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Optimising the integrity of safety critical petroleum assets: A project conceptualisation approach

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Abstract

The failure of safety critical petroleum assets (SCPA) is often accompanied by devastating safety consequences. The conceptualisation, design and construction of SCPA need to integrate factors that will maintain the asset's lifecycle integrity. In this paper, a risk-based assessment of a case petroleum pipeline asset in Nigeria was used to examine the project conceptualisation phase of an asset. The paper adopts a case study method, semi-structured interviews, field observations and drew on pipeline failure data. Key managerial issues that need to be considered in project conceptualisation for SCPA were identified. These issues include consideration for risk receptors and the need to assess organisational capabilities with respect to owning, operating and regulating SCPA. The paper contributes theoretically by providing a performance-based learning framework for the conceptualisation of new SCPA.

Key words: Project conceptualisation learning, Asset integrity, Safety critical petroleum asset(s), Risk management, Performance-based learning.

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1 Introduction

Safety critical petroleum assets (SCPA) such as high-pressure pipelines play a vital role in the supply of volatile products around the world [1]. Operators are required to demonstrate the integrity of their assets, and assess and mitigate risks in a context that accommodates stakeholder interests, including people who would be involved or affected by the construction and operations of the assets [1]–[3]. The construction of SCPA should, therefore, integrate factors that will ensure that integrity is maintained throughout its operational lifecycle [4]. Project conceptualisation provides a phase in project lifecycle where ideas and information regarding the design and construction of SCPA can be generated and utilised to ensure minimal failure [4]. Project conceptualisation phase has been described by Akbar and Mandurah [5] as an important stage of defining the project scope upon which project management activities are planned and delivered [6]–[9]. The conceptualisation phase is seen as central to project management processes [10] and crystallises ideas into a well-defined concept [11]–[15].

Highlighting the importance of project conceptualisation is critical because as much as 80 per cent of a product can be specified in this early phase [16], [17]. For SCPA this is where design and construction should take into consideration the need for optimal asset integrity during operations without which failure with impact to safety (human and environmental safety, and asset safety) is eminent [4]. Unfortunately, this is not always the case even with world leading oil and gas companies. Examples of known SCPA that have catastrophically failed due to issues related to poor conceptualisation include the 1976 Piper Alpha [18] and the 2010 Deep Water Horizon disaster [19]. Designs for both cases did not consider the sociotechnical perspectives of the assets. The September 2010 catastrophic San Bruno pipeline accident is also another example of a SCPA that was owned, operated, and maintained in light of deficiencies in public awareness programs [20]. Yet, it appears that the global petroleum industry has learned little (if any) lessons from these case examples. The current controversy surrounding the North Dakota Access Pipeline is an example of an ongoing SCPA project with poor project conceptualisation regime. Moreover, similar asset integrity issues have been reported in Mexico, Colombia, Nigeria, Indonesia, USA, UK, Canada, Iran, Iraq, Russia, Colombia and Saudi Arabia, where poor project conceptualisation contributes to poor asset safety and integrity performance [21]. Indeed, based on these examples there is a need to pay attention to the conceptualisation of SCPA projects.

As established from the reviewed literature, research focused on project conceptualisation pays greater attention on how to systematically extract and disseminate management lessons within projects [22], [23], how to share knowledge across projects [9], [24]–[26], and the role of stakeholders in project conceptualisation [27]–[30]. However, an ignored factor which is critical in the case of SCPA is the need to integrate knowledge of the performance of existing assets (especially similar SCPA) whilst conceptualising new projects. Consequently, operators are unable to learn from the performance of existing SCPA in conceptualising new projects as seen in the aforementioned examples [18]–[20]. Hence, this study focusses on the *identification of issues related to the risk and sociotechnical operational deficiencies of the SCPA, and how the conceptualisation of new SCPA projects can learn from these issues.*

This is an area still needing theoretical development, what Edmundson and McManus [31] would label as intermediate theory. Accordingly, a hybrid approach using quantitative and qualitative data from a detailed case study of the management of challenging pipeline asset Nigeria's [21], [32] can provide the basis for improved approaches to project conceptualisation of SCPA. Consequently, we assessed the risk associated with the case pipelines and analysed how the sociotechnical operational deficiencies interact to weaken its safety and integrity performance [33], [34] whilst identifying project conceptualisation learning points. The case study is a good example of SPCAs in the petroleum industry, in a country that is dependent on petroleum resources for the national economy with particular complexity [21], [32] but not unusual in natural resources rich countries. As such it can exemplify the general challenge of conceptualisation of a SCPA while learning from its performance to inform the conceptualisation of new assets as explained in section 3. The methodological choice of case study hybrid research is supported by project learning literature [33], [34]. The paper identifies some of the key managerial issues that need to be considered in project conceptualisation for SCPA and contributes theoretically by expanding the project-based learning framework [17], [22], [24], [25] to performance-based, hence, answering the call by Folds [37] on the need for research with practical systems engineering implications.

The paper is structured as follows: the next section theorises project conceptualisation learning and asset integrity. This is followed by an appraisal of the case study. An explanation of the method employed to achieve the research aim is covered in section four. Section five, six and seven presented result and discussion, managerial and practical implication, and theoretical contribution of the paper respectively. Section 8 is the conclusion.

2 Theorising project conceptualisation learning and asset integrity

Metcalfe and Lynch [38] asserts the need to approach project conceptualisation as a continuous process across project lifecycle. They criticised the fact that project conceptualisation is normally thought of as something completed at the outset of a project. This dynamic view of project conceptualisation, offers an opportunity to learn within and across projects for the attainment of organisational success. But how important is project learning to achieving organisational success? To explore this, we turn on the literature on project learning as a subset of organisational learning.

A number of authors [36], [39], [40] agree that project learning is important particularly for the attainment of organisational learning [41], knowledge sharing success in project-based organisations [24], [25] and as a mean of retaining project maturity within an organisation [42]. William *et al* [43] identified project learning as a means of optimising risk management and planning capabilities across projects. Other researchers considered project learning as a medium for improving decision making within and cross projects [22], [23] and enhancing stakeholder engagement [3]. Indeed, the literature supports the importance of project learning to organisational success in various ways. However, in reality project learning rarely happens

[41], and in many instances, fails to deliver the intended results [44]. So, what supports or inhibits project learning?

Learning within and across projects is a complex process and requires optimal attention, process and resources [45]. Indeed, when project learning is captured either via process-based or documentation-based methods [46], the extraction of new project management knowledge (tacit and/or explicit [47]) happens if actors process and establish systems and practices [48] with supportive learning culture, organisational and communication structures [35]. This will allow project learning to flourish through knowledge sharing by storey telling, practice, and systematic thinking [49], [50]. However, because of the temporary nature of project organisation, time pressure and decentralised nature of project environment, learning can be inhibited [51]. Hence, to overcome some of these inhibitors, Milton [44], [52] believes that learning should start at the conceptualisation phase of the project so that project begins with complete knowledge. Moreover, adopting a dynamic view of project conceptualisation [38] will allow for continuous integration of learning. Furthermore, from a project conceptualisation theoretical perspective, a system approach introduced in Whelton and Ballard [53] and further contextualised by Ballard [54] provides the framework which we have used as theoretical conception of how project-based learning can be achieved within and across project management processes in SPCA projects.

The approach by Whelton and Ballard considered two motions in a project conceptualisation conversation and concept thinking. The first is the circular motion between the three primary elements: Ends (set of project goals), Means (set of process actions and decision rules) and Constraints as shown in *Figure 1*. Purposes are formed in conversation with design concepts and constraints, then the means for achieving those purposes are specified as characteristics of the asset to be designed and constructed, then finally those values are translated into technical specifications [17], [53], [54]. For instance, if the purpose is to construct a pipeline asset, one value is 'asset integrity', and the design criteria can be an asset with acceptable risk level. Meaning that the design and operation must demonstrate that the cost involved in reducing the risk further would be grossly disproportionate to the benefit gained, known as the ALARP (as low as reasonably practicable) principle [4].

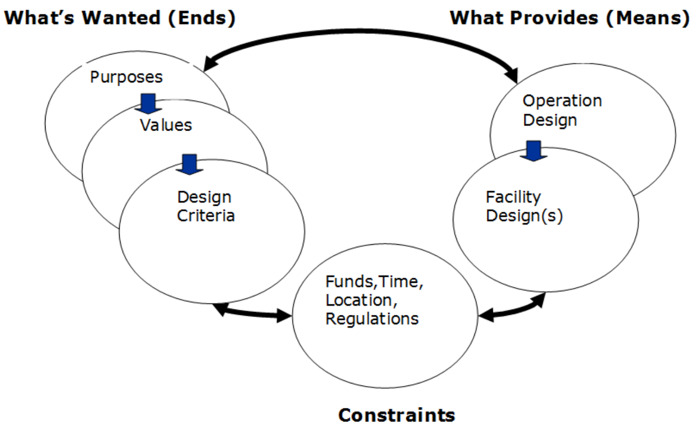


Figure 1: Project definition process. Adapted from Ballard [54].

The second developmental motion occurs within means, and consists first of design concepts for how an asset is to be used; referred to Figure 1 as "operation design". The idea is to first determine how an asset will be used before trying to design the asset. Once the asset's use is determined, attention can turn to design of the asset itself and how to construct the asset [17]. Hence, in establishing how a new asset will be used, the integrity performance of similar asset can be sought and lesson drawn from it.

Juxtaposing on the first motion between the three primary elements defined by Whelton and Ballard, and by adopting Metcalfe and Lynch's [38] dynamic view of project conceptualisation, the link between project conceptualisation, project-based learning and asset integrity can be established using the connection between purpose, value and design criteria. For SCPA the value (e.g. asset integrity) element in project conceptualisation outlines the ability of the asset to perform its required functions effectively and efficiently with optimal protection to health, safety and the environment. It also outlines the means of ensuring that adequate sociotechnical systems and processes are in place to deliver asset integrity without which the project product will be considered ill-conceived. Indeed, because of the sociotechnical context of delivering an optimised asset integrity [33], [37], [55]–[57] in SCPA projects and the need for understanding the safety consequence of failure of such assets [58], the link between project conceptualisation and learning needs to go beyond project management processes. Project conceptualisation needs to learn from similar sociotechnical systems. This is because design criteria element (e.g. risk from asset must be ALARP), for instance, establishes links between the asset conceptualisation and the varying acceptability of risk emanating from such asset from both individual and societal risk perspectives [59], [60]. For example, in the Netherlands, risk level must be less than $1E^{-6}$ per year to be adjudged acceptable for new assets [61]. The Western Australia's maximum acceptable risk level also stands at $1E^{-6}$ [62]. In the UK, an individual and societal risk limit has been established in BS PD8010-3 [2]. These examples demonstrate how individuals and societies often set-up acceptable risk levels, with a view to conceptualising, designing and operating assets with risk levels to what can be termed 'bearable'. The decision process on the acceptability of risk is generally based on risk acceptance criteria, stakeholder's perception, environmental consideration and lessons from past incidents, with the view of using such criteria as a tool to facilitate decision making [60]–[63]. Assets designed and constructed without this consideration are likely to have poor integrity and safety performance throughout their operational lifecycle [4]. Hence, it is important for the project delivery process of SCPA to learn within and across projects as effectively captured by Whelton and Ballard [53] and supported by many project learning literature [22], [24]–[26], but also important to integrate the knowledge of performance of similar assets.

We adopted Whelton and Ballard's theoretical framework as a theoretical lens for conducting a risk based-study that exposes the effect of poor project conceptualisation. However, their framework focuses on project-based learning via "reflection cycles", and therefore limits learning to project management processes. To overcome this limitation, the theoretical conception has been protracted beyond project management processes by integrating lessons from the knowledge of performance of similar project products. To achieve this, the next section lays out the problematic dimensions of the Nigerian National Petroleum Corporation (NNPC) pipelines and provides justification for the case selection.

3 The case pipeline system in Nigeria: the intervention context

The pipelines covered within this research constitute the 5001 kilometre(km) transmission system for liquid petroleum products in Nigeria which moves large quantity of products from refineries in Kaduna and Warri, and two in Port Harcourt, and import jetties to local distribution depots as shown in *Figure 2* [64]. Mainline pipes, pumps, and compressor and booster stations, and other facilities that form the transmission system are all considered within the terminology "pipeline system". The pipeline system is strategically located across the country and classified into five regions of operations. NNPC own and operate the asset via its subsidiary the Pipeline Product Marketing Company (PPMC).

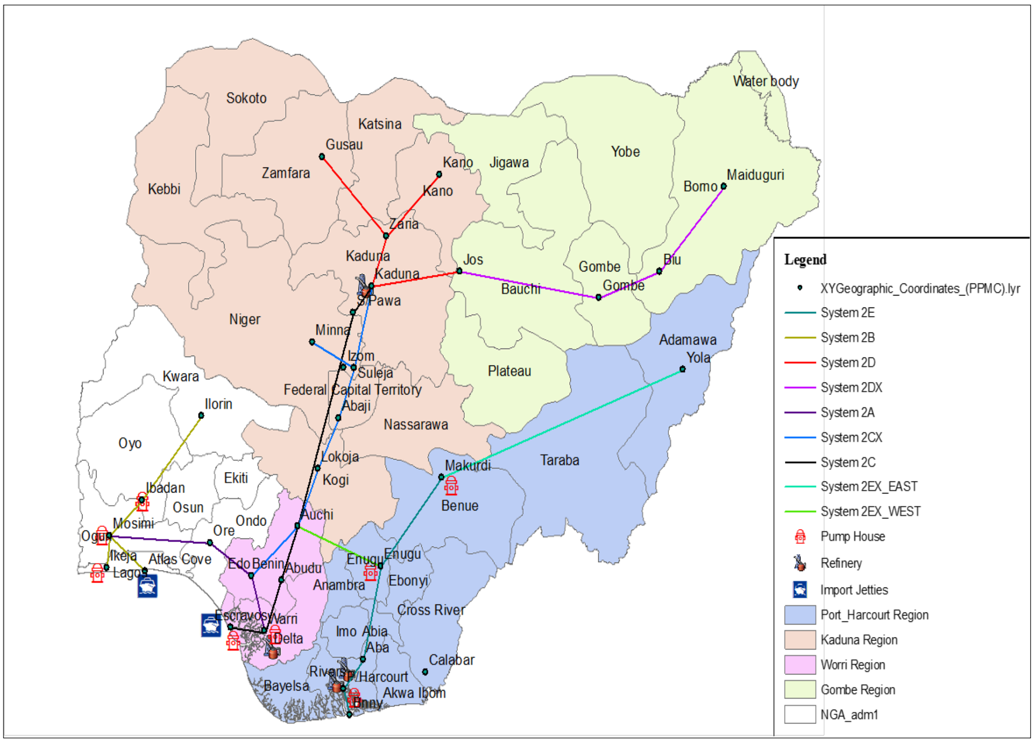


Figure 2: Map of Nigeria showing pipe network and petroleum depots
Adapted from: NNPC [64] and PPPRA[65]

The NNPC pipelines represent an example of a SCPA with challenging socio-economic and political problems affecting the safety and integrity of the pipeline. At the core of this problem is the issue of interdiction and sabotage [21], [32]. In 2011 for instance, NNPC reported a total of 2,787 line failures out of which 2,768 were the result of interdiction, while 19 cases were due to material deterioration. Research (e.g., [66], [67]) further illustrates the complex causal dimensions of such interdictions on the pipelines including theft by well-equipped actors and deliberate sabotage due to the politics of petroleum resource in Nigeria. Indeed, Ogwu [68] also asserted that these causations has been disputed by host communities and linked to the surface exposure of the pipelines. Whether other failure causation can be identified beyond the scholarly focus on socio-economic and political dimension of interdiction and sabotage and how this link to the pipeline's design is and construction dynamics remains unknown; hence, an in-depth understanding is required to provide a source of lesson for the conceptualisation of new SCPA. The sociotechnical operating context of the pipelines is not also without blame [32]. For instance, because a large section on the pipeline network was constructed in 1978/80 with a limited lifespan of 20 years, material and protection deterioration has contributed to corrosion and impact damage due, surface exposure from erosion [69]. Furthermore, Omeje [70], Engobo [71] and Ambituuni *et al.* [66] attributed the causes of failures to operational deficiencies including poor practices and bureaucratic bottlenecks. However, it remains unknown how these deficiencies interact to weaken failure prevention barriers and the link to the design and construction of the pipelines.

As theoretically established in section 2, the effective conceptualisation of SCPA and the optimisation of project delivery processes can be achieved via project based learning [22], [23] with implication for organisational learning [39] and success [42], [43]. However, this does not guaranty the integration and optimal consideration of human interactions with the asset's systems, a critical dimension of integrity performance for SCPA. Indeed, we have seen numerous failures of the case pipelines, linked to sociotechnical deficiencies, thereby, suggesting a failure in sociotechnical integration. For instance, the December 26th, 2006 pipeline explosion in Ilado-Odo around Lagos in Nigeria which killed more than 250 people was attributed to pipeline rupture and explosion caused by material defects and poor emergency responds [67]. Similarly, a pipeline rupture and explosion at Jesse community on the 15th October 1998 resulted in large scale pollution and killed over 1,500 people [71]. The question, therefore, is how can the failure and consequence causations of the pipelines be identified to inform managerial practice with implementable actions via project conceptualisation? We broke this down into three research questions as follow:

- RQ1: How are risk variables (i.e., the frequency and consequences of failure) of the pipelines linked to project conceptualisation?
- RQ 2: How does sociotechnical deficiencies of the pipelines hierarchically interact to weaken failure prevention barriers and how is this linked to project conceptualisation?
- RQ 3: How can the conceptualisation of SCPA projects learn from the pipeline's integrity performance and sociotechnical deficiencies?

To address these questions, we adopt a case study method [72], [73], for this intermediate theory research [31], employing a focussed lens to illuminate the risk and sociotechnical problems, hence providing an in-depth understanding of failure causations upon which the conceptualisation of SCPA can learn from.

4 Method

The research adopts Yin's [72], [73] explanatory case study methodology as it is particularly suitable for answering "how" and "why" questions, and for exploring "system bounds" [74]. Case study provides a robust method particularly when a holistic, in-depth investigation is required [75]. Indeed, the choice of a case study allowed for the pipelines to be studied in its "real world" unique sociotechnical context and the challenges it poses to reveal interesting insights on lessons to be learned in the conceptualisation of new pipelines for optimising safety and integrity. In addition, the adoption of a case study also allowed the utilisation of both qualitative and quantitative data and mixed analytical method in a way that ensured the research aim was achieved within an environment rich with contextual variables [75]. The method allowed us to empirically identify practical dimensions that needed to be considered in project conceptualisation given the already existing knowledge on the case pipelines (e.g., [21], [32]), and to draw on existing knowledge in order to provide new perspectives for project conceptualisation learning. By doing this, we aligned our methodological fit to Edmondson and McManus [31] intermediate theory. Indeed, because the NNPC pipelines exist within a sociotechnical context, we adopted Rasmussen's framework as a way of conducting a hierarchical sociotechnical study of the system. Similar approach has been used to study sociotechnical systems by Trotter *et al*. [76]. The cited case examples of failures of SCPA opened the need for risk-based research.

Yin's [73] five components of an effective case study research design were applied: (1) research questions; (2) propositions or purpose of study; (3) unit analysis; (4) logic that links data to propositions; and (5) criteria for interpreting findings. The explanatory case study was used to answer questions that sought to explain the causal links in real-life interventions that are too complex for the survey or experimental strategies, through pattern matching achieved by series of iterations to examine the data closely at both surface and deep levels. The questions we tackled drew from the paper's problem context, aim and theoretical framing.

The second component of case study research design is to define the study purpose clearly [74], [75]. The purpose of this study was to develop an understanding of the risk and sociotechnical operational deficiencies of the case pipelines, and how the conceptualisation of new SCPA projects can learn from this complex example. Hence, two key definitions bind the case: (1) the pipeline risk i.e. failure frequencies and consequences; (2) the pipeline's sociotechnical context i.e. the interactions between technical systems, organisational, regulatory, humans, and the environmental aspects [33]. Consequently, our unit of analysis focused on the "risk" and "sociotechnical context" of the case pipelines.

The fourth component of case study research design was to connect data to propositions. This connection was achieved following the data collection phase, as themes emerge. We analysed the data whilst building explanations to the causal links that appear in the data to the theoretical propositions of the paper, thereby, answering the research questions. Finally, interpretation of findings was achieved through carefully extraction of meanings from the analysis vis-à-vis the theoretical conception of the paper [72] to develop an understanding of the risk and sociotechnical operational deficiencies of the case pipelines, and to identify learning points for SCPA projects conceptualisation.

The paper's methodological fit [31] can be seen from four dimensions. The research seeks to address questions of practical and theoretical importance specific to the context of SCPA. Second, the study drew on existing theoretical and empirical work on approaches to project learning in organisational context [35], [36], [41], project conceptualisation [3], [27] and how asset integrity can be achieved during project conceptualisation in a reflection cycle [53] without which the asset is likely to fail [4]. The theoretical framing of the paper also established the need for learning in project conceptualisation to go beyond project management processes. The study also drew on existing knowledge and the uniqueness of the case pipeline to justify the focus on project conceptualisation. This approach informed the hybrid data collection and analysis techniques used in line with the case study method adopted. Finally, managerial and theoretical contributions were informed by the findings of risk assessment and analysis of sociotechnical deficiencies of the pipelines. Yin's tactics (construct validity, internal and external validity, and reliability) were carefully integrated. Construct validity was achieved by the used of multiple source of evidence and establishment of chain of evidence. Internal and external validity were addressed mainly through explanation building and replication logic respectively. Reliability was achieved using case study protocols and database such that data collection procedure can be repeated [73].

4.1 Data collection

Based on the intermediate methodological fit of the study [31], data collection took a hybrid form. First, is the need to collect data that allows for quantification of risk, i.e., failure frequencies and consequences of the pipelines. To achieve this, quantitative data was collected including: documented data related to the design, construction, operation, and maintenance of the pipeline from the operator, i.e., PPMC. The data provided analytical variables for understanding the characteristics of the pipelines and the operating parameters including: pipeline diameters, wall thickness, steel grade, length, fluid type, line capacity, design flow rate (min/max), design pressure, cathodic corrosion protection, depth of cover, etc. Historic pipeline failure data was also obtained from PPMC. This comprised data from thirteen years report (from 2000-2012) containing information on failures in the entire 5001 km pipeline system across the five operation and distribution zones. Overall, the quantitative data was used for quantitative pipeline risk assessment as described in the data analysis framework in section 3.2. This provided crucial framework for systematically identifying risk and analysis of failure causations, consequences, and the link to ill-project conceptualisation.

Second is the need to develop an in-depth hierarchical explanation of the sociotechnical, organisational and regulatory dimensions of failure causations of the case pipeline. Consequently, semi-structured interviews were conducted with key purposively sampled participants. The semi-structured interview technique was selected mainly because it provided the opportunity to modify the predetermined questions based upon the researcher's perception of what seems most appropriate. This allowed question wording to be changed and explanations given; particularly questions which seem inappropriate with a particular interviewee can be omitted, or additional ones included [77]. As used in case study research [72], [73], semi-structure interviews also allowed data to be gathered and further reasoning behind responses to be explored, for a better understanding of the participant's experience, opinion and knowledge, within the case problem [78], and a means of confirming insights and information the researcher already holds. Interaction between participants and the researcher allowed for data generation, which is an indication of the researcher's immersion in the field. Because of this, constructivism and interpretivism [79] commonly permeate the implementation of the research design. Participants were purposively sampled [77] from relevant departments and communities with the right affiliation and knowledge of the subject matter as shown in Table 1 below. For the purposes of confidentiality, the participants' names and their position within their affiliated organisations are excluded.

Table 1: Semi-structured interview schedule

Participants	Number of participants	Participants role
Nigerian National Petroleum Cooperation (NNPC)	3	Asset owner
Pipelines and Product Marketing Company (PPMC)	6	Asset operator
Department of Petroleum Resources (DPR)	2	Asset regulator
National Oil Spill Detection and Response Agency (NOSDRA)	4	Asset regulator
Pipeline host communities	5	Risk receptors

A total of twenty semi-structured interviews were obtained. The interviews spanned between forty minutes to seventy minutes and were all conducted in three interconnected sessions. The aim of the first session was to discuss and understand contextual risk factors and underlying causes of pipeline failure. In the second session, the discussion tilted towards understanding the regulatory and operational limitations related to the construction and operations of the pipeline facilities. The last session explored the possible collaboration for maximum research impact. All interviews were done with complete integration of ethical considerations. The interviews were conducted face-to-face to enhance rapport, interest and attention [77] based on a designed interview guide developed and tested in a preliminary pilot study with consideration for the research aim and purposive selection of participants based on analysis of stakeholders [66]. The interviews were later transcribed and analysed using the framework described in section 4.2. Rigour was achieved by engaging key stakeholders and focusing on verification and validation. This included responsiveness of the researchers during the interviews, methodological coherence, appropriate sampling frame and data analysis.

Lastly, field observation was conducted on a sampled section of the pipeline (Figure 3- system 2B- along the Atlas-Cove to Mosimi section) to obtained site specific data on the condition of ROW. The section of the pipeline inspected was purposively selected due to its activeness. 2B accounts for 70 per cent of the service gateway for product importation. The area inspected is classified under the Mosimi region. In total, about 13 kilometres of that section was inspected over a period of four days. Details of inspected coordinates are given in Table 2. The inspected area cuts across towns and countryside.

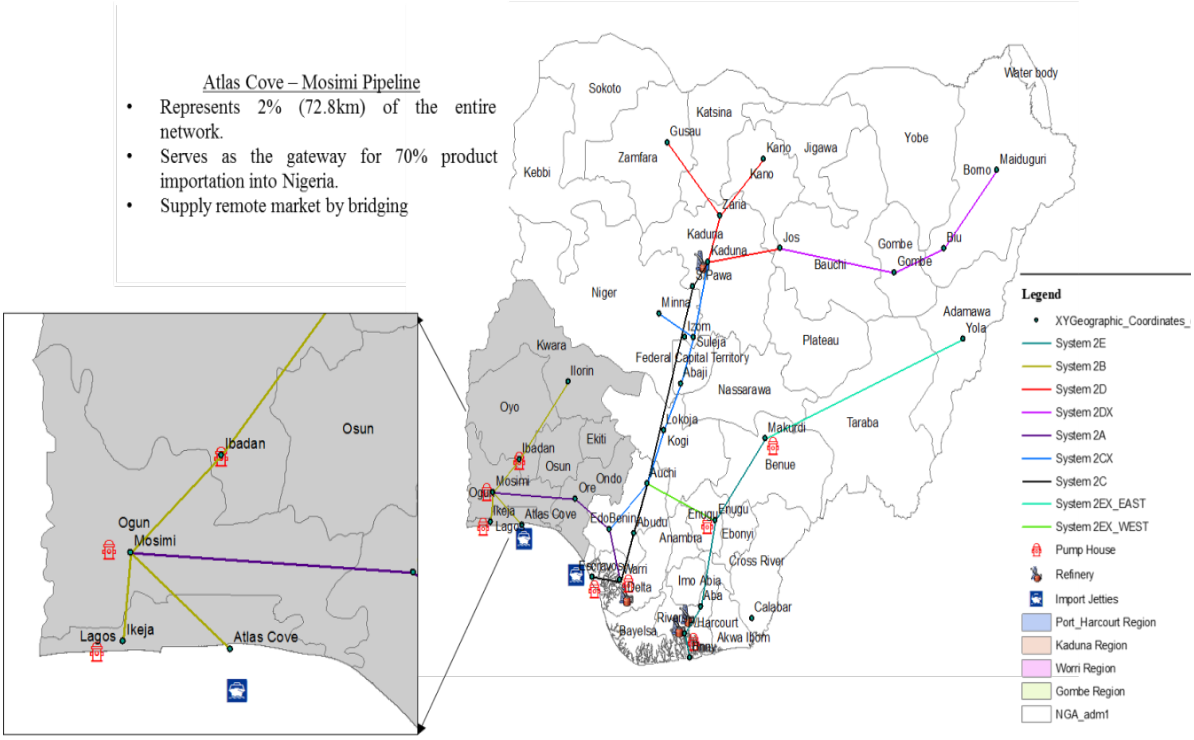


Figure 3: ROW inspected area

Table 2: Coordinates of section of pipeline ROW inspected

Start point Coordinate:	6°35'00.4"N	3°16'15.2"E
End point Coordinate:	6°27'55.14"N	3°15'14.91"E
Distance:	13.26 km	
Initial bearing:	008°01′00″	
Final bearing:	008°01′07	
Midpoint:	06°31′28″N,	003°15′45″E

As there are no standardised ROW visual inspection processes in Nigeria, the recommended process by the Association of Oil Pipeline was adopted. This method simply involves: (1) determining section of the pipeline ROW to be inspected; (2) determining the method to transverse ROW (in this case, foot patrol and patrol vehicle were used to transverse the sampled area); (3) ensuring the researcher has a clear understanding of which pipeline need to be inspected; the location of the pipeline; and the beginning and ending points of the pipeline, and documenting all notable observations on the ROW.

4.2 Framework for data analysis

The framework used for data analysis consisted of three interconnected elements designed to achieve explanatory case study data analysis. First, a quantitative pipeline risk assessment was conducted to establish the pipeline failure frequency, failure consequence and risk estimation. There are a variety of different systems in use for risk assessment. Palmer-Jones *et al.* [80] placed the systems into three generic methods i.e. point-scoring, ranking and quantified. This paper considered these three methods, and tailored a method utilising analytical techniques that best suit context of the case pipelines. To achieve this, failure frequency was computed based on the model used in Ambituuni *et al.* [32] and De Stefani *et al.* [81] as the sum of reported failures f due to: f_{TPD} third party damage; f_{MF} mechanical faults; f_{CO} corrosion; f_{NH} natural hazard; and, f_{IN} sabotage and pilferage expressed in equation 1.

$$f = f_{TPD} + f_{MF} + f_{CO} + f_{NH} + f_{IN} \qquad (1)$$

Using historic data, the consequence of releases was also assessed at this stage. This included: ignition frequencies; fatality and casualty frequency. The quantitative individual risk (IR) of the pipeline was also computed as a measure of the frequency at which an individual, at a specific distance from the pipeline, may be expected to sustain a specified level of harm from realisation of a specific hazard. For this study, we assumed an individual at a point *x,y* from the pipeline, and adopted the calculated failure frequencies from equation. 1, and the associated ignition frequencies to estimate a value of IR from point *x,y* with equation 2.

$$IR_{(x,y)} = \sum_{j=1}^{n} (f.\, dx.\, p_i.\, p_{cy})_j \qquad (2)$$

f = failure frequency (per km-yr), p_i= ignition frequency, p_{cy} = casualty frequency, dx =step length (m). At this point, failure and consequence characteristics of the pipelines began to emerge in quantitative terms.

The second element of the data analysis involved the analysis of interview data which allowed making sense of causations, as well as providing in-depth explanations behind the quantitative results. It was important to choose the most suitable method for data analysis so the information obtained from the interviews could be interpreted efficiently and effectively. An inductive approach was utilised based on the strategy described in Braun and Clarke [82].

Consequently, the thematic analysis method [83] was used to codify themes within the data to establish pipeline failure causal factors as well as factors contributing to the consequential nature of such failures. Data familiarisation was first obtained by repeated reading of the entire data set for ideas and identification of possible patterns. As all but one of the interviews was recorded in audio format, transcription provided a good opportunity for familiarisation. Meanings were interpreted and notes taken during this period. Afterwards, initial codes were produced from the data. The codes identified are features of the data that appears interesting to the research. The next phase involved sorting the different codes into potential themes, and collating all the relevant coded data extracts within the identified themes. Subsequently, relationships were established between themes and codes and between themes from participating stakeholders. Afterwards, themes were revisited and refined. Some irrelevant themes were excluded while similar or different themes were either collapsed to form a clearer cohesive theme or separated to form different themes. This ensured that the obtained data was reduced into meaningful categorises [82], [83].

For the last element of the research data analysis, Rasmussen's risk management framework [33][39] and Accimap [84] was used to establish a structured hierarchical understanding of pipeline failure causation from technical, human, organisational and regulatory perspectives. The result of the quantitative pipeline line risk assessment was triangulated with the result of the interview analysis and ROW inspection to achieve this. Accimap was used to analyse and link the integrity performance of the pipeline asset to its conceptualisation regime. Accimap analysis typically focus on failures across the following six organisational levels: government policy, regulatory bodies, company policies, company management, staff and physical work processes. By using the Accimap, a holistic view of the issues was mapped. This made it possible to identify the causal and contributory factors, explain the general trajectory of the faults across the sociotechnical pipeline systems and the interactions between them. Where appropriate, descriptive quotes have been used to express views of the participants.

The amalgamation of data analysis tools allowed for qualitative and quantitative data to be blended in a hybrid approach [31] such that quantitative variables provided risk-based measure of the sociotechnical issues of the case pipeline and qualitative data provided in-depth insights into dynamics of the issues. Explanatory data analysis further allowed us to analyse the case study data by building an explanation about the case and identifying causal links such that project learning is conceptualised based on the identified issues.

5 Result and discussion

5.1 Pipeline failure frequency (*f*)

The integrity of a SCPA depends on minimal failure frequency [4]. Hence, an assessment and explanations of the failure frequencies and causal factors of the case pipelines was needed for developing an understanding of causation link to conceptualisation. Table 3 shows the pipelines within each distribution region and the computed failure frequency per kilometre year. The 13 years mean value of failure per km-year across the pipeline network stance at 0.351 per km-year. This rate is very high compared to failure rate from other database such as: the Oil Company European Organisation for Environment Health and Safety (CONCAWE) with a computed failure rate of 0.54×10^{-3} and 0.24×10^{-3} per km-yr from 1971 to 2011 and 2007 to 2011 respectively; United Kingdom Onshore Pipeline Operators' Association (UKOPA) with failure rate of 0.23×10^{-3} per km-yr from 1962 to 2012; and US with failure rate of 0.135×10^{-3} per km year from 1994 to 2012.

Table 3: Failure frequencies within each NNPC distribution region

Regions	L (km)	Failure incidents	Failure frequencies per km year
Port-Harcourt (PH)	1526.6	9246	0.47
Warri (WR)	1561.2	4659	0.23
Mosimi (MS)	512.6	3419	0.51
Kaduna (KD)	1132.8	2443	0.17
Gombe (GB)	267.8	2642	0.76
Mean *f* value			0.351

As expected, the exponential differences are mainly due to problems of vandals and interdictors within the pipeline systems in Nigeria. Based on equation 1, f_{IN} has a mean contributory value of 96.49 per cent of the pipeline failures while failure from rupture (i.e.,f_{MF} and f_{CO}) accounted for 3.51 per cent. Whilst the act of pipeline interdiction has been attributed to criminal sabotage and politics of oil resources in Nigeria [85], the percentage contribution of f_{IN} also suggests that concerns about the sociotechnical operational context of the pipeline asset was ignored at the conceptualisation phase the pipeline construction. Further evidence from the interviews revealed that no environmental and social impact assessment (ESIA) was conducted at any point during the project delivery process. This finding provides a rival interpretation to the causes of interdiction on the pipeline beyond the politics of oil resources, to a more fundamental issue related to the lack of understanding of the environmental and social impact of the case pipeline on its host community. The scale of problem of product losses due to high failure frequencies can be seen in financial terms in Figure4. On average, the operator loses about 100 million USD per year.

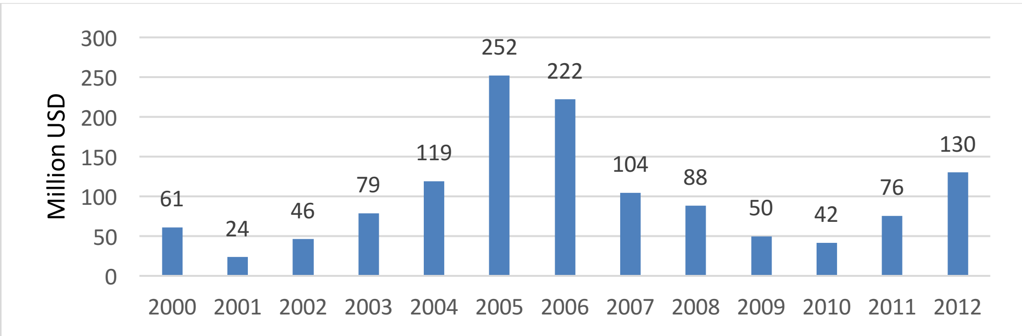


Figure4: Dollar value of product loss

The findings on interdiction and failure frequencies of the case pipeline reveal lessons to learn for project conceptualisation of similar assets especially the need to conduct ESIA to identify ways to engage host communities and ensure failure from interdiction is minimised. Indeed, community engagement can occur during conceptualisation as a means of setting "purposes" to align with design concepts and the need to identify operational constraints [53]. The problem identification, (setting objectives) and definition (appraisal of solutions, analysis of risks and benefits) aspects of project conceptualisation also offer opportunities for conceptualisation of operational planning that allows for community engagement [32], [67] to occur through continuous monitoring and inspections.

5.2 Effect of age of pipeline on failure frequency

The pipeline systems were classified into two according to the year of construction i.e. 1978/80 and 1995 categories. From Table 4 it can be seen that there is a significant difference between failures from interdiction (f_{IN}) across the two construction periods. The newer lines have a higher hit rate.

Table 4: Pipeline age and mean failure frequency. Note that f_{IN} is failure due to interdiction and f_{Rup} is failure due to rupture

Variables	N(yrs)	Mean	StDev	Minimum	Maximum
f_{IN} (1978/80)	13	0.493	0.428	0.057	1.180
f_{IN} (1995)	13	0.765	1.065	0.000	3.208
f_{Rup} (1978/80)	13	0.02011	0.01230	0.00390	0.03902
f_{Rup} (1995)	13	0.00203	0.00365	0.00000	0.01132

This finding demonstrates the predisposition of the newer pipeline to interdiction, similar to the older pipelines. Indeed, this further reinforce our earlier argument on the need for project learning to go beyond project-based learning [46], [49] to performance-base. The case pipeline provides insight on how the poor integrity dynamics linked to interdiction of the older pipelines appeared to have been inherited and even exceeded by the newer pipelines. This, however, is unsurprising as the integrity management systems of both pipelines remains the same and weakened by deficiencies across various sociotechnical context of the pipeline operation as later shown in section 5.6.

As expected, failure due to rupture (f_{Rup}) increased with pipeline age. i.e, for the 1978/80 pipelines f_{Rup} is about 0.02 per km-year, while 0.002 per km-year was computed as the f_{Rup} for the 1995 pipelines. Unfortunately, the available data did not permit further analysis to ascertain the precise relationships, i.e. whether the ruptures are related to time dependent threats, e.g. internal/external corrosion and material fatigue or time independent, e.g. ground movement and incorrect operations. Notwithstanding, this finding suggests that there is no sufficient integrity-based inspection and maintenance schedule designed to fit operating context from the conceptualisation stage, especially as it relates to the lifespan of the pipeline. Indeed, ill-project conception and operational dynamics of the pipelines are evident in the fact that the pipelines remain operational even after exceeding its 20 years lifespan [70], making it vulnerable to corrosion, material fatigue and impact damage.

5.3 Ignition causes and frequencies (*pi*)

Only the pipeline failure records from 2007 had causes of ignition. Prior to 2007, only the numbers of ignitions recorded per year were reported. Of the 106 ignitions recorded from 2007 to 2012, 74 per cent were caused by vandals as shown in Figure 5.

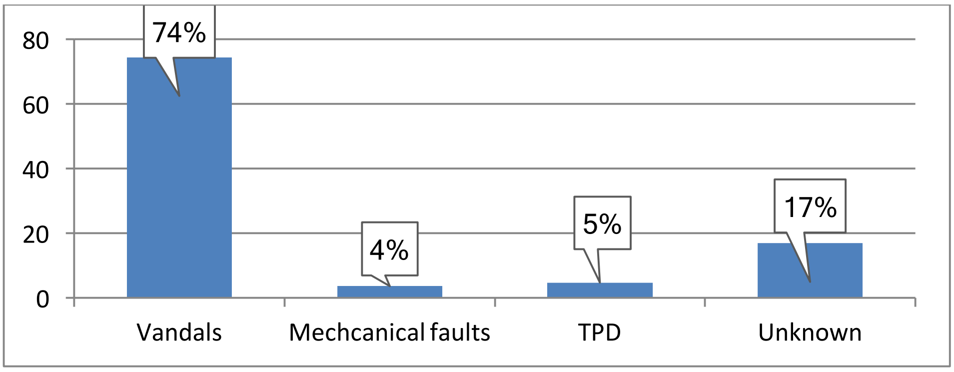


Figure 5: Ignition causal factors

Most of the reported sources of fire from mechanical faults were associate to pump overheating, failed mechanical seal, electrical fault and auto ignition. Sparks from electric overhead cables, bush burning for hunting purposes, and construction activities were mostly the sources of fire from third part damage (TPD). We observed an interesting insight from the way the operator report and linked ignition causations to factors that on the surface seem unavoidable and are mere part of day to day safety critical operations (e.g., pump overheating, electrical fault, and auto ignition). This practice ignores the link between such faults and deficiencies in the sociotechnical operating system of the case pipelines. The implication of these practices on safety and integrity performance of the pipelines can be argued from two perspectives. First, the operator is unable to accept responsibility for its poor safety performance and, therefore, unable to see faults in its safety systems and procedures which could, otherwise, be a pivot for learning especially in the context of conceptualising new assets. Second, such practice will avert criticism and regulatory sanctions of safety performance which may lead to a false sense of safety and integrity management capabilities.

To further evaluate any observable differences in the reported ignition frequencies across the NNPC distribution regions the ignition per failure incidents in each region was calculated. From Table 5, Port-Harcourt region (PH), Warri (WR), Mosimi (MS) and Kaduna regions all have ignition per failure incidents within the same range, while Gombe (GB) region recorded the lowest ignition frequency of approximately 1 in 100 reported failures.

Table 5: Ignition frequencies within NNPC-PPMC distribution regions

Regions	Pipeline failure (2000 to 2012)	Fire incidents (2000 to 2012)	Ignition frequency
PH	9246	206	2.23E-02
WR	4659	122	2.62E-02
MS	3419	76	2.22E-02
KD	2443	50	2.05E-02
GB	2642	27	1.02E-02

There are questions as to the reason why ignition rate is high in PH, WR and MS regions. Perhaps this could be associated to the flash point of the petroleum products involved. However, the overall rate of ignition per pipeline failure exposes the deficiency in emergency response and limitations in the leak detection and incident response technologies. Indeed, the ignition frequency dynamics of the pipeline offers learning on the link between the design criteria element (e.g. ensuring risk of the asset is ALARP) and the acceptability of risk through the design and implementation of robust integrity management systems which will minimise ignition frequencies and reduce failure consequences.

5.4 Fatality

The consequences of the high ignition frequencies computed above can be seen in the fatality record of the pipeline system as represented in Table 6. The pipeline systems in PH, WR and MS regions recorded fatality of 0.044, 0.071 and 0.38 per km-yr. However, surprisingly, KD region recorded no fatality even though the ignition frequency in that region is similar to ignition frequencies in PH, WR and MS. As discovered during the pipeline ROW inspection, other influencing factors such as poor pipeline route planning, the proximity of buildings to the pipelines and ease of access to incident sites contribute to pipeline failure consequences.

Table 6: Fatalities from1998 to 2012

Regions	Fatality report (1998 to 2012)
PH	1004
WR	1665
MS	2889
KD	0
GB	0

5.5 Individual risk (IR)

IR of a SCPA is defined as the fatality rate at a point *x,y* if someone would be present at that point 100 per cent of the time unprotected by clothes or buildings [2]. When a pipeline is designed with optimal integrity management system, the IR value is such that people living within the vicinity of the asset are safe from the minimised failure probability and consequence. Developing such an integrity system requires understanding of factors such as the failure dynamics of the pipeline, proximity of people, routing, emergency response procedures and risk communication to be conceptualised when designing and operating the pipeline, without which the value of IR will be considered intolerable. Figure 6 illustrates the calculated IR associated with the section of the pipeline inspected. The figure also illustrates the adopted IR limits established by PD8010 [2] because of its general appropriateness within the global pipeline industry best practices. At about 40 metres from the pipeline, the IR value is not within tolerable limits. Above 40 metres the IR value is tolerable if the risk is ALARP. The ROW inspection conducted during this study revealed that in many cases buildings and other public infrastructures are located less than a meter from the pipeline. This may be the reason for the high fatality rates recorded which affects the IR values along the pipeline. The focus on attaining tolerable IR levels for conceptualising, constructing and operating SCPA with similar characteristics should, therefore, be on integrating the aforementioned factors in order to mitigate the risk associated to the failure of such asset.

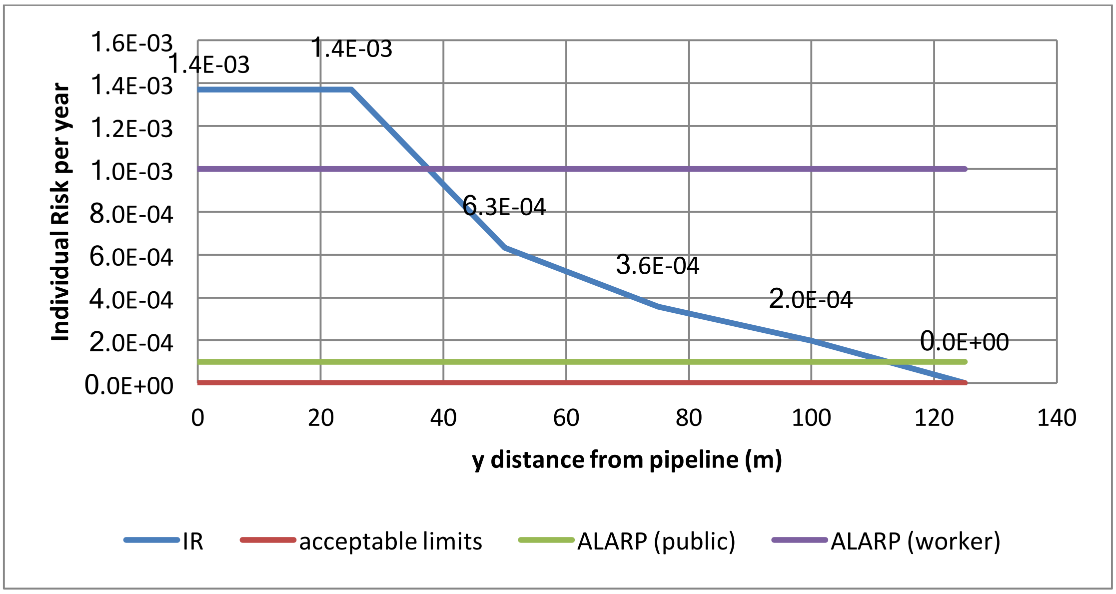


Figure 6: Pipeline IR values

Indeed, beyond the measure of risk and the learning thereof identified for SCPA project conceptualisation, what is important is the manner in which sociotechnical deficiencies are likely to weak failure prevention barriers of the asset. The next section analyses how this happens in the case pipeline as a means of establishing what SCPA project conceptualisation learning can be further identified from such deficiencies.

5.6 Hierarchical description of pipeline failure causes

The risk associated with the case pipelines was assessed using failure records and pipeline design and construction data and the results presented in sections 5.1 to 5.5 above. This section combined the risk assessment with the result of the analysis of semi-structured interviews conducted and site observation to explore the "faults" and the interactions within the holistic pipeline sociotechnical complex systems and how these faults offer learning for the conceptualisation of similar assets. The result of the analysis is shown in Figure 7.

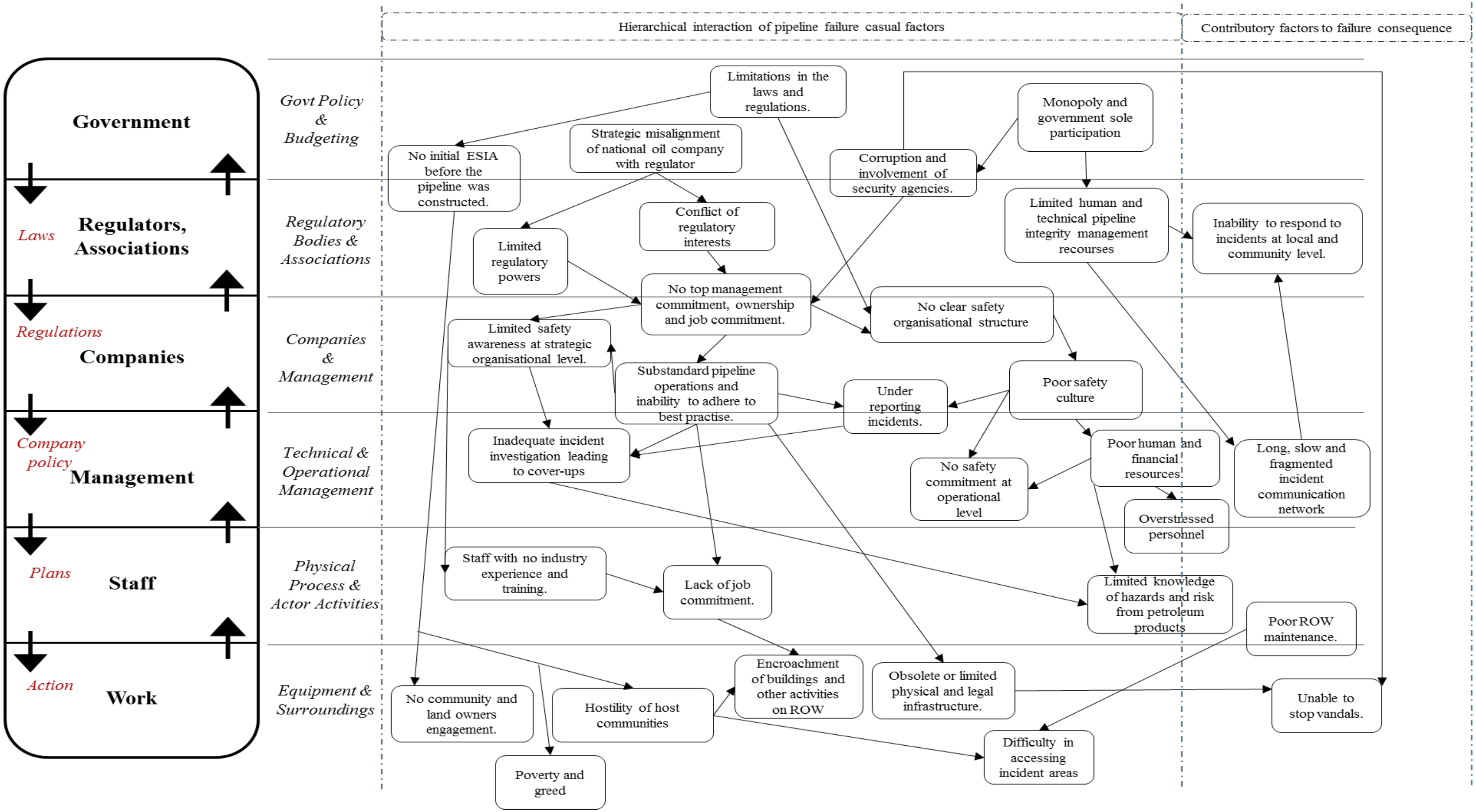


Figure 7: AcciMap showing the interaction of pipeline failure causal factors and factors contributing to elevated failure impact

The first failure-causal theme explores governmental and regulatory issues. At both levels, the limitations in the regulatory framework of the pipeline are attributed to government's sole involvement in the construction, operations and regulations of the pipelines. During the project delivery stage of the pipelines, the government took no consideration of the host communities and, over the years, this has become a point of grievance. The interviewed stakholders agreed that the pipeline was constructed without an ESIA. Also, due to regulatory deficiencies at governmental levels, the regulator (DPR) appears to be deliberately weakened as they equally receive administrative directives from the Minister of Petroleum Resources (as illustrated by the interview citation below). This strategic organisational misalignment weakens the pipeline integrity through defective regulatory systems. Indeed, in the conceptualisation of new assets attention needs to go beyond reducing pipeline risk through the technical design of the asset to strengthen the failure prevention barrier. This can be achieved by integrating an organisational capability assessment into project conceptualisation phase.

> *"There was a time when DPR was buried right inside NNPC, at that time it was just a small office in Lagos, their salaries, and everything was together…so, I am sure once DPR steps-in by attempting to be strict, some people will tap them on the shoulder and say: hey slow it down. This oil is getting Nigeria about 80 per cent of its income, so we don't want any hustle" (NNPC interviewee).*

The next failure-causation theme explores faults at company (NNPC and PPMC) level. Not surprising, issues such as poor safety culture and limited safety awareness came top of the list. These issues can be traced to lack of top management commitment as even the operator admits the inadequacy in their safety organisational structure. When asked about their organisational challenges, the responders noted that:

> *"Almost every aspect of implementing the Health Safety and Environmental Management System, there is a challenge for us….The (organisational) structure: there is also a problem there." (PPMC interviewee).*

> *"The major challenges we have is the structural position of the HSE department. If you look that the organisational structure of HSE department in Shell or other multinational oil and gas company, the position of the HSE department is a direct link to the CEO of such organisations. It is not the case in NNPC…" (NNPC interviewee).*

This lack of commitment gives rise to poor safety culture and bottlenecks the allocation of resource [66] which also limits the technical know-how of running, maintaining and optimising the integrity of the pipelines. Evidently, NNPC and PPMC are not capable of owning and operating such SCPA. The last theme identified issues associated with operational and technical (work) levels and the pipeline operating environment. The pipeline operator (PPMC) lamented that its ROW maintenance staff are stressed and sometimes inexperienced. This makes it practically impossible to effectively patrol the ROW. Indeed, an organisation wishing to operate a SCPA can identify and mitigate these issues through an in-depth organisational capability assessment during the project conceptualisation stage.

"Go and check…is there any part of the world where you have over 5000 kilometres of pipelines and the number of people maintaining it is less than 100? Will they be able to go round and ensure that it is safe? There are even no funds to do the job." (PPMC interviewee).

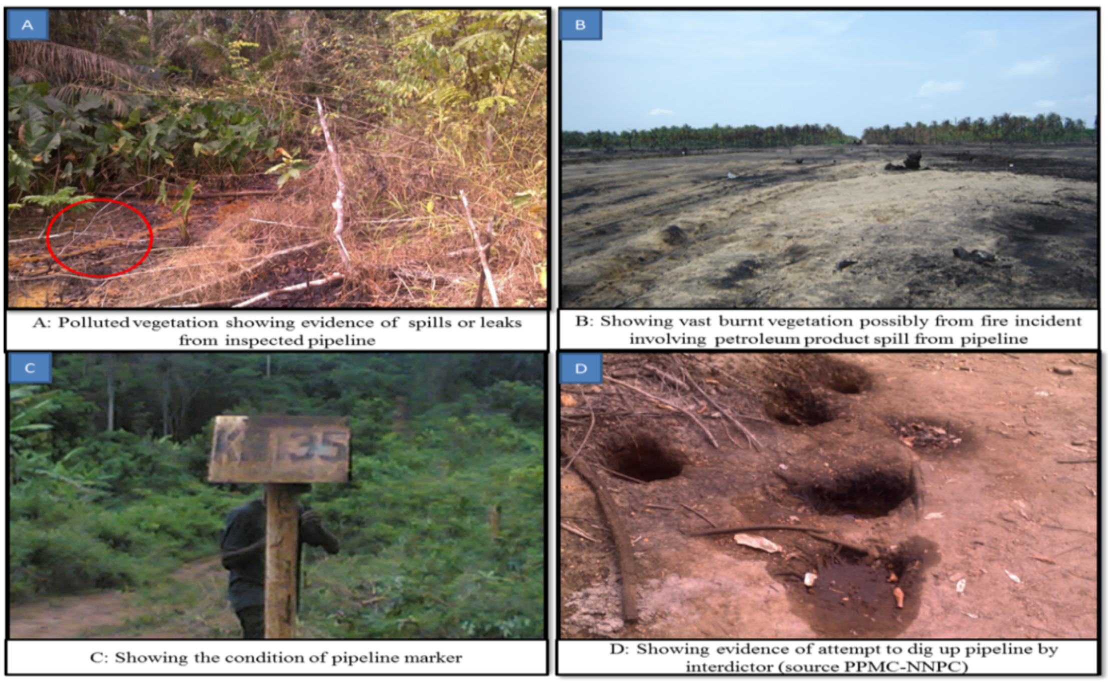
The condition of the ROW is an important factor in understanding the degree of control the operator has in maintaining good industry practice and avoiding third party interference. ROW condition also influences incident impact on safety and environment based on proximity of receptors and accessibility for emergency response. In

Table 7, the key findings from the risk-based field observation conducted are summarised. From the inspection result, there is an obvious case of inadequate maintenance of the pipeline ROW. There are issues with encroachment of buildings. This increases the vulnerability of the pipeline to threats from third party activities and the consequences of failure as close proximity to pipeline increase the values of IR of the pipelines. Incident response can also be constrained by the proximity of buildings to ROW. The operator also claimed that it has become difficult to maintain the ROW (as cited below) due to the hostile attitude of host communities which has earlier been linked to lack of community engagement, a direct consequence of not conducting ESIA during project conceptualisation.

"Sometime when we hear about a break in our line, we get there, and the community will not allow us access the line. In some cases, they tell us to pay access fee, or to pay for compensation before fixing it". (PPMC interviewee).

Table 7: Findings from risk based inspection of ROW

ROW Condition	Description
Evidence of spills or discharge from pipeline	No active leaks or spills were detected. However, there were about 3 spotted evidence of spills, possibly from past incidents as shown in Figure 8A. There are also vast areas of oil films on both land and water around Ijegun area. The researcher found no evidence of clean-up activities within that location. In one location, close to Onilu Village, the vegetation is vastly burnt (see Figure 8B), possibly from a fire incident from spilled product. In Dec 2012, NNPC reported a fire within the Mosimi region. Onilu village is located within this region.
Forest encroachment on ROW	While some sections of the ROW along country-sides remain clear, some sections alone Amuwo Odofin and Ije Ododo area are completely overgrown by grasses and trees. There are evidence of farming activities, timbering and excavation alone the ROW in Ije Ododo area. A section of the pipeline ROW is now used as access road, popularly called “the pipeline road” by the locals
Encroachment of development	A more disturbing aspect of the ROW condition is the indiscriminate and uncontrolled developments of buildings and roads on the ROW especially within Amuwo Odofin area, Ije-Ododo area, and Ijegu area. In some cases, shops and residential buildings are located less than a metre away from the pipeline markers which suggested that such developments are sadly located on the ROW.
Blasting within distance that could impact the pipeline	No evidence of blasting or mining activities were detected
Damage to pipeline makers and signage	At various locations around the Ijegu area, pipeline markers have been found either damaged, blocked with overgrown vegetation or worn-out and unreadable (see Figure 8C)
Exposure of pipeline	While no evidence of pipeline exposure was found, there is evidence of deliberate attempts to dig up and expose pipeline for pilferage (see Figure 8D).
Active act of interdiction	The researcher did not experience any active act of interdiction within the inspected area. However, evidence in the form of pictures were given by the ROW department of PPMC.



A: Polluted vegetation showing evidence of spills or leaks from inspected pipeline

B: Showing vast burnt vegetation possibly from fire incident involving petroleum product spill from pipeline

C: Showing the condition of pipeline marker

D: Showing evidence of attempt to dig up pipeline by interdictor (source PPMC-NNPC)

Figure 8: Condition of sampled pipeline ROW

Lack of contextual pipeline regulatory code of practice affects the regulators ability to deploy and adhere to best practice operational and technical procedures. Moreover, poor technical capabilities generated as a result of the absence of a robust national standard meant that PPMC is unable to employ and retain staff with the required experience and skills.

In all, the influence of these identified failure causal factors gives rise to multiple failure causation. Active events such as interdiction on the pipeline although seen from the risk assessment result as the immediate cause of most failures are in fact a manifestation of interactions between faults within the sociotechnical operating structure of the pipeline, arguably, caused by poor project conceptualisation. Faults such as organisational and regulatory issues, lack of human and technical capabilities, limited safety commitment, poor safety culture, obsolete technologies, and inappropriate ROW acquisition and maintenance have rendered failure prevention barriers ineffective within the entire pipeline systems in three ways. First is the lack of barriers or existence of weak barriers such that preventive measures are either missing or ineffective. These missing or weakened barriers are both in the form of physical and procedural conditions. For example, from the physical perspective, poor pipeline routing and the encroachment of buildings into the ROW has weakened the "barrier" in the form of buffer zone which is required to restrict the activities of third parties by reducing their proximity to the pipeline. Second, the faults identified also limit the availability of resources so that necessary means to counter or neutralise pipeline failure is constrained.

Lastly, precarious conditions are also generated from the identified faults such that small active failure results in high consequence accident due to inappropriate response strategies or inadequate risk communication. For instance, some people within the host communities are not aware that petroleum products have flash points – defined as the lowest temperature at which a liquid (usually a petroleum product) will form a vapour in the air near its surface that will "flash," or briefly ignite, on exposure to an open flame [4]. As cited by an interviewee, these people engage in risky activities such as scooping petroleum products from failed pipelines or even coming out to look as products leaks out.

"Our people don't know the danger of this fuel. They think fuel is just like the water they fetch from the river or their wells. They hear of fuel, fuel, fuel, fuel, so when a leak occurred, they logically went to take a look at it." (Community leader).

People's understanding of pipeline risk needs to be assessed at the pre-front end engineering design (pre-FEED) stage of project conceptualisation to draw on the knowledge of the local stakeholders through a facilitated process. This will provide a useful understanding of the local population and their understanding of the risk associated with pipelines.

6 Empirical and managerial implication

The risk associated with a SCPA was assessed and the sociotechnical deficiencies of the pipeline analysed. Some key considerations for project conceptualisation were identified as the lessons to be learned when conceptualising new similar assets. The assessment showed that third party interference is the major cause of failure to the pipelines, accounting for over 96 per cent of pipeline failure. These failures were found to be attributed to lack of community engagement during and after the conceptualisation stage of the asset. The pipelines recorded a failure frequency of 0.35 per km-year which have been found to be well above failure frequencies reported on other pipeline systems around the world (e.g., the UK and USA). Consequently, the ignition frequencies, fatality, and product losses from the Nigerian pipelines were found to be high. This made the values of individual risk for the pipelines to fall outside tolerable limits. Fatalities from pipeline failures range from 0.04 to 0.38 per km-yr, depending on the region of operations in Nigeria. As established in this study, on average, the operator of the pipeline system loses about $US100 million/year due to these failures. These findings reveal a strong link between the robustness of project conceptualisation, particularly of the need to have stakeholder buy-in and asset integrity.

One of the more significant findings to emerge from this study, revealed the need to assess organisational capabilities with respect to owning, operating and regulating SCPA. It is evident that there needs to be an alignment of capabilities from both the regulator and operator to ensure robust accident prevention barriers are in place. The literature reviewed [66], [67], [71] confirmed that the operator and regulator need to understand their commitment to ensuring consistent optimised asset integrity at regulatory, organisational, management and work levels. Without this commitment, the deficiencies identified in the asset case example used in this study, which includes regulatory capture, poor management commitment on the side of the operator, poor safety culture of the operator, limited technical knowhow and limited safety commitment, will weaken the accident prevention barriers.

The findings from this study further underline valuable lessons to learn for project conceptualisation of a SCPA with vital generalisability which practitioners can draw from to comprehend the effects of poor project conceptualisation on the integrity and safety performance of systems in other safety critical industries. Moreover, given that failure due to poor conceptualisation of sociotechnical systems is even more critical when operating in environments with poor institutional control, the issues highlighted in this study is particularly relevant for the management of safety critical assets in these environments.

7 Theoretical contribution

The findings of this study reinforced the theoretical link between project conceptualisation and asset integrity, and recognised the need to have a robust project conceptualisation process to ensure the integrity of a petroleum asset is maintained across its lifecycle. The research drew on the risk-based performance of an existing pipeline to identify how new assets can learn from the integrity deficiencies of the case pipeline, hence, expanding the theoretical conception of learning in project conceptualisation beyond project management processes to lessons from safety and integrity performance of similar asset. The core of activities for project conceptualisation should, therefore, go beyond understanding the most effective and efficient way of delivering the project, and address how the delivered project will perform throughout its lifecycle. We have demonstrated how this can be achieved in *Figure 9* below. First is the need to adopt a dynamic view of project conceptualisation [38] and then allow for knowledge creation [35], [48] through performance-based learning of issues affecting the safety and integrity performance of similar assets as identified using the case example of a challenging pipeline asset in Nigeria.

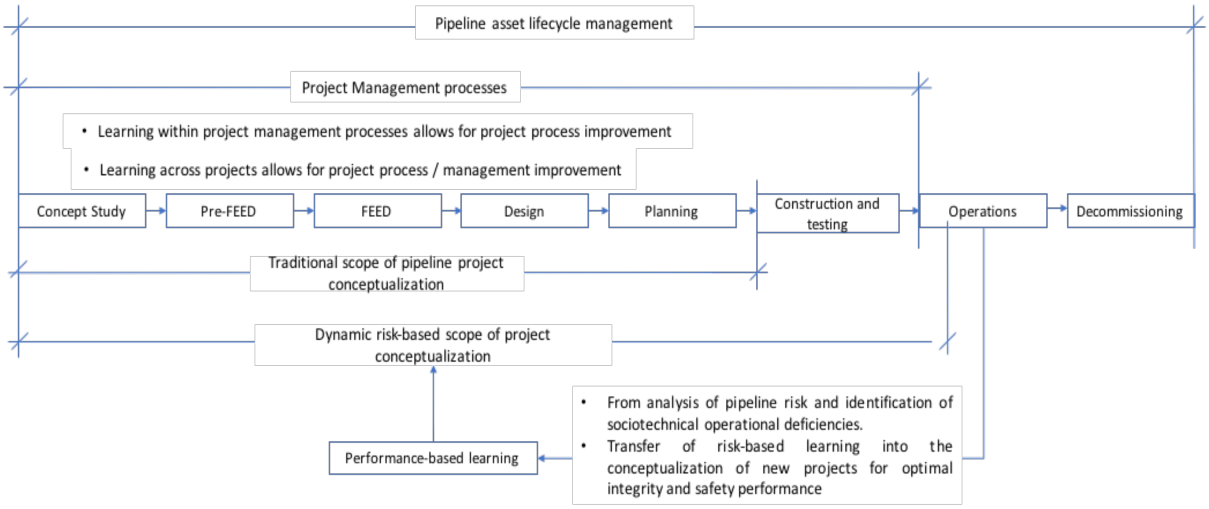


Figure 9. Performance-based project conceptualisation learning framework for SCPA

Indeed, the result of risk assessment of the case pipeline demonstrates some of the theoretical dimensions of learning that should be conceptualised when conceptualising the "value" (asset integrity) whilst establishing the "purpose" of a new project. Performance-based learning from stakeholder and community understanding of risks, organisational and regulatory capabilities, and safety consequences of failures should form part of the learning reflective cycle in order to ensure that operation concept design of new assets adequately reflect how the asset will be used before the design and construction stage is delivered. This will allow proactive risk management technical specifications to be established. Once this is established, attention can turn to design of the asset itself and how to construct the asset. Notably, also, this should not be seen as a one-off process, but executed in a loop [37] given the imperfect understanding of stakeholder requirements at this point.

As the project moves to the design stage, design criteria need to be formulated based on acceptability of risk obtained from knowledge of performance of similar assets. For instance, as shown in this study, the acceptable limit for IR of the case pipeline stands at 40 metres if the risk is ALARP due to the close proximity of buildings and public infrastructure. New and similar assets, faced with similar constraint can, therefore, learn by integrating the need for relocating risk receptors within their IR risk contours or developing mitigation strategies that reduces the probability of failure within its design criteria. Moreover, given the case example illustrates that a system's operational capabilities are a function of its safety and integrity performance, the design criteria of such system, when conceptualised, needs to look closely at the technical knowhow of both the operator and regulators. Indeed, at this early project stage, design conceptions may be constraint by lack of clarity on the integrity objectives of the asset, hence the need to look beyond the project itself to integrate lessons from similar sociotechnical systems. Because of the scope of the dynamic view on project conceptualisation, the aforementioned model of loop execution will allow the redefinition of safety and integrity performance even after construction and testing. Consequently, as the asset undergoes operational integration across Rasmussen's operating sociotechnical levels, industry lessons can continuously be integrated vis-à-vis the analysis of design and performance of the assets itself.

8 Conclusion

This study presented a risk-based assessment of a case pipeline in Nigeria to identify the issues related to the risk and sociotechnical operational deficiencies of the pipelines, and how the conceptualisation of new SCPA projects can learn from these issues. To achieve this three research questions were set and addressed using explanatory case study method as follows:

RQ1: The failure frequencies of pipelines were found to be exponentially high (0.351 per km-yr). The results indicate that third party interference is the major cause of failure to the pipelines, accounting for over ninety-six per cent of pipeline failure. This was found to be attributed to poor asset integrity management capabilities and lack of community engagement during and after the conceptualisation stage of the asset. The findings further revealed a strong link between the significance of project conceptualisation, particularly of the need to have stakeholder buy-in to achieve asset integrity. The catastrophic nature of failures can be seen in the high frequencies of ignition and fatality. Ignition and fatality frequencies are high because of deficiencies in emergency response, weak leak detection and incident responds strategies, close proximity of buildings and people, and lack of risk communication all of which are strongly linked to weakness in the design and operation of the pipelines. This makes the value of IR intolerable. This finding accord with an observation made in the literature, which suggested that failure consequences can be reduced via the design of emergency systems and ROW pivoted on the concerns of risk receptors [29], [69], [71] during project conceptualisation.

RQ2: The case pipeline illustrates how deficiencies within sociotechnical context including regulatory capture, poor management commitment on the side of the operator, poor safety culture of the operator, limited technical knowhow and limited safety commitment hierarchically interact to weaken failure prevention barriers. This finding revealed the need for assessing organisational capabilities with respect to owning, operating and regulating SCPA during project conceptualisation.

RQ3: Managerial practice can learn from some of the key issues identified from the case pipelines whilst conceptualising SCPA projects by adopting a dynamic view of project conceptualisation and allowing for project knowledge creation through performance-based learning of issues affecting similar SCPA. We argued that this framework, though context specific, has general application to other safety critical industries, thereby, contributing to literature on sociotechnical asset integrity optimisation and project conceptualisation learning e.g. [1], [37], [56], [86].

Finally, two important limitations need to be considered. First is the need to identify that findings presented, although provided opportunity for practitioners to comprehend the effects of poor project conceptualisation is also likely to be affected by wider issues which may not be a direct link to the conceptualisation process of the asset. For instance, there are studies which highlighted the general poor safety culture of the Nigeria the petroleum industry [66]. Moreover, there is also documented evidence of pipeline sabotage related to the politics of petroleum resource in the Niger-Delta region of Nigeria [21]. Second is a limitation related to the comprehensiveness of data used. Obtaining comprehensive data was especially challenging for this study due to the secretive nature of the petroleum industry in Nigeria. For example, we experienced deliberate deletion of some key details from the pipeline failure reports due to confidentiality claims. This constrained further analysis, (i.e. it was not possible to ascertain the relationship between aging of the pipeline, failure frequency and project conceptualisation). The secretive nature of the Nigerian petroleum industry was also observed during the interview data collection stage of the research. Participants tended to 'play safe' while being interviewed. However, in general, the interviews provided valuable opportunities for the authors to gain first-hand knowledge of various elements of the research, without which the research would not have been successful.

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