ONSHORE PIPELINE RISK AND CONSEQUENCE ASSESSMENT

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ABSTRACT

The mode of transporting crude oil via pipelines was understood to have a potential for a very large volume of fluids to be released from the pipeline system. This incident will pose its small but finite risk to both population and environment along the route. This paper discusses the potential hazards usually encountered in the transporting crude oil using pipeline. The risk, consequence, and risk reducing measures are also presented. It is found that the pipeline mode of transporting crude is safe and reliable. Fatalities per ton-kilometer transported are much lower than for any other means of transportation.

1.0 INTRODUCTION

Risk is the potential for realisation of unwanted, negative consequences of an event or combination of events to individual groups of people or to physical and biological systems. Generally, risk is considered as a monolithic concept which considers only the probability and consequences of events.

The intent of this paper is to show that the risk associated with the transportation of crude oil is ideal complex and requires a coherent, well-structured and acceptable methodology to determine acceptable levels of risk for society and the environment to undertake.

Pipeline is a safe and reliable mode of transportation. Fatalities per ton kilometer transported are much lower than for any other means or transportation. The amount of oil spilled per unit transported is also very low. Pipelines in general therefore represent a small risk to human life and to environment [1]. However, pipelines represent large capital cost, and any pipeline failure has significant economic impact because of the cost of repair ant the lost of transportation capacity.

2.0 ROUTE OF TRANSPORTATION

The route that the pipeline would take has to be carefully chosen. The size of pipelines hence the capacity of transportation as well as the existence of other mode of transportation is evaluated. The pipeline has to be built and laid in accordance with standard industry practice. Major populated areas should be avoided if possible otherwise due safety measures, e.g. right distance from housing estate must be observed. The conservation of natural reserves must also be taken into consideration when planning the route.

3.0 RISK ANALYSIS

The term risk assessment is the quantitative evaluation of the likelihood of undesired events and the likelihood of harm and damage being caused, together with the value judgements made concerning the significance of the results. For each event that occurs, there are a variety of consequences that can occur. For example, for the event involving the occurrence of crude oil spillage from pipeline, the consequence range from human injury, effect on flora-fauna to fire.

The consequences of the hazard are usually determined in terms of:

- Potential harm to human
- Damage to property

By combining the level of hazard with the frequency of occurrence, the risk to personnel, property and environment can be predicted. Event trees can be used to evaluate the probability of each out come and hence the overall risks, refer Figure 1. While fault tree can be used to identify the sequence of incident leading to the major event as shown in Figure 2.

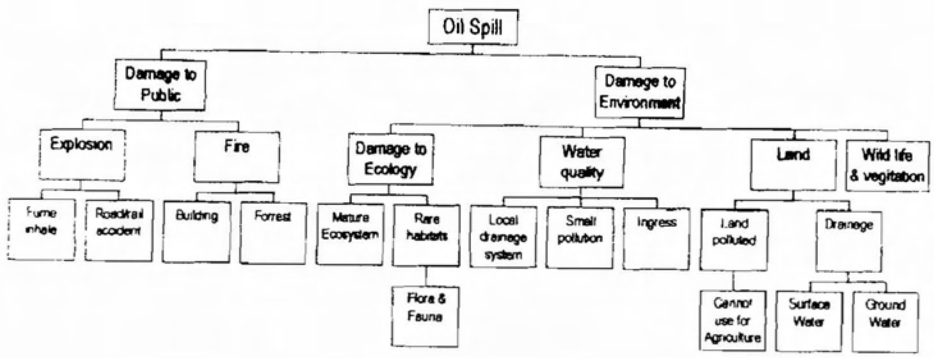


Fig. 1 Consequences Of Oil Spill

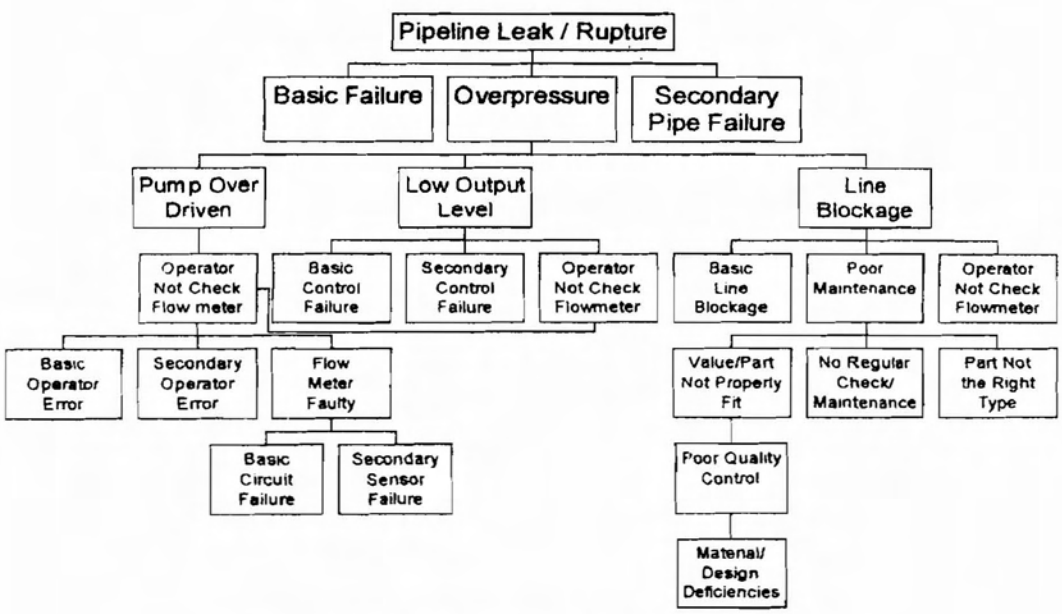


Fig. 2 Fault Tree For Pipeline Rupture / Leakage

In the risk analysis of pipeline system, there are four stages as follow [3];

i. The identification of the potential hazards

ii. The likely frequency of occurrence of those hazards

iii. The consequences of these hazards

iv. The assessment of the risks

3.1 Identification of Potential Hazards

The identification of the potential hazards may be entirely straight forward, however, in the case of onshore pipeline it may requires rigorous, systematic analysis due to its vast area coverage. Here, hazards are identified by three separate methods;

First : A checklist, which simply categories the process into small readily identifiable units, and then considers the potential hazards of each unit.

Second: A qualitative review is carried out. This review aims to use experience of other similar systems and practical experience of the operation of such systems to pick out the likely hazards.

Third : A coarse hazard and operability study would be carried out. This type of study is much smaller version of the full HAZOP technique. Its purpose is to look at failures in the systems be they leaks, control failures and how they might arise, then to look at the response of the system to the failures.

Potential hazards that might occur on the pipeline can be grouped as follows;

i. Natural Hazards

a. External corrosion

b. Thermal effect

c. Abrasion and chafing

d. Erosion

e. Earthquake

f. Landslide

ii. Manmade Hazards

a. Operator error
b. Equipment inadequacies
c. Equipment malfunction
d. Internal corrosion
e. Fire and explosion
f. Undetected damage during construction
g. Material deficiencies
h. Poor quality control
i. Design deficiencies

The severity and the likelihood of these hazards are summarised in Table 1.

Table 1 Summary of Severity and Likelihood of Potential Hazards

		Damage Potential			Probability Of Occurrence		
	Potential Hazards	Extensive	Moderate	Minor	Most Probable	Expected Occurrence	Least Probable
Natural Hazards	External Corrosion	X			X		
	Thermal Effect		X			X	
	Abrasion and Chafing			X			X
	Erosion			X		X	
	Earthquake	X					X
	Landwash/Landslide	X					X
Manmade Hazards	Operator Error		X			X	
	Internal Corrosion	X				X	
	Equipment Inadequacies	X				X	
	Equipment Malfunction	X				X	
	Fire and Explosion / Pipe Rupture	X					X
	Undetected Damage During Construction		X			X	
	Material Deficiencies		X				X
	Design Deficiencies			X			X
	Poor Quality Control		X				X

3.2 The Likely Frequency of Occurrence

An important part of a risk analysis is the need to place the hazards from one part of the installation in perspective with the other hazards to which the installation may be subjected. In order to predict the frequency of occurrence, as well as assessing its consequences one should consider every issue related to pipelines from construction, commission to operation. The relative importance is use as a basis for decisions on where best to expend effort in risk reduction. The only way to be able to make such distinctions is based on their expected frequency of occurrence. This in turn must come from the historical accident record.

3.2.1 Relative frequency of occurrence

Check with historical accident data, e.g. Figure 3 and Table 2 [2]. From Figure 3, it can be deduced that the overall failure rate of these pipelines during the fifteen years period shows a marginally increasing trend. It is expected that a leakage incident likely to occur once for every 1×10^{13} tonne-km of product transported. Table 2 shows current failure frequencies predicted for large crude oil carrying transmission pipelines operating in Western Europe [2].

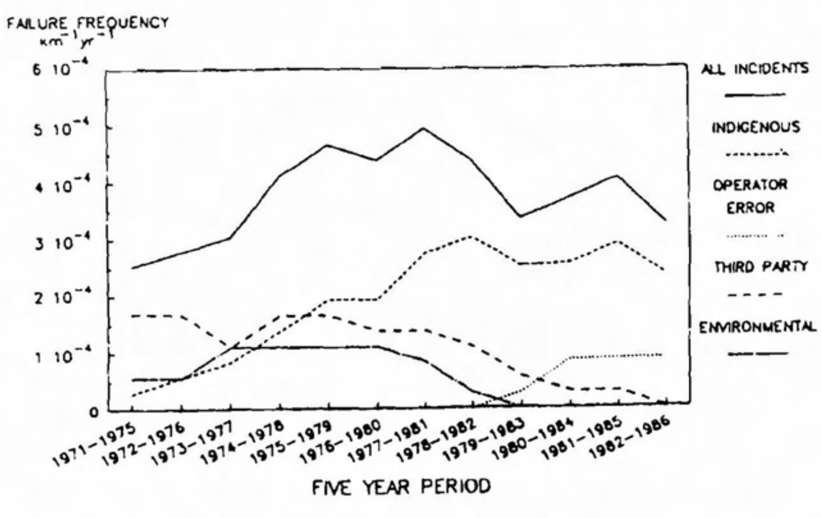


Fig. 3 Failure Frequency Trend For European Crude Oil

3.2.2 The risk in perspective – The absolute frequency.

The estimated mean failure rate of significant leakage from pipeline.

Table 2. Predicted Frequency of Failure [2]

Failure Cause	Predicted Frequency $10^{-5}\ km^{-1}\ yr^{-1}$
Indigenous-mechanical	14.7
Indigenous-corrosion	8.8
Operator error	8.8
Third party activities	2.0
Environmental causes	2.0

3.3 The Consequences of Leakage

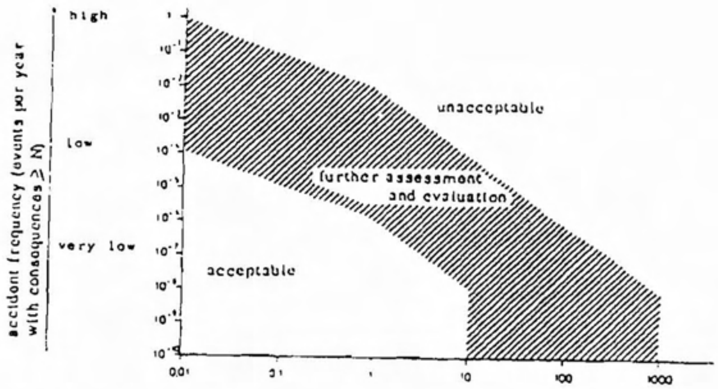
With high-pressure pipeline, crack of even small dimensions may results in sizeable release. Section 7 in this paper discusses further this issue.

3.4 Assessment of Risk

Having examined the type and origin of the hazards, the expected frequency compare against other hazards and the consequences of the hazards, the final steps are to summarise the risk picture and to assess the significant of the results.

There are many different ways of presenting and assessing the risk. These include;

- ranking
- criteria for risk to risk to individual employees
- criteria for society or public risk
- criteria for total pipeline risk
- criteria for preventive safety measures against each hazards, (e.g. API RP14C)



qualitative scale for environmental damage	slight local environmental damage	considerable local environmental damage	serious environmental damage	serious local contamination and pollution	prolonged disturbance of the environment, large-scale damage	environmental disaster in large area which will be unfit for habitation for a long time
Examples	damage to vegetation to pesticides	oil gusher at Schoonebeek (the Neth.)	fish killed on a massive scale due to discharge of toxic substances	oil disaster in Biesbosch (the Neth.)	Seveso (Italy, 1976)	major disaster with a nuclear power station

Fig. 4. Example of Environmental Risk Criteria [4]

Figure 4 shows an example of environmental risk criteria [4]. Those potential hazards identified in Section 3.1 can further be categorised as follows;

i. Minor hazards
   a. small volume spillage
   b. erosion
   c. abrasion and chafing
   d. thermal effects

ii. Serious hazards
   a. operator error
   b. external corrosion
   c. equipment malfunction
   d. undetected damage during construction

e. material deficiencies
f. design deficiencies
g. medium volume spillage
h. third party's impact on pipeline

iii. Major hazards
a. large volume spillage
b. fire and explosion
c. pipeline rupture
d. subsidence
e. landwash/landslide

iv. Catastrophic
a. Landslide
b. Earthquake
c. very large spillage

3.4.1 Potential accident in terms of location and circumstances.

Small volume release in remote areas poses a minor hazard to the environment and human. Affected areas could easily be cleaned. Erosion as well as abrasion and chafing poses a minor hazards and regular inspection are required to ensure that the rate is within tolerable limit.

3.4.2 Quantification

Releases can be due to several causes as listed in Section 4. Following that, shut down is expected on average of 60 minutes for a leak. Great amount of crude losses (>50 tonnes) is anticipated during depressurisation. It is also anticipated that without any artificial depressurisation by pumping one third to one half of the contents of the pipeline stretch so damage to be lost. To minimise this, several shutdown systems would be placed along the route depending on the length (and other parameters) of the pipeline. Frequencies of release referring to Table 2, giving the worst case due to mechanical failure with predicted values of 14.7×10^{-5} per km-yr. This is equal to 0.027 times per year; i.e. once in every 37 years.

4.0 FAILURE TRENDS

Each year there are hundreds of pipeline failures, resulting in pollution, loss in transportation capacity and costly repair expenses. Most of the failures occur on onshore pipeline because they cover a much greater distance.

The incident related to crude transportation via pipeline can be divided into five groups as the following, [2,5];

1. Indigenous-mechanical
   Those incidents likely to have been cause by growth of pre-commissioning defects in the pipe material, and which may have been introduced during fabrication or construction. The category could include for example, welding defects, lamination, stress-corrosion cracking, etc.
2. Indigenous-corrosion
   Those indents attributed directly to corrosion and resulting from loss of material since commissioning.
3. Operator error
   Those incidents occurring through poor operation, maintenance, etc.
4. Third party
   Those incidents caused by third parties, for example following impact by excavators, augers, etc.
5. Environmental
   Those incidents cause by subsidence, land washout due to heavy rain, etc.

5.0 FAILURE RATE

Figure 3 shows the trend of pipeline failure frequency in Western Europe [2], operating in the mid 1970s from which one could made a valid prediction of indigenous defects and their related rate of failures.

Failure frequencies predicted for large crude-oil carrying transmission pipeline are shown in Table 2 [2]. These values are estimated from the final trend period shown in Figure 3.

6.0 OIL SPILLS

The mode of transporting crude via pipeline was understood to have a potential for a very large volume of fluid to be released from the pipeline system. For each spillage scenario, the relative likelihood of different consequences has been estimated and these are shown on the event tree in Figure 5. The range of the harmful effects from each of these consequences are then calculated taking into account any topological, weather or mitigation features that are relevant

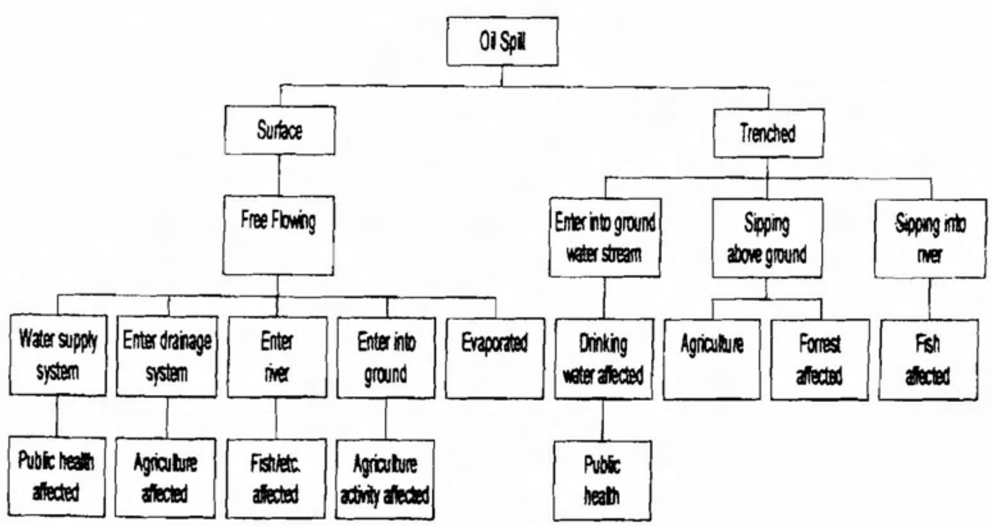


Fig. 5 Event Tree For Oil Spill

There are two practical approaches to the estimation of release quantity given a pipeline incident; firstly a historic approach, considering the quantities which have been released in the past, and secondly a deterministic approach, incorporating modelling of the outflow rate and duration, given a particular hole size [2]. Frequency estimation is based on Concowe database, allows the former approach to be adopted, as the quantity of fluid release is reported for each release incident. The contribution of the various failure modes to the total commulative probability versus spill volume relationship is presented in Figure 6. Table 3 shows the relationship between spill volume distribution and failure cause. From Figure 7, one can predict that the most likely failure mode to result in large spillage (rupture type) events is that classed as indigenous-mechanical.

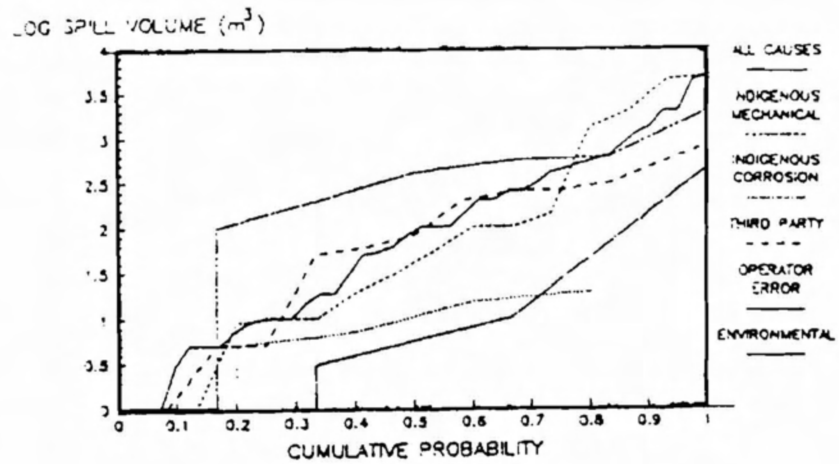


Fig. 6 Spill Volume Versus Cumulative Probability For European Crude Oil Pipeline ≥ 16in Diameter – CONCAWE Data [2]

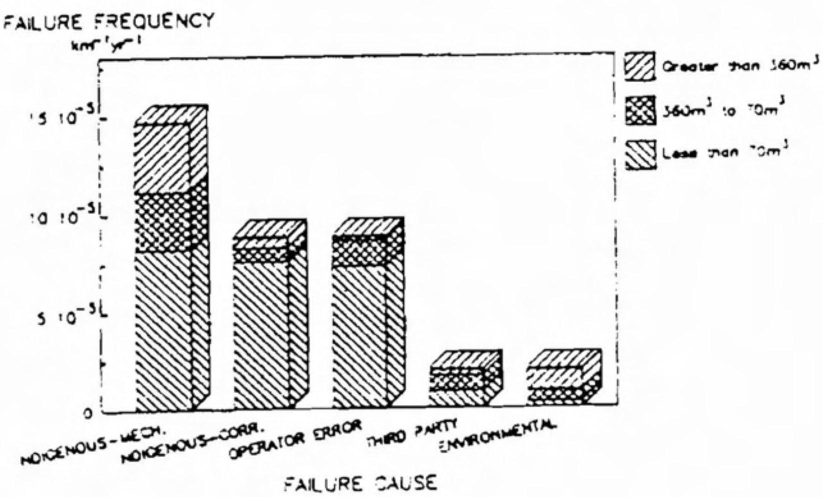


Fig. 7 Spill Volume Frequency By Failure Causes For European Crude Oil Pipeline ≥ 16in Diameter – CONCAWE Data [2]

7.0 CONSEQUENCES ANALYSIS

Each consequence has its own description and may result from more than one event. For each event with multiple consequences, there is a probability associated with the occurrence of a specific consequence based upon the condition that the event occurs. Thus, the probability of a consequence occurring depends on the probability of an event occurring, the probability of a specific consequence occurring if the event takes place, and the aggregation of these compound probabilities from all events that lead to the specific consequence.

Table 3 The Relationship Between Spill Volume Distribution And Failure Cause For European Crude Oil Transmission Pipelines [2]

Failure Cause	Relative Probability Of Occurrence		
	<70 m3	70 to 360 m3	>360 m3
Third party	0.45	0.41	0.14
Indigenous-mechanical	0.56	0.20	0.24
Indigenous-corrosion	0.86	0.08	0.06
Operator error	0.83	0.15	0.02
Environmental	0.17	0.30	0.53
This analysis shows that the estimated distribution of spill volume is dependent to a high degree on the cause of failure			

Consequence analysis is the determination of the possible outcome of the hazard for non-hydrocarbon events, this may include;

- Structure failure
- Impact damage

For hydrocarbon events, this may include;

- Discharge of (pressurised) fluids
- Spread of liquids

Figure 8 shows the possible consequences of pipeline operation on environment, Figure 9 shows the possible consequences of pipeline construction.

8.0 RISK REDUCING MEASURE

At this stage, the risks analysis of pipeline is complete, the potential hazards have been identified, their likelihood and consequences examined.

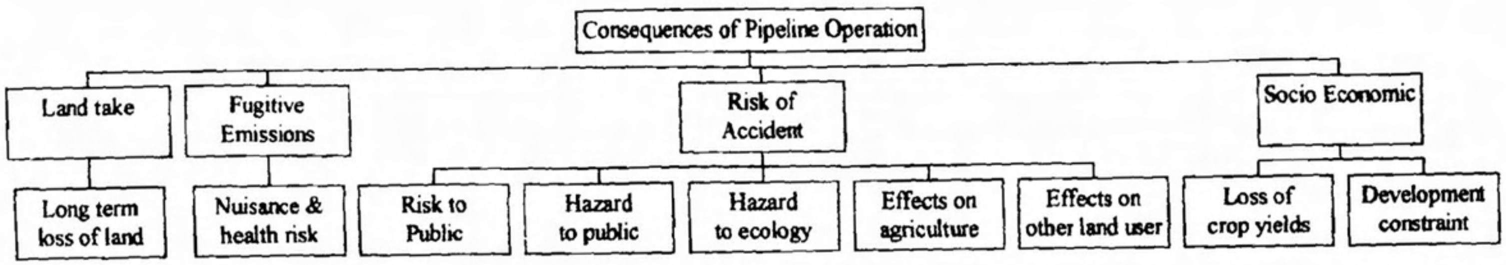


Fig. 8. Consequences of Onshore Pipeline Operation

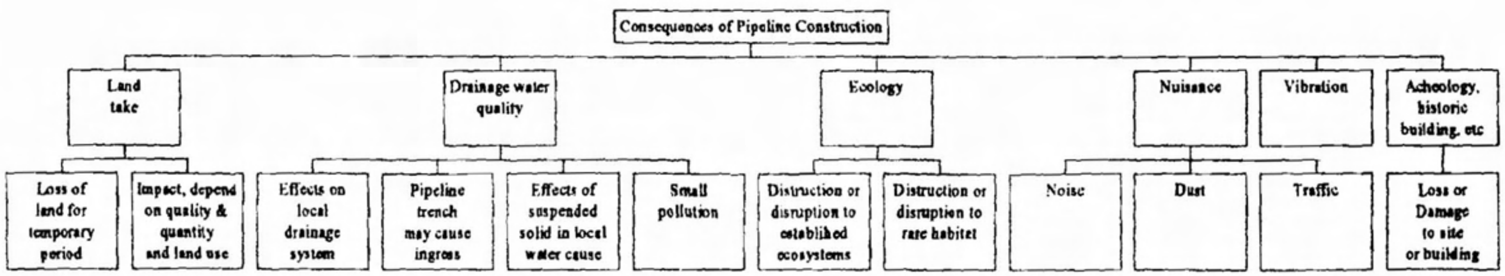


Fig. 9. Consequences of Onshore Pipeline Construction

8.1 Ways of Minimising the Probability of Leakage

Minimising the probability of damage to pipeline and the associated systems can be achieved in two ways;

- Corrosion protection
- Bury the pipeline

8.1.1 Corrosion protection

An effective corrosion control programs is essential if the operator is to avoid the high cost of leak repair, pipeline replacement, clean-up, production shut down, damage equipment, etc, and the attendant risk of continuing operation in a partially corroded situation beyond safe limit.

The methods of controlling external corrosion are generally used, namely protective coatings and or cathodic protection [3].

8.1.2 Bury the pipeline

Burying the pipeline will significantly reduce the risk of damage due to external elements. However, proper and correct preparation must be observed to support the pipeline at suitable location and interval.

8.2 Ways of Minimising the Consequences of Leakage

Emergency shut down operation (ESD) is incorporated in the pipeline system as discussed in Section 4. There may be several shutdown systems required for the pipeline between the start to the end of the transportation line.

9.0 CONCLUDING REMARKS

1. Transportation of hydrocarbon by what ever means, will pose its own small but finite risk to both population and environment along the route and also risk of potentially major economic loss for the operator involved.

1. Transportation of hydrocarbon by what ever means, will pose its own small but finite risk to both population and environment along the route and also risk of potentially major economic loss for the operator involved.
2. It can be concluded that the risk of catastrophic and major events as mentioned in Section 4 to environment and peoples are very small.
3. The worse case of failure frequencies is due to mechanical failure with predicted occurrence of once in every 37 years.
4. Transporting crude oil via pipeline is safe and reliable. Fatalities per ton-kilometer transported are much lower than for any other means of transportation.

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