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Life Cycle Asset Integrity Management Strategy of Aging Crude Oil Pipelines

Nwando Maureen Ogu-Jude*, John Okoli, Celestine Ebieto

Faculty of Engineering, University of Port Harcourt, Rivers State, Nigeria

***Corresponding Author**

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ABSTRACT

This study developed an asset integrity management strategy to ensure continuous safe operation of the 24in Trans-Niger pipeline case-study till its design end-of-life in 2025 and life-extension thereafter, despite low flow conditions and associated ongoing Microbiologically Induced Corrosion (MIC). The case-study for the work is a 24inches by 55km carbon steel oil pipeline which was commissioned in 1995 to evacuate production from four (4) flow-stations to an export terminal. In the course of the work, a critical analysis of the current pipeline integrity management system (PIMS) in place against industry best practices was carried out. A Corrosion Management System (CMS) for the pipeline asset was developed by defining a company-wide corrosion policy for this pipeline, conducting a corrosion risk assessment for the threat of low flow conditions, carrying out a Failure Mode and Effect Analysis for low flow condition, proposing an Integrity Management Team and developing a roadmap for the execution of the proposed Integrity Management System. Both quantitative & qualitative data were employed in carrying out the study scope of work. Quantitative data used in the study included: pipeline design/as-built data, inspection & monitoring data, historical production data, and pipeline integrity management system. While qualitative data was derived from interviews and discussions with pipeline integrity and operations personnel. From the analysis conducted, a goal of zero corrosion leaks on the 24in Trans-Niger pipeline would be achieved through the Corrosion Management Strategy managed by the Head of Pipeline Integrity. The output of the FMEA rated the criticality of failure mode as high due to the product of the susceptibility of failure and Asset, Environment, and reputation consequence. An essential component of the CMS is the CMS execution team composition and their interdependencies, as CMS execution requires team effort with clear responsibilities and accountabilities. This study concluded that Asset Integrity Management without following best practice or industry standard methodology is grossly ineffective and would lead to dire consequences as in the case of the 24in Trans-Niger pipeline case-study with its failure in 2018.

Keywords: Asset integrity; Asset management; Aging pipelines; Life cycle management.

INTRODUCTION

Portraying the significant capacity of flowlines, Kishawy and Gabbar (2010) compared it to that of a human vein and said: "Pipelines work as veins serving to bringing life-necessities like water or petroleum gas and to remove life by-products like sewage". "Also, they are viewed as the most preferred method of transportation of oil and gas in huge amounts". Oil and gas are frequently packed in regions other than where they would be required. Pipelines transport hydrocarbons over significant distances, from creating wells and districts to send out terminals, processing plants, and fuel stations. All things considered, pipelines are viewed as the most affordable and proficient method for huge scope fluid transportation for crude raw petroleum and flammable gas (Ilman, 2014) and are intended for the protected evacuation of estimated hydrocarbon volumes (creation profile) over their plan life (ordinarily 30years) at suggested stream speeds > 1m/s (Henkes, 2014). The working state of pipelines decides the plan and the management technique of the pipeline framework. As per Gabbar and Kishawy (2011), the framework to be set up relies upon whether the pipeline would be exposed to high pressure/high temperature or low tension/low temperature in activity.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue IV, April 2026

Pipelines as a method for offtaking oil-based goods is associated with risk and difficulties. Pipelines come up short in activity due to imperfections like breaks, corrosions, scratches, punctures, and so on, prompting harm and holes on the pipeline coming about to tremendous downtime, cost, and natural dangers. These issues have immense natural, financial, wellbeing and security impacts on the pipeline operators and host networks the same. Awful inland and seaward mishaps credited to pipeline failures are main issues for operators, controllers, and general society (Peekema, 2013). On many events they have brought about loss of lives for workers and host networks with more than 2500 lives lost in a span of last 10 years (Okoli, 2019). During the lifecycle of a pipeline, there are significant changes to forecast volumes due to decline in reservoir performance, shortage of reservoir discoveries, divestment of production assets, etc. The pipeline asset could be exposed to “low flow” condition (flow velocity <1m/s), which in aging pipelines become the precursor to asset failure due to microbiologically induced corrosion (MIC). The MIC can be aggravated by under-deposit corrosion, which is characterised by settling of suspended solids and precipitated phases (especially water accumulation at low spots) at the bottom of the pipeline (Moloney, 2017).

The Nigerian oil & gas industry is threatened by the impact of low flow conditions to asset integrity due to oil reservoir decline and lack of “big” reservoir finds due to insufficient funding caused by the sharp drop in oil prices since the Covid-19 pandemic (Petroleum Economist, 2020). OPEC, in its 2019 annual statistical bulletin stated that Nigeria’s crude oil reserves stood at 37.453 billion barrels in 2017 and 2016; 37.062 billion barrels in 2015 and 37.448 billion barrels in 2014 (ASU, 2019). On February 20, 2020, the Department of Petroleum Resources (DPR), were taken on record by The Economic confidential (2020) as saying in 49years, it is expected that the Nigeria oil reserves would be significantly depleted. Both reports allude to the issue of low investments in the Nigerian Oil and gas industry which would in turn drive a downturn in exploration which is required in increasing reserve volumes. Probably the most serious issue confronting the pipeline business is the way that the world's pipeline framework is maturing. As indicated by Achebe et al. (2012), 41% of Nigeria's pipeline network is over 30 years of age. The vast pipelines joined with their different scope of activities, sizes, materials, age, and natural impacts add to the perils related with the pipeline business. Regularly, these combined risks make oil and gas pipeline security an exceptionally complicated process. Interestingly, a study conducted in 2011 (Okoro, 2011) arrived at a projected production profile (captured in Figure 1) for the Nigerian Oil and Gas industry using the Hubbert’s oil prediction model which seem to agree with more recent predictions. This study developed an asset integrity management strategy to ensure continuous safe operation of the 24-inch pipeline case-study till its design end-of-life in 2025 and life-extension thereafter, despite low flow conditions and associated ongoing MIC.

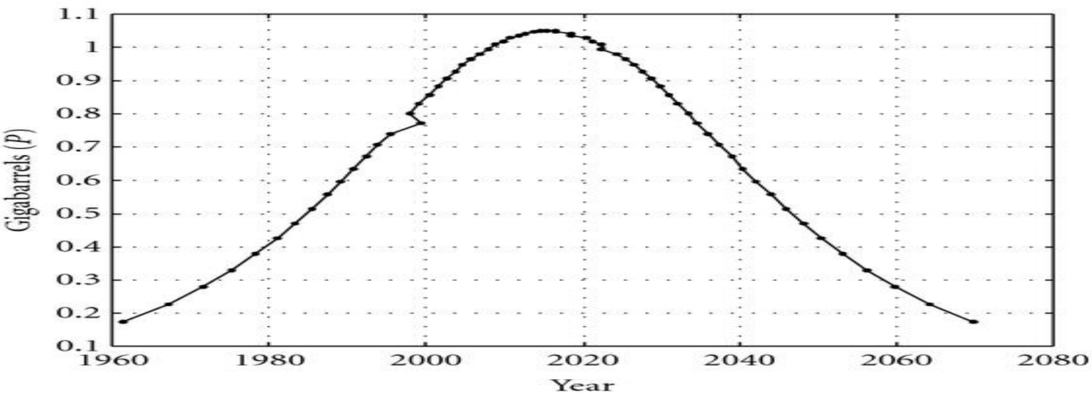

Figure 1: Hubbert's oil production curve showing Nigeria's likely oil peak (Okoro, 2011)

From figure 1 above, it can be predicted that with steady decline in reserves, the industry would operate aging assets in low flow conditions which would require smart asset integrity management strategies to ensure continued safe & profitable operations.

Studies have been conducted to understand the mechanism and impact of microbiologically induced corrosion (MIC) on production assets as well as the various kinds of operational flow conditions and impact on production assets (Askari, 2019). But this study looked at establishing the relationship between low flow conditions and

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue IV, April 2026

MIC & other associated integrity threats, as well as propose a management system which would ensure the operation of the pipeline asset through its lifecycle and the possibility of a life extension.

METHODOLOGY

DATA

Both quantitative & qualitative data were employed in the execution of the methodology expanded below. Quantitative data used in fulfilling individual objectives included the following:

Pipeline design/as-built data – Such as the pipeline dimensions (wall-thickness, nominal pipe size, length, and profile of the pipeline) and other design information including pipeline design envelope (pressure, flowrate & temperatures) gotten through desktop study from pipeline as-built documents and other records from the company. This data was used in understanding the as-built conditions of the pipeline, the current risks to the pipeline for data capture and integrity and benchmark of the entire study.

Table 1 Case Study Pipeline as-built data

S/N	PIPELINE PARAMETERS	DATA
1.	Installation year	1995
2.	Pipe length	55km
3.	Pipe diameter	24 inches
4.	Wall thickness	10.31mm
5.	Pipeline pressure limit	12 bar
6.	Temperature limit	35ºC
7.	Pipe material	Carbon Steel
8.	External Coating	Polyethylene
9.	Insulation	None
10.	Flow rate/ Recommended velocity	>0.5m/s

Table 2 Case Study Pipeline expected fluid content

S/N	PIPELINE FLUID CONTENT	VALUES
1.	Oil condensate	21,000 bls/day
2.	Water	18,000 bls/day
3.	Bicarbonates	122 $mgCaCO_3/day$
4.	Sand and Silt	None

Inspection & Monitoring data – this data was gotten using desktop review from the company's pipeline pigging records, intelligent pigging reports & water sampling results. Information on the existing maintenance and operation activities, corrosion damage and defect characterization within the pipeline was used for risk quantification and assessment with corresponding activities or mitigations set to ensure a lower risk of asset failure.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue IV, April 2026

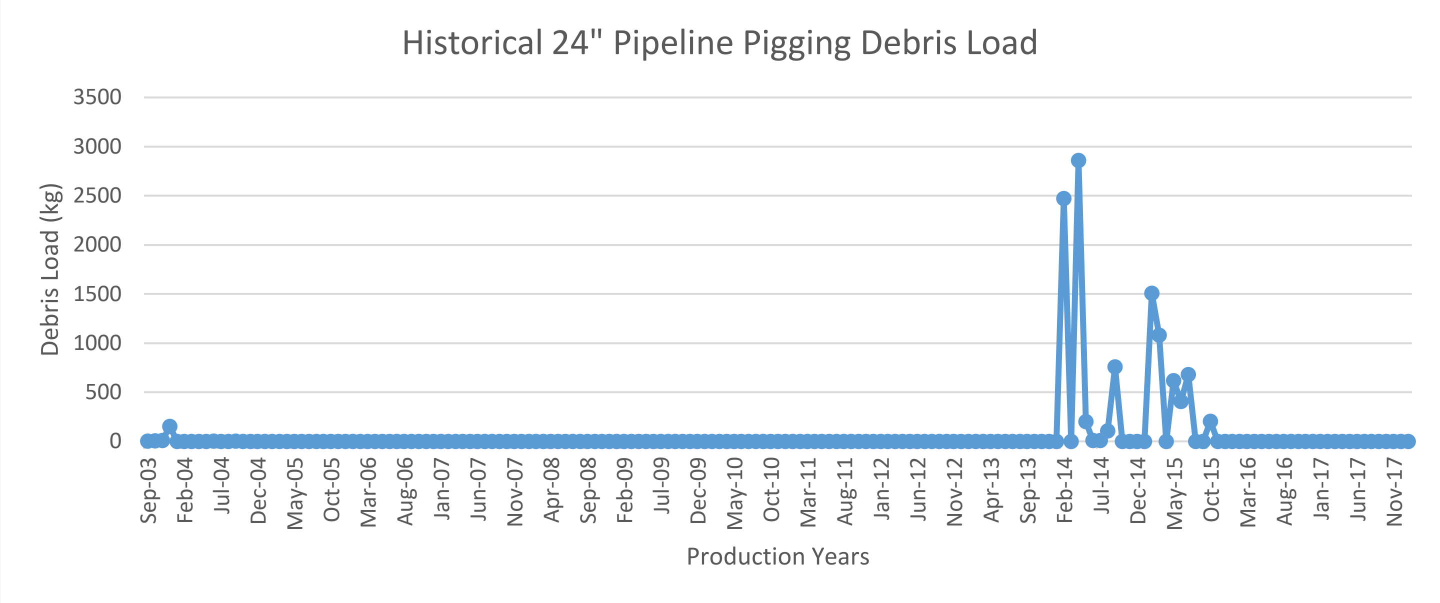

Figure 2: 24in pipeline case-study historical pigging debris load (2003 – 2017)

Historical production data – Twenty-five (25) years production data gotten from the company's Production Management Centre database through desktop analysis and was aggregated and used in correlating the impact of flowrate on flow velocity and therefore established the risk of low flow for the pipeline case-study.

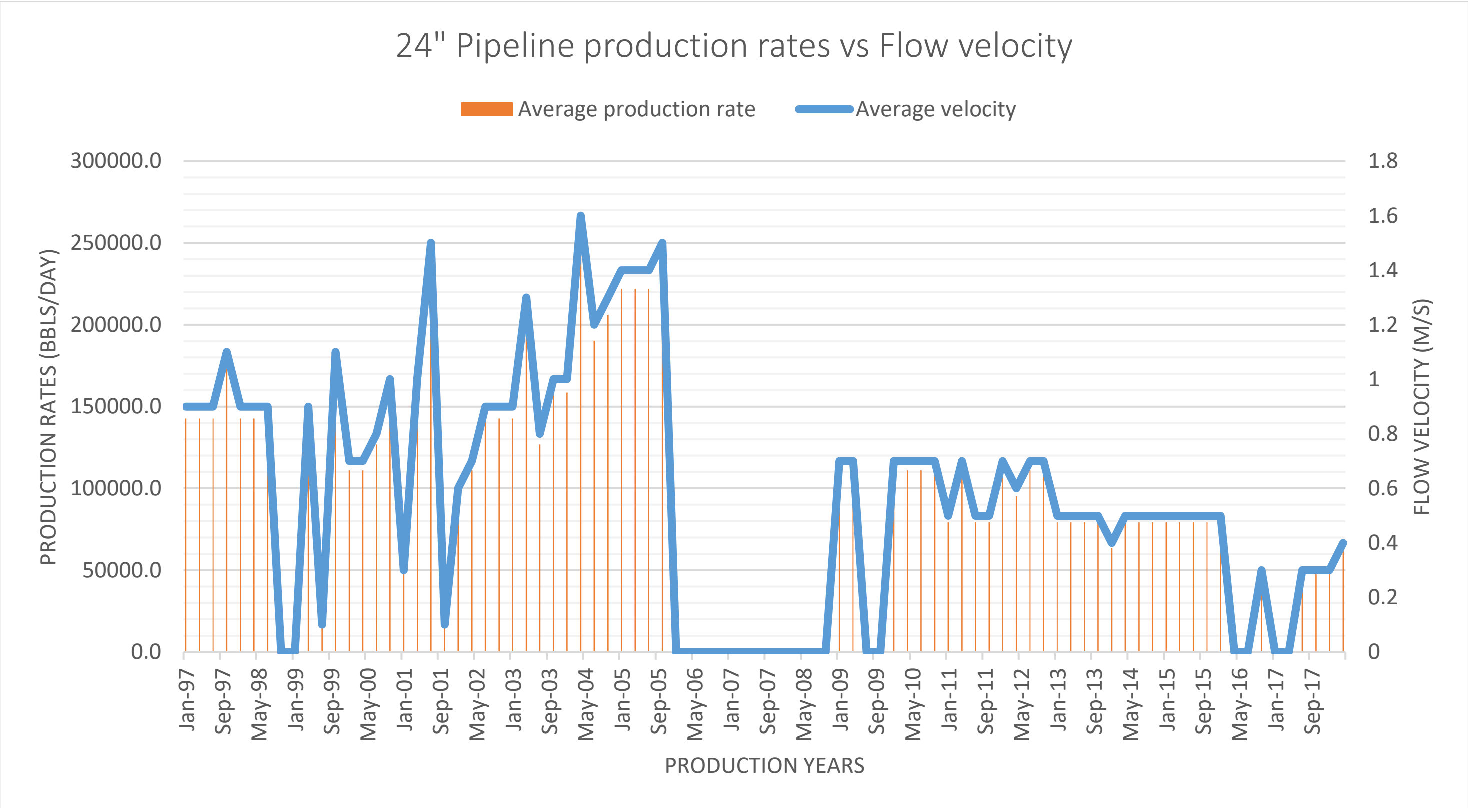

Figure 3: 24in pipeline case-study historical production rate against velocity (1997 – 2018)

Pipeline Integrity Management System – this was achieved through a desktop review of suite of documents showing the current PIMS as used for the management of the pipeline case-study including organizational structure/communications & job competence profiles and Operations & Maintenance procedures & activities which served as a benchmark, reviewed to identify gaps.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue IV, April 2026

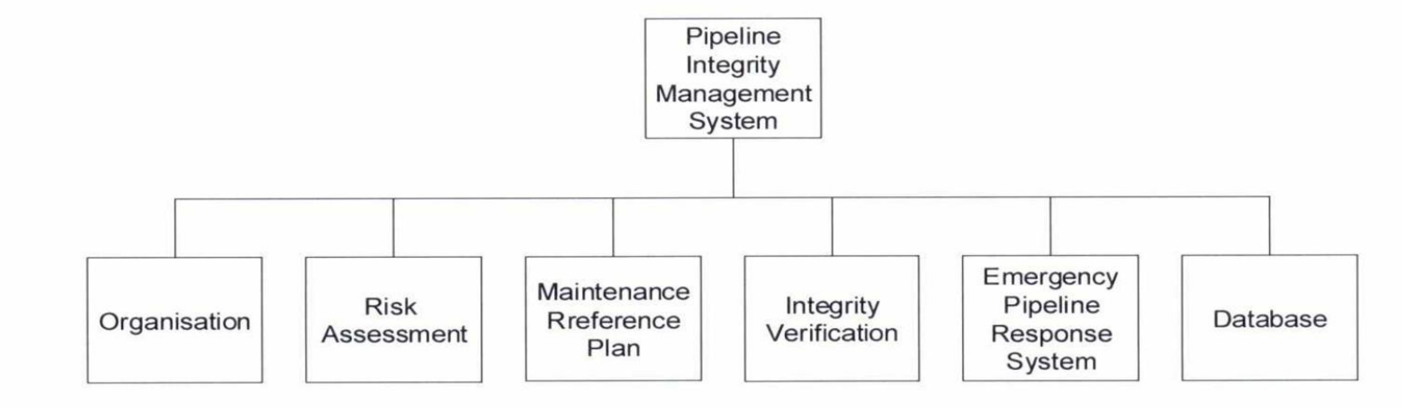

Figure 4: Pipeline integrity management system (Shell Petroleum Development Company, 2014)

Qualitative data was derived from interviews and engagement with pipeline integrity and operations personnel as summarized in the table below:

Table 3: Comparison between Pipeline Integrity Management System in Place and Best Practices

S/N	PIMS STRUCTURE ANALYSED	PIMS IN PLACE	SHORT FALLS FROM BEST PRACTICES	BEST PRACTICES
1	Frequency of risk assessment updates	A generic FMEA was developed during the design stage	no further risk assessment is carried out except during a management of change process of which the risks identified and eventually treated are risks associated with the change rather than general pipeline risks or threats that could lead to failure	General pipeline risks or treats are to be identified and mitigated
2	Poor deviations management	Deviations from the MRP timelines were not properly managed	Poor execution of the MRP, inability to perform deviations and poor closeout of existing deviations	Where the MRP activities are not met within a stated timeline, it is to be managed through the process of deviation which would highlight the risks associated with deferring the activity, stated mitigations to managing said risks and a recovery plan to ensure the execution of the activities.
3	Lack of a Corrosion Management System	The CMS is lacking within the overall PIMS in place	there is no focused attention on the management of corrosion risks	A detailed CMS should be put in place, within the PIMS to mitigate all corrosion associated risks.

The 5-why tool (see table 4 below) was deployed to ascertain the root cause of these shortfalls and possible improvements.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue IV, April 2026

Table 4: 5-Why Analysis for identified PIMS shortfalls

5-Why Analysis

PIMS Shortfalls, Root Cause Analysis and Improvement Paths

	Why 1	Why 2	Why 3	Why 4	Why 5	Root Cause	Improvement Paths
1	Frequency of risk assessments updates	Staffing oversight or poor awareness on the need for it	Lack of visible procedure requirement	Failure to comply with Process safety management requirements	Poor Leadership oversight on Process Safety requirements	Non-compliance to the Management system requirements	Carry out an audit, benchmark current practices against existing processes and best practice guides .e.g. OGP, identify gaps and close out.
			Lack of competence	Poor training/awareness	Poor Leadership oversight on Process Safety requirements	Non-compliance to the Management system requirements	Secure leadership commitment to drive effective capability management which would ensure effective recruitment and retention of a fully competent workforce at all times (http://www.hse.gov.uk/offshore/kp3review.pdf)
2	Poor deviations management	Increasing number of deviations	No awareness of the impact of SCE on the risk of major incidents	Poor risk assessment for raising the deviations	Weak technical authority structure in the organisation	Technical authorities were under pressure, often reacting to immediate operational problems rather than taking a strategic role to provide expertise and judgement on key operational engineering issues.	Secure leadership commitment to drive the elevation of the profile of Technical authorities in the organiation with direct comunication channels between management and technical authorities.
				Poor training or competence of operators managing the process on the asset integrity requirements	Poor knowldege retention during staff reduction	Management focused on cost cutting objectives over Asset integrity	Commitment by management to undertake company-wide training on Asset integrity management requirements
3	Lack of a Corrosion Management Strategy	Non-compliance to best practice & guidelines .e.g. EI corrosion management guideline for oil & gas processing	No awareness of the impact	Poor training or competence of operators managing the process on the asset integrity requirements	Poor capability management system	Leadership oversight on importance of capability development and retention	Secure management support to conduct capability audit and gap closure in the area of corrosion management.

Corrosion Management System

To address the objective of the development of a corrosion management system for the 24inches by 55km pipeline case-study, the following strategy was adopted. Several sub-objectives were satisfied in the following order and as in the figure below

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue IV, April 2026

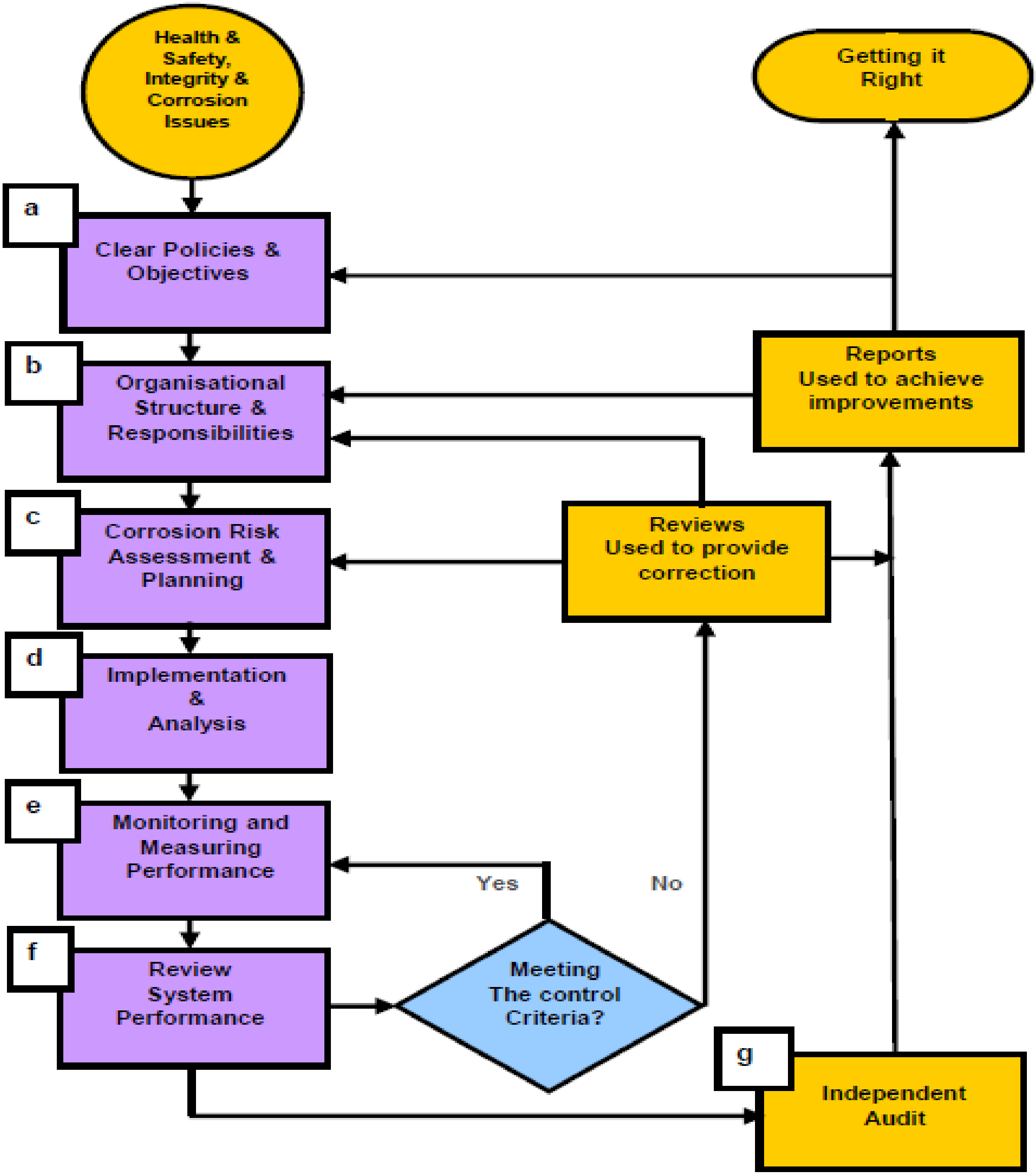

Figure 5: Corrosion Management System Decision Tree

Define a Corrosion Policy

Based on the guidelines of Energy Institute, a corrosion policy is an integral part of the policy for integrity management. Hence, to fulfil this objective, a literature review of the integrity management policy documented in the HSSE & SP control framework of the company. In alignment to the company policy on integrity management, a corrosion management policy was proposed for the 24in Trans-Niger pipeline case-study based on the Energy Institute framework as below (publishing.energyinst.org/topics/process-safety):

a) Defined **WHO** within the organization would deliver CMS.

b) **WHAT** the expectations and objectives of the CMS are.

c) **WHERE** this CMS would relate to – in this case the 24in pipeline case study.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue IV, April 2026

d) **WHY** this CMS is important to the organization.

e) **HOW** the CMS would be implemented.

Conduct an FMEA with a Corrosion Risk Assessment

In assuring the process of the need to adapt the corrosion management system to providing mitigation for the risk of low flow in the 24in Trans-Niger pipeline case-study, Failure Modes, and Effects Analysis (FMEA) for low flow was developed as below:

1. Failure mode was defined as low flow.
2. The effect of the failure mode was stated.
3. The probable causes of low flow as identified from RCAs and failure investigations highlighted in the introduction of this report were documented on the FMEA template.
4. The assessment methodology for low flow impact on the asset was also highlighted.
5. Possible controls & mitigations for this failure mode were included in the template and subsequently on the corrosion management guide to be described in subsequent sections.
6. A corrosion risk assessment was carried out and stated on the template as well. The FMEA described above was populated on a table as shown in Table 4:

Table 4: FMEA Template

Failure Mode	Effect	Cause	Assessment	Control	Susceptibility to Failure	Consequence				Criticality
						A	P	E	R	

Carry out corrosion risk assessment

To fully populate the FMEA table, a corrosion risk assessment (CRA) was conducted, to assure the business of the risk rating of the failure mode already defined. Risk is generally expressed as a product of the probability and consequence of failure. The CRA was carried out using S-Risk Based Inspection Criticality Matrix (Figure 2) below which is aligned to the API RP 580 methodology for Risk Based Inspection (api.org). This tool helped in readily quantifying the risk of low flow against the metrics of cost of Asset protection, People safety, Environmental preservation, and reputation of company.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue IV, April 2026

		StF	Criticality				
PROBABILITY CLASS	H	High	L	MH	H	E	E
	M	Medium	L	M	MH	H	E
	L	Low	N	L	M	MH	H
	N	Negligible	N	N	L	M	MH
CONSEQUENCE CATEGORY		ECONOMICS (US$) (Assets)	slight damage (<10k)	minor damage (10-100k)	local damage (0.1-1m)	major damage (1-10m)	massive damage (>10m)
		HEALTH & SAFETY (People)	slight injury	minor injury	major injury	single fatality	multiple fatalities
		ENVIRONMENT	slight effect	minor effect	moderate effect	major effect	massive effect
		REPUTATION	slight impact	minor impact	moderate impact	major impact	massive effect
CONSEQUENCE CLASS			NEGLIGIBLE	LOW	MEDIUM	HIGH	EXTENSIVE

Figure 6: S-RBI criticality matrix (Shell, 2019)

Propose an Integrity Management Team Composition

To fulfil this objective, a review of the current organizational structure set-up to manage the asset as documented in the existing Pipeline Integrity Management System was carried out. Comparing it to requirements of the Energy Institute guideline as well as the requirements of the CMS being developed, a Responsible-Accountable-Support-Consult-Inform chart (RASCI), which identifies all action parties, activities/scope of work and team's interdependencies in delivering the requirements of this CMS.

All objectives satisfied in the preceding sections were put together into the Corrosion Management Guide (CMG), which puts all the CMS results in a format that can be easily reviewed, executed, and monitored.

In this case, all results already gotten were documented under the following columns:

1. Defined corrosion loop & Sub-system, which is the pipeline case-study.
2. Description of the pipeline case-study, in terms of material of construction, coating, wall-thickness and other physical properties of the asset.
3. A threat column had low flow specified. Under this column, the probability of failure was highlighted as well.
4. A barriers column was generated, which captured data on the type of barrier originally planned into the asset during construction to mitigate the failure mode. In addition, the current status of the barrier was defined based on the current state of the pipeline asset and the justification for the status was stated as well.
5. The Integrity Operation Window was populated primarily with process parameters (minimum, maximum & actual) – flow temperature, pressure, water & oil flowrate, and flow velocity were populated on a separate column.
6. Proposed monitoring frequency and location based on the corrosion Risk assessment carried out in previous section.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue IV, April 2026

7. A Maintenance Reference Plan (MRP) was identified and captured to ensure maintenance of integrity of the pipeline asset as well as to ensure life extension of the asset. Every MRP activity underwent an Impact – Cost/Effort criticality assessment based off the matrix represented in Figure 3. Depending on which of the quadrants the activity falls into would determine if such an activity should be implemented immediately, implemented if practicable, implemented as a form of continuously improving the system or an activity should be abandoned.

8. A last column was generated to capture management actions for the maintenance of the CMG and hence the CMS. Therefore, this column highlighted Key Performance Indicators (KPI), key action owners to respond to possible excursions and the actions expected to be taken to revert the system back to its original configuration.

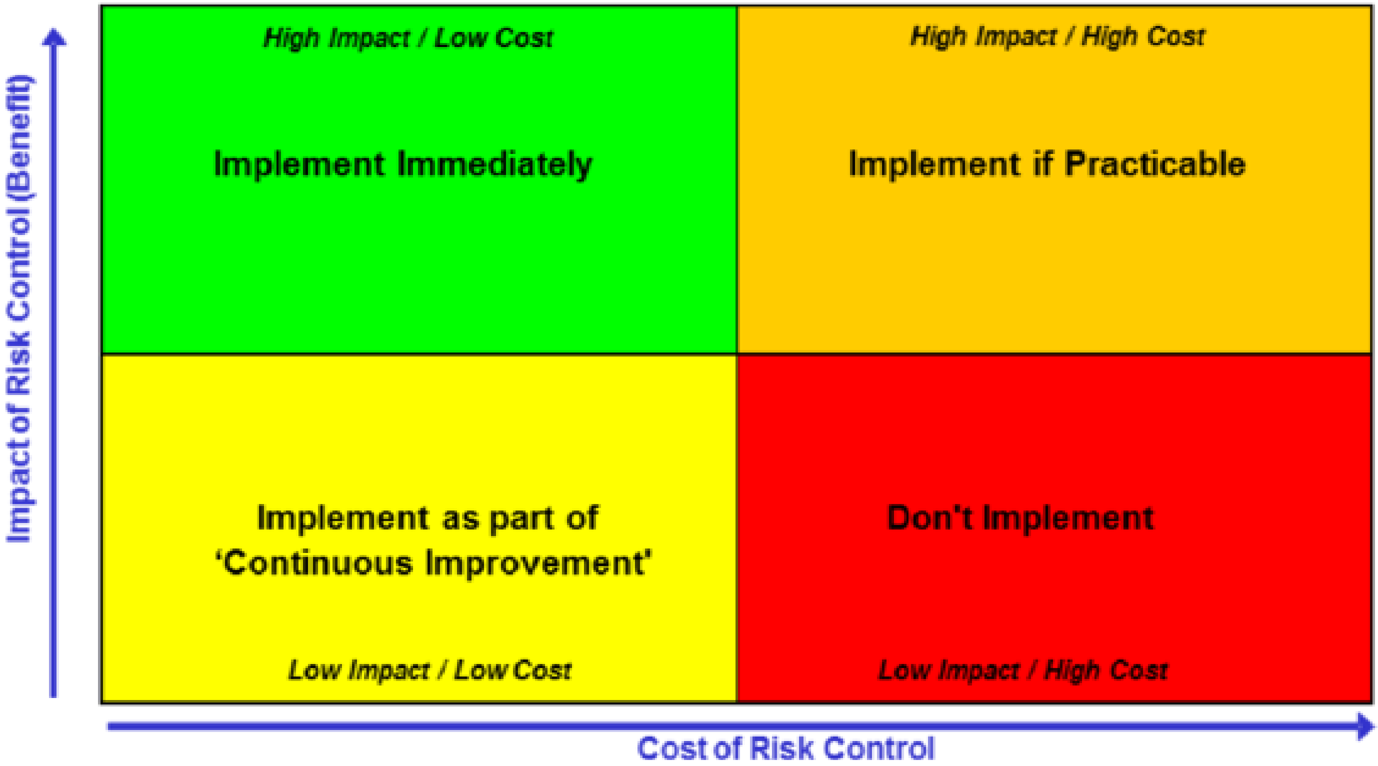

Figure 7: Impact – Cost/Effort Matrix (Shell, 2019)

Integrity Management Execution Roadmap

To develop a roadmap which would help manage the introduction of the CMS into the system in a manner which would allow for quick adoption and execution required, a literature review of the two leading change management models, namely, the bridges model postulated by Williams Bridges (wmbridges.com) and the eight (8) steps change model by John Kotter (kotterinc.com/8-steps-process-for-leading-change/).

Based off the review, the following were developed to generate the roadmap:

1. A proposed change management team composition to drive adoption of the CMS for this specific asset and similar assets across the organization.

2. A Gantt chart was developed highlighting various diverse company-wide engagements of various stakeholders. This Gantt chart also highlighted proposed timelines for achieving key milestones of the launch.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue IV, April 2026

RESULTS & DISCUSSIONS

Define A Corrosion Policy

Based on the asset integrity policy of the company to "keep their asset safe and know it" (Shell 2019), the corrosion policy for this proposed CMS is, based on known impact of corrosion on asset integrity, a goal of zero corrosion leaks on the 24in Trans-Niger pipeline would be achieved through the Corrosion Management Strategy managed by the Head of Pipeline Integrity, who would ensure the following:

a. All pipeline integrity activities are carried out in accordance with the CMS.
b. Resources (human, tools, equipment) are adequately managed to ensure the execution of the CMS.
c. The CMS is to be regularly reviewed by a multi-disciplinary team quarterly, while an audit is to be carried out on the entire process bi-annually.

Conduct A Fmea With A Corrosion Risk Assessment

At the conclusion of the FMEA for low flow failure mode, the output of the exercise is captured below (see also Table 5):

The output of the FMEA rated the criticality of failure mode as high due to the product of the susceptibility of failure and Asset, Environment and reputation consequence based on the S-RBI tool (directindustry.com) (Figure 2).

Find below the justifications for the susceptibility and consequence levels chosen for each parameter:

1. The susceptibility for failure was assumed 'High' on the basis that a failure due to this mode had already occurred on the case-study pipeline and is currently a prevailing failure mode.

2. The consequence of failure on the asset was rated medium because the direct cost for repairs of damage & environment clean-up was circa $1mln for the failure currently investigated.

3. The consequence of failure on people was rated negligible, as there was no direct impact of the current failure of the pipeline on the health & safety of personnel. The consequence of failure for environment was rated medium because the failure of the pipeline led to spills, circa 3000 barrels which damaged vegetation and required clean up to remediate. In addition, there were complaints received from the surrounding communities along the pipeline Right-of-Way.

4. The consequence on reputation was ranked a medium as well, as the community and Government regulators were aware of the failure in addition to the attention the failure and ongoing repair works received in national media.

The criticality of a 'High' for this failure mode means a detailed investigation of the failure mode is to be implemented and the CMS executed immediately.

Propose An Integrity Management Team Composition

An essential component of the CMS is the CMS execution team composition and their interdependencies, As CMS execution requires team effort with clear responsibilities and accountabilities. A team composition (see Table 6) has been proposed by this study based on analysis of the current work system in place, with gaps identified to ensure all aspects of the CMS is duly attended to.

Based on the composition, find below the team definition, roles & responsibilities:

The Pipeline Integrity Team – This team led by the Head, Pipeline Integrity is accountable for the performance of the PIMS, and the CMS proposed. On this role the Head would lead the team to drive the development and execution of all pipeline integrity activities & tasks tabulated in the RACI above (analyst-

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue IV, April 2026

zone.com/techniques/rasci-chart) and more to ensure the integrity of the pipeline is maintained and business objectives satisfied. The pipeline integrity engineer would be the focal point of the 24in Trans-Niger pipeline case-study and would be responsible for the approval of integrity activities & inspection recommendations, interface management of all support teams, management of all integrity documentation & database, change management on the asset, review of integrity data and effective communication of results.

The Engineering Discipline Team – acts as custodian to all engineering standards, codes and best practices used within the organization. For the delivery of the CMS, support would be gotten from the Production Chemistry, Process Engineering, Materials & Corrosion Engineering and Pipeline Engineering sub-teams.

a) **Materials & Corrosion Engineering** – They are custodians of all corrosion engineering and inspection & monitoring related codes & standards as well as the corrosion models of all assets, providing technical authority oversight on all corrosion related activities. The material & corrosion engineer would management the execution of inspection requests, analysis, and reporting of inspection & corrosion modelling results. In the same light, the Technical Authority for Materials & Corrosion would be involved in the evaluation of the effectiveness of the CMS with respect to corrosion management for the asset. This would involve activities like attending all strategic reviews & audits, provision of technical advice on corrosion issues and approves technical deviations related to corrosion prevention over the course of executing the CMS.

b) **Pipeline Engineering** – They are the custodians of all pipelines related codes and standards, providing technical authority oversight on all pipeline activities especially in resourcing of critical pipeline integrity roles.

c) **Process Engineering** – This team is the custodian of all codes and standards related to the process & flow assurance of the flow-station producing into the pipeline. They would provide all information and data on the facilities upstream the pipeline.

d) **Production Chemistry** – This team is responsible for chemical management system which includes chemical & chemical vendor qualifications, dosage rates, monitoring of chemical usage and chemical treatment performance measurements.

Production Operations Team - This team provides oversight to the management of the entire upstream production process. This involves, plant performance management and monitoring.

The final CMS output is the Corrosion Management Guide (CMG) (assetintegrityengineering.com) which comprises of three main sections (see Tables 7 – 12).

The first section is the threat and barrier section (Table 7); the properties of the asset, the threat considered (low flow), the barriers/mitigations & their status are highlighted. For our case-study, most of the barriers are ineffective in mitigating the known threat of low flow (reasons highlighted).

The Integrity Operating Window of the pipeline containing the current state of the pipeline (Tables 8 – 9) shows that the pipeline is being operated outside expected production rate limits at circa 39kbbls /day gross, which is less than the volume required to achieve flow velocities > 0.5m/s.

The aim of the IOW column is to allow for monitoring, failures occur assets when operated outside stated design limits. Data gathering is to begin on all parameters immediately.

In addition to the IOW monitoring, key integrity actions have been identified for integrity assurance for the asset (see table 10 – 12). Based on the current state of the asset, there are actions required to be carried out to assure integrity despite ongoing low flow condition, actions have been articulated as part of the Maintenance Reference Plan. In addition, all Key Performance Indicators – leading and lagging that would be monitored to ensure that the state of the system remains visible enough to manage excursions through the clearly identified action parties are identified.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue IV, April 2026

Table 5: FMEA Worksheet

FMEA OUTPUT SHEET										
Failure Mode	Effect	Cause	Assessment	Control	Susceptibility to Failure	Consequence				Criticality
						Asset	People	Environment	Reputation	
Low Flow	Solid deposition and settling leading to reduced internal capacity, MIC & UDC	Reduced crude-oil production rates	Flow-rate, flow pressure & flow velocity monitoring	Increased throughput through pipeline	High	Medium	Negligible	Medium	Medium	High

Table 6: Responsible – Accountable – Support - Consult – Inform (RASCI) chart of team composition

S/N	Activity List	Production Operations	Materials & Corrosion Engineer	Pipeline Integrity Engineer	TA2 Materials & Corrosion	TA2 Pipeline Engineer	Production Chemistry	Process Engineer	Pipelines Operations & Mainten	TA1 Pipelines	TA1 Materials & Corrosion	Head, Pipeline Integrity	Asset Integrity Manager
	CMS Implementation												
1	Verification of barrier status and IOW monitoring	R	R	I	R	I	R	R	I	I	I	A	I
2	Identification of actions for barrier maintenance execution	R	R	R	R	C	R		I	S	S	A	I
3	Provides current process description and operating conditions for normal start-up and shut-down conditions.	R	I	I			C	A,R	I	I	I	A	I
4	Identifies existing Mitigations/barriers, operational control and limits for IOWs, Chemical, injections, pigging, CP, coatings, etc.	R	R	C	R	C	R	R	C	I	S	A	I
5	Identifies corrosion/damage rate, type of mechanism, locations for damage, morphology, and prior equipment Inspection history.	R	R	R	R	C	R	C	R	I	S	A	I
6	Filter actions from the threat assessment and previous tasks.		R									A	I
7	Develop & update corrosion loops	C	R	C	R	I	I	C	I	I	S	A	I
8	Secure CMF review/audit agreement & sign-off		R	I	R	I	C			S	S	A	I
9	Develop Inspection Programme	C	R	C	R	C	C	I	C	I	S	A	I
10	Implement inspection program	I	I	I	I	I	I	I	A	I	I	A	I
11	alerts/alarms as required.	I	C	R	R	I	R	C	R	I	I	A	I
12	Ensure systems are in place to update and analyse IOW routinely	R	C	R	C	C	R	C	I	I	I	A	I
13	Update and maintain CMS	C	R	C	R	C	I	I	C	I	S	A	I
14	Update and maintain Inspection Plan	C	R	C	R	C	C	I	C	S	S	A	I
15	Review CMS assurance Improvements (Quarterly reviews & Audits)	C	A	R	S	S	C	S	C	S	S	A	C
16	Review CMS action close out, assurance and improvements	R	C	A,R			C	I	S	C	C	A	C

R	Responsible
A	Accountable
S	Support
C	Consult
I	Inform

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Table 7: Threats & Barriers table of the CMG for low flow condition of the 24" Pipeline

24in Pipeline Threats & Barriers											
					Threats			Barrier			
Corrosion Loop	Description	Material	External coating	Insulation	Type	Notes	Likelihood	Type	Status	Reason for Status	Actual CR (mm/ y)
24" x 55 km TL WT = 10.31mm Installation year 1995	Pipeline and River crossing	CS	Polyethylene	none	Low velocity (<0.5m/ s)	*High susceptibility to MIC*	High	Process modification	red	Low production flowrate with respect to the size of the pipeline (<80kbopd)	0.5mm/yr from 2012 intelligent pigging inspection.
					Low velocity (<0.5m/ s)	*High susceptibility to MIC*	High	Biocide Injection	red	No biocide injection.	
					Low velocity (<0.5m/ s)	*High susceptibility to UDC induced MIC due to carbonate scale deposits as identified from investigations.*	High	Scale inhibition injection	red	No Scale inhibition.	
					Low velocity (<0.5m/ s)	*High susceptibility to UDC induced MIC due to sand deposits as identified in reports*	High	Sand control		Sand screeners are deployed upstream of the pipeline, but monitoring status of the effectiveness of screens are unknown.	
					Low velocity (<0.5m/ s)	*High susceptibility to UDC induced MIC*	High	Pigging	red	Infrequent pigging schedule as shown by historical pigging records.	

Table 8: 24in Trans-Niger Pipeline integrity operating window

24in Pipeline Integrity Operating Window [sampling and monitoring required].							
				IOW			
Process Parameter	**Actual**	**Integrity Min**	**Integrity Max**	**Monitoring Frequency**	**Location**	**Notes**	**Standarised actions if outside IOW**
Temperature (deg C)	35	0	80	Daily	Inlet & outlet	Trend	Inform the Integrity Management Team.
Pressure (bar)	12	NA	40	Daily	Inlet & outlet	Trend	Shutdown pipeline and inform the Integrity Management Team.
Oil/ Condensate (bls/ d)	21000	NA	NA	Daily	Inlet	Trend	Inform the pipeline integrity and Pipeline engineering personnel for hydraulic analysis and advise.
Water (bls/ d)	18000	NA	NA	Daily	Inlet	Trend	Inform the pipeline integrity and Pipeline engineering personnel for hydraulic analysis and advise.
Sand content (pptb)	NA	NA	10	3 Monthly	outlet	Trend	Ensure status of internal barrier is green
Dissolved H_2S (ppm)	NA	NA	10	6 months	Pipeline outlet	Trend	Inform the Integrity Management Team.
Velocity (m/ s)	0.5	1	4	Daily	Calculated	Trend	Inform the Integrity Management Team.
Bicarbonates mgCaCO3/ l	122	NA	NA	Annually	Inlet & outlet	Trend	Inform the Integrity Management Team.
Iron Count (ppm)	NA	±10	±10	3 months	Pipeline outlet	Trend	Inform the Integrity Management Team.

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Table 9: 24in Pipeline integrity operating window contd.

24in Pipeline Integrity Operating Window [sampling and monitoring required].							
IOW							
Process Parameter	**Actual**	**Integrity Min**	**Integrity Max**	**Monitoring Frequency**	**Location**	**Notes**	**Standarised actions if outside IOW**
Sessile Bacteria Count (col/ ml)	NA	NA	10	Monthly (every pig run)	Pig debris	Trend	Inform the Integrity Management Team.
Planktonic Bacteria Count (col/ ml)	NA	NA	1000	Monthly	pipeline outlet	Trend	Inform the Integrity Management Team.
Biocide Residuals (ppm)	Not started	NA	3	Monthly	pipeline outlet	Trend	Inform the Integrity Management Team.
Scale Inhibitor Residual analysis	NA	10ppm	3	Monthly	pipeline outlet	Trend	Inform the Integrity Management Team.
Corrosion rate (monitoring) mm/ yr	0.5	0.1	0.1	3 months	Desktop analysis	Trend	Inform the Integrity Management Team.
Max. Defect growth rate (mm/ y)	0.5	0.1	0.1	3 months	Desktop analysis	Trend	Inform the Integrity Management Team.

Table 10: 24in Trans-Niger Pipeline Maintenance Reference Plan and KPIs

24in Pipeline Maintenance reference plan and KPIs.						
Maintenance Reference Plan	**Priority Rank**	**Management / AIPSM KPI**				
		Implementation Indicator	**Action Owner**	**Frequency**	**Target Indicator**	**24'' Pipeline**
1. Commence biocide & scale inhibition injection (Use only qualified Inhibitors).	HL	Actual Corrosion Rate mm/ year	Materials & corrosion Engineering TA2	Quarterly	< 0.1 mm/ y	
2.Conduct weekly routine pigging using brush and scraper pigs. conduct sampling before and after each run. Report solids and follow up bacteria count for the first-run. This should be immediately followed by batch biocide application between two pigs with >30mins contact time. Target biocide concentration =5000ppm only first run. Duration=2 months. For 2 month, complete monitoring and then evaluate increase to monthly	HL	CMS Developed	Materials & corrosion Engineering TA3	Quarterly	100%	95%
3. Conduct weekly sampling/ performance monitoring of sessile/ planktonic bacteria post-pigging operation. Issue reports to the Integrity management team for evaluation to optimize pigging/ batch biocide frequency.	LL	MRP Implemented (all optimization and improvement recommendations are implemented by asset)	Pipeline Integrity/ operations	Quarterly	100%	Not Started
4. Complete MIC assessment and optimise biocide injection rate.	LL	Corrosion Monitoring/ sampling in-place	Production Chemistry/ Pipeline Integrity	Quarterly	100%	Not Started

Table 11: 24in Pipeline Maintenance Reference Plan and KPIs Contd.

24in Pipeline Maintenance reference plan and KPIs.						
Maintenance Reference Plan	**Priority Rank**	**Management / AIPSM KPI**				
6. Immediate completion of sampling program - Bacteria, scaling tendency, sand count, Fe count,chloride content, alkalinity, pressure and temperature at the inlet etc. (See IOW frequency & priority).	HL	IOW excursions	Materials & Corrosion Engineering TA2 / Pipeline Integrity Engineer	Quarterly	Zero	Not Started
7. Install a reinforced thermo-plastic (RTP) as a liner in current pipeline in place.	HH	Hydrocor modelling completed	Materials & Corrosion Engineering TA2 / Pipeline Integrity Engineer	Annually	100%	Not Started
8. Update Corrosion & Flow assurance models with pipeline plan & profile (Model corrosion rates at low spots, onplot piping and compare with inspection data)	HL					
9. Dig verification: Identify UT monitoring locations and monitor wall defect growth. Verify IP wall profile data with UT results	HH					

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Table 12: 24in Trans-Niger Pipeline Maintenance Reference Plan and KPIs Contd.

Asset KPI				
Implementation Indicator	**Action Owner**	**Frequency**	**Indicator**	**24" Pipeline**
Injected chemical residual & water chemistry sampling/ analysis done to planned frequency	Production Chemistry / Production Operations TL	Monthly	100%	Not Started
Chemical / Inhibitor availability target as defined in CMS	Production Chemistry / Production Operations TL	Weekly	100%	Not Started
Performance monitoring / IOW data carried out and communicated	Pipeline integrity Engineer	Monthly	100%	Not Started
Monthly CM performance data review and optimization recommendations issued to the AM cc: Ops & Mtce TL	Materials & Corrosion Engineer	Monthly	100%	Not Started
Chemicals injection points / stock available	Production Operations TL	Monthly	100%	Not Started
Integrity assessment conducted and corrosion rate determined as per CMS recommendation	Pipeline Integrity/ Materials & Corrosion Engineering	6 monthly	100%	Not Started

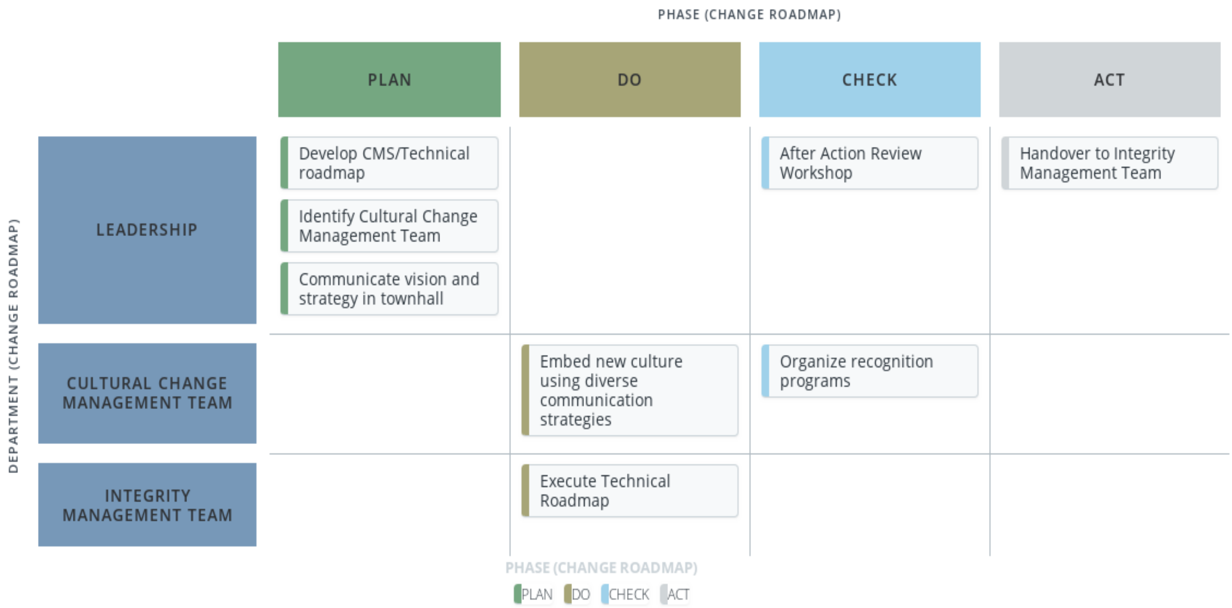
Integrity Management Execution Roadmap

A roadmap details the activities to be executed to achieve set objectives. The overall aim of ensuring the 24" pipeline is operated through to its end-of-life and beyond would be ensured through the execution of the technical roadmap in Table 13. A change roadmap was also created based on Kotter's 8-steps (airiodion.com/john-kotter-change-model/) and Bridges Change management models (wmbridges.com), to ensure that the CMS is setup to drive a cultural change in the way of working; from undocumented processes, to processes properly documented, made visible and transparent for the organization. These roadmaps would become templates that would ensure that this entire CMS process can be replicated across other pipeline assets.

Table 13: Technical Roadmap for the Asset Integrity Management of the 24" Pipeline

Quick fix focused on immediate solution	Urgent requirement and identify long term solution	Execution of long term solution	
• Reactive Time based "Like-to-like" Pipeline sectional Replacements to bring the pipeline back into production. • Redefine Maximum Allowable Operating Pressure (MAOP) to allow for production without further impact on integrity.	**Corrosion Mitigation Improvement for low flow condition** • Developed Pipeline CMS for the 24" pipeline. • Execute CMS with monitoring and sampling plan. • Setup and empower integrated pipeline management team to provide management focus. • Plan for CI, BI & SI injections as part of CMS recommendations. **Improvement/Root Cause Studies** • MIC Investigation. • Scale tendency investigation. • Pipeline Optimization • Operational and Intelligent Pigging Inspection review. **Pipeline Rejuv Execution** • CMP Execution (CI Skids Phase 1 Execution) • SC formed to provide management focus	**Corrosion Mitigation Improvement for low flow condition** • CMS Effectiveness. • Close-out of studies recommendations. • OP & IP / FFS Enhancements. • Pipeline Winning team capability building (OP Certification) • Pipeline Life Extension Studies **Pipeline Rejuv Execution** • Pipeline Replacements • Pig traps installation • CI Skids • Sampling/Monitoring points • H2S analyser • Uprate MAOP of pipeline • Bring more wells online to drive higher production rates. **PIPELINE LEAK RISK PROJECTED TO BE MEDIUM/LOW BY 2022 THUS ACHIEVING ZERO VERY HIGH AND HIGH RISK PIPELINES and ZERO LEAK ASPIRATION**	**Pipeline Life Extension** Utilization of alternative pipeline replacement options to rehabilitate the 24" pipeline. • Criteria of alternative options is driven by technical qualification and low cost to reap the highest return of investment. • Progressive closure of low producing/High UPC intra-field pipelines operating beyond original design life.
2018 2019	2020 2021	2021 2022	2022 2023

Table 14: Asset Integrity Change Management Roadmap for the 24" Pipeline



CONCLUSION

The 24in Trans-Niger pipeline is a critical asset for the company as it was designed to evacuate circa 100 kbopd from four (4nos.) production facilities; if the pipeline is not in operation, that translates to a huge economic loss for the company & Nation (more than N8 million daily). This economic viability of the 24in pipeline is similar for pipeline assets generally. Pipelines as critical economic infrastructure need to be preserved effectively over their designed life cycle, to ensure that business & organizational objectives are met. To maintain the integrity level required to meet business goals is the principal aim of Asset Integrity Management. This study concludes that Asset Integrity Management without following best practice or industry standard methodology is grossly ineffective and would lead to dire consequences as in the case of the 24in Trans-Niger pipeline case-study with its failure in 2018. The Energy Institute Guidance on Corrosion Management in Oil and Gas Processing facilities premised on the Plan – Do – Check – Act model, provides a method for ensuring the management of an asset in a visible, transparent, and auditable manner, which ensures that extant threats do not lead to sudden & unexpected asset failures.

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