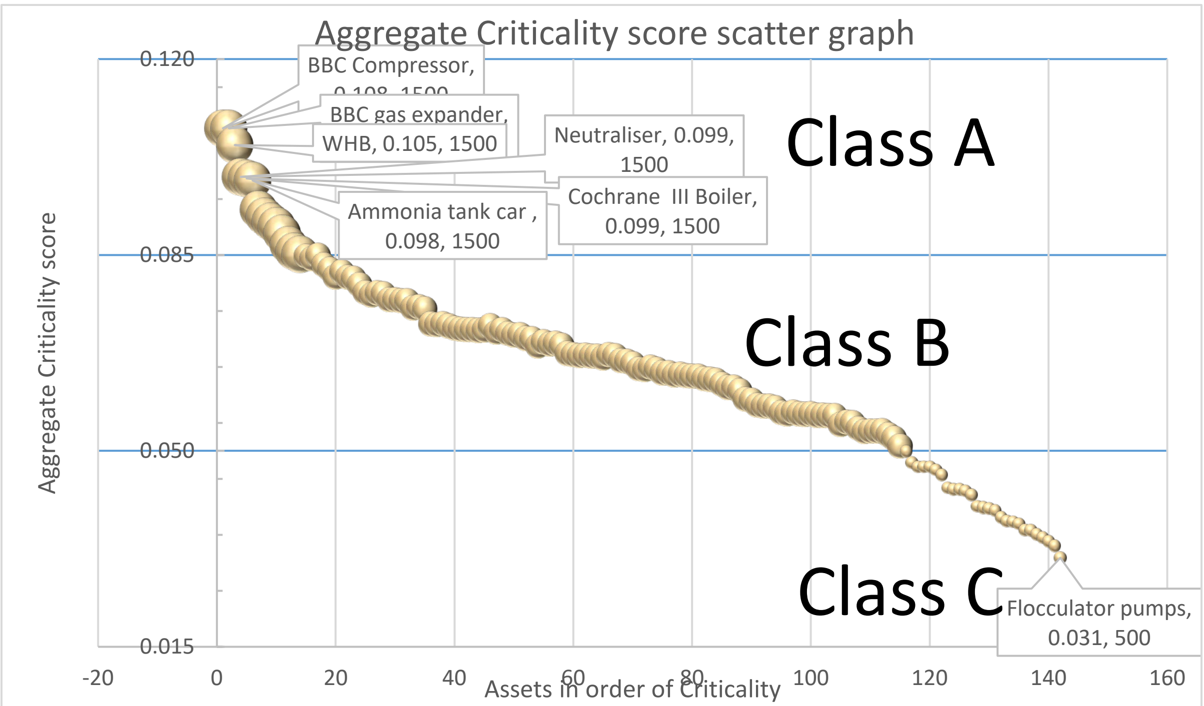

Figure 6: Sub system criticality score presentation

5.5 Management Impression of Assessment Tool

An interview of the Engineering (Asset Manager) Manager by the author confirmed that the tool produced reasonable results that were very useful in asset management decision making. The interview record confirming the accession was captured.

6 Conclusion

The question "How can asset criticality assessment be done effectively for a fertilizer manufacturing plant?" has been answered by saying, one can use AHP a Multi Attribute Method, while leveraging on a methodology that first determines the contextual interpretation of identified single matter experts (SME) in a setup (organization) and applying the interpretation in determining the appropriate decision making criteria for determining quantified asset criticality. The quantified asset criticality can be used as an integral part of the assent management system detailed in ISO 55001.

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