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REHABILITATION OPTIONS FOR INTERNALLY CORRODED OIL PIPELINES IN A HIGHLY ENVIRONMENTALLY SENSITIVE AREA

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1 ABSTRACT

This paper describes a recent project where the interplay of issues arising from both environmental and engineering factors were examined to reveal the options available to remedy internal corrosion problems within an infield flowlines system. Environmental issues were notable due to their number, variety and importance. The evolution of an engineering solution was prolonged by consideration of options involving rehabilitation as well as new-build. The project revealed little overall differentiation between these 'solution families' when arrayed against the large control matrix of environmental and license to operate factors. The use and value of a corporate project development methodology is described when developing a solution to a problem with multiple redundancies.

2 INTRODUCTION

Penspen have recently worked within a team from BP on a project to develop suitable engineering options to problems derived from internal corrosion within infield pipelines. The internal corrosion has been investigated in depth in previous research and the rehabilitation methods commented upon. [(1), (2), (3)] Further new information and events have crystalised the need to obtain a safe, environmentally friendly long-term solution to the pipelines suffering from internal corrosion and avoid the intermittent cycle of investigation, excavation, repair and reinstatement that pipeline rehabilitation using epoxy collars has tended to cause until now.

In commencing a project that aims to produce an engineering solution effective for the remainder of the oilfield life, a contemporary project such as this will of necessity consider and incorporate all relevant factors and almost as a consequence have to review as many possible engineering solutions as appear potentially feasible as time permits. This can give rise to the possibility of a modern project dilemma 'multi-criteria immobility'. This self-coined term describes the malaise whereby the multitude of factors impinging upon a project give birth to a wide number of possible engineering solutions To evaluate all options in the required detail against the multiplicity of issues that differently affect each option within a finite project period is an increasing problem of conceptual study work. The danger of not examining an option in sufficient detail is self evident and includes:

- Option adoption with issues that later manifest at critical moments during detailed design and/or construction.

- Option preference over safer, more traditional options for reasons which later turn out to be less clear-cut.

- Failure to consider issues which later on 'road-block' the project.

The necessity and need, therefore, for a modern project evaluation framework to guide, assist, adjudicate and decide at appropriate moments in the project gestation is critical when facing such a multi criteria project.

This paper incorporates some discussion on the project development methodology employed by BP and its successful use and application to the project subject of this paper.

The recommended solution to the problem of internal corrosion in the infield flowlines gradually manifested as rehabilitation using close-fit lining. Although such an option might from an *a priori* review of the problem and factors have seemed contiguous with the framing of the question, this paper records how in the event when considering all factors it was selected by the narrowest of margins.

3 BACKGROUND TO THE PROJECT

3.1 History of Site

3.1.1 Site Location

The site of the project was BP's Wytch Farm located in Dorset, south-west England, 90km from Southampton. Wytch Farm is the largest onshore oilfield in Western Europe containing 460 million barrels of light crude. [(4)] Small isolated discoveries of oil had been made in the environs during the 1950's after which larger reserves were proven. A succession of onshore wells have been drilled since the mid 1980's and they have been interlinked by a network of infield flowlines. The production wells, though onshore have, through the development of directional drilling techniques allowed exploitation of resources up to 11km remote from wellsites.

3.1.2 Infield Flowlines System

These carry crude production, water injection, produced water and other products. The flow from the oilfield in the production lines is three-phase (oil, gas and water). Oilfield voidage is filled by produced/seawater injection. As the field has matured and is on the slope of a twenty-year taildown the quantity of water injection is rising steadily.

The infield flowline system conveys the crude production to a process centre known as the Gathering Station. This facility undertakes the following principal functions:

Oil Processing –	Stabilisation of crude oil, cooling, metering and pumping via export pipeline
Gas Processing –	Cooling, dehydration, fractionation and processing prior to export of sales gas and gas liquids
Process Water Systems –	Filtering, chemical addition and combination with seawater prior to pumping to wellhead

Figure 1 illustrates the relative positions of wellsites designated A, D etc. and the Gathering Station. The overall distances are not large with the site F to Gathering Station being 4.5km approximately.

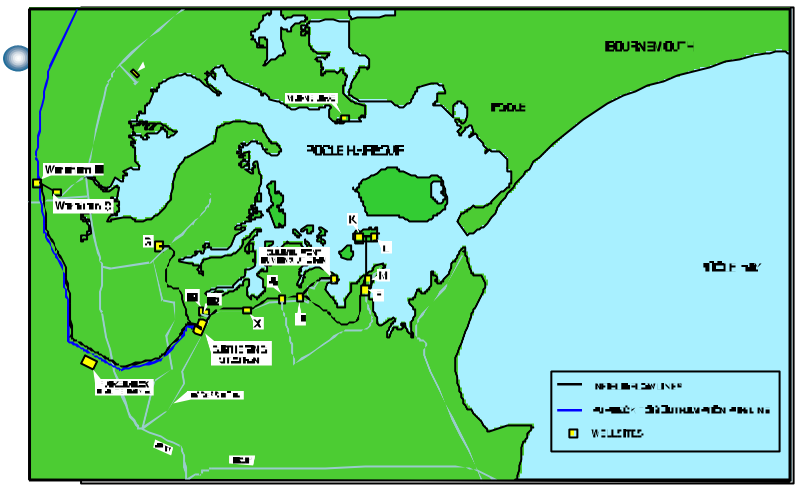

Figure 1: Wytch Farm Oilfield Locations

3.1.3 Infield flowline Design and Construction

3.1.3.1 Design

Table 1 provides general information on the main design elements of the Infield Flowlines.

	Crude Production & Test Pipelines	Produced Water & Seawater Injection Pipelines
Main Design Code	ANSI/ASME B31.4 Liquid Petroleum Transportation Piping Systems	
Linepipe Specification	API 5L and as modified by BP Engineering Standards	
Pipeline Diameter Range	6-12"	6-10"
Wall Thickness Range	0.280"- 0.330" (7.11mm - 8.38mm)	0.375"- 0.562" (9.52mm – 14.27mm
Design Pressure (barg)	35	145.5
Design Temperature Range (°C)	-10<T 70	-5<T<100
Corrosion Allowance	Nil	Nil

Table 1: Infield Flowlines – Design Elements

3.1.3.2 Construction

The infield flowlines were constructed between 1987 – 1988 by three pipeline contractors.

Some specialist techniques were used in order to mitigate environmental issues such as pipeline fabrication onto a raft and sinking of this in position across the wetland area of Shotover Moor. This became significant during the later stages of this project when the presence of hot bends either side of the fabrication had to be taken into account in considering close-fit liner pit locations.

The infield flowlines were constructed predominantly in a common trench and right of way. The crossing from the mainland to Furzey Island was undertaken as a pipe bundle within a 26" diameter Horizontal Directional Drill (HDD) carrier pipe.

3.2 Environment and License to Operate (LTO) Factors

3.2.1 General

The oilfield location at Wytch Farm is significant in as much that it is overlain by:

- An Area of Outstanding Natural Beauty (AONB).
- Three (3) Sites of Scientific Special Interest (SSSIs).
- An internationally designated RAMSAR wetland habitat.
- Poole Harbour – the second largest natural harbour in the world and used by, amongst others, thousands of boating and water sports enthusiasts throughout the year.

- An area visited and used by a large transient population of holidaymakers who are attracted to the natural beauty and pleasant surroundings.

BP is justifiably proud that its presence and operations at Wytch Farm are ‘invisible’ to the general public and also take full cognisance of all environmental and third party requirements affecting the conduct of its work.

3.2.2 Environmental Considerations and Constraints

The existing pipelines are located within an AONB noted for its landscape, ecology and amenity value.

Sites of Special Scientific Interest (SSSI) are designated under the Wildlife and Countryside Act 1981 and amendments. They comprise a natural series of representative sites of biological, physiographic and geological interest. The intertidal fringes of Poole Harbour are additionally a further SSSI and also classified as wetland under the RAMSAR Convention on Wetlands of International Importance. RAMSAR sites comprise an international network of areas that regularly support 20,000 or more waterfowl, substantial groups of waterfowl or more than 1% of the population of the species of waterfowl. [(6)]

These protected areas coupled with their collective location within a tourist area with large seasonal influxes of visitors combine to constrain to a significant degree the acceptable design and construction of pipelines.

Examples of the constraints on pipeline design and construction operations include:

Work Area	Environmental Constraints
Select Diameter for Pipeline	• One larger pipeline preferred to multiple pipelines
Select Steel Grade and Chemistry	• Exotic steels will probably take longer to weld; longer construction period and probably more consequential damage
New Pipeline Construction Route	• Does route cross a SSSI, RAMSAR or other site? • If so what mitigation is proposed e.g. HDD • Implications for construction plant access and deliveries • Required working areas.
Rehabilitation Options	• How many pits/access points are required? • What size will they be and for how long will they be open? • What are the logistics of transporting, for example, the liner to site?

Table 2: Examples of Environmental Constraints

3.2.3 LTO considerations and constraints

The Production License for Wytch Farm was granted in 1972 for a period of 40 years. (4) Attached to the license were conditions supplemental to a strict consultation and control procedure to be followed for all ensuing work.

These consultations and the resulting controls on operations currently amount to c. 300 constraints in number when combined with those of environmental sources. The consultation process was initiated at the time of the original site development. However, a continuing dialogue has been maintained to ensure all views and requirements are taken into account when formulating proposals to deal with engineering issues, such as the subject of this paper.

The consultation bodies include the following: (4)

County Trusts for Nature Conservation	The Council for British Archaeology and Local Archaeology Groups
Electricity, Gas, Telecommunications Companies	The Council for the Protection of Rural England
English Heritage	The Country Landowners Association
English Nature	The Countryside Commission
Environment Agency	The Department of the Environment
Harbour Authorities	The Department of Trade and Industry
Local Amenity Groups	The Health and Safety Executive
Local Emergency Services	The Ministry of Agriculture, Fisheries and Food
Local Landowners and Residents	The Ministry of Defence
Local Members of Parliament	The National Farmers Union
Mineral Planning Authorities	The Ramblers Association
National Rivers Authority	The Royal Society for Protection of Birds
Parish and District Councils	Water Companies
The Civil Aviation Authority	

4 MANIFESTATION OF A PROBLEM

4.1 Discovery

After construction the infield flowline system was operated successfully and without incident until 1997.

In 1997 BP discovered, through internal pigging results, internal corrosion on two flowlines (10 and 12" diameter). These were believed to have been caused by CO_2 in the transported fluid (sweet corrosion). The severity of the corrosion was related to the flow conditions, with the incidence of corrosion pits being higher in areas of high flow rate. [(7)]

The corrosion defects were principally in the 5 to 7 o'clock position. The corrosion mechanism has been attributed to a combination of higher inorganic and lower bicarbonate levels than predicted in the produced water giving rise to a corrosion rate three times that originally estimated.

Corrosion in the lines was originally identified by internal inspection. However, this inspection did not identify problems at girth welds which was discovered following two failures. It seems that the internal inspection has been unable to identify small (10mm) diameter corrosion pits located on the pipeline girth welds. In addition, higher mean corrosion rates were identified at the pipeline girth welds, believed to be a result of localised turbulence. More accurate external inspection techniques including gamma radiography and ultrasonic inspection were applied to approximately 30% of the girth welds. This data was used to improve the interpretation of the original internal inspection data and catagorise all the girth welds by severity of corrosion.

A number of welds were identified as having more than 60% wall loss due to internal corrosion although this was confined to relatively small areas. However, the corrosion was predicted to continue albeit at a reduced level, with the possibility of defects growing through the pipe wall within a number of years. [(7)]

The discovery of internal corrosion led to several immediate implications:

- A need to formulate a long-term strategy to ensure the continued use of the pipelines for the remainder for the oilfield life.

- Urgent action to remedy the through wall defects and make these safe.

The advent of through wall defects also quite obviously had very serious implications with respect to the environmental and LTO constraints and continued production. As loss of containment would be an infringement of the LTO conditions, measures were introduced immediately to isolate the production pipelines affected by the defects and use alternative pipelines on a temporary basis.

4.2 Further Investigations and Initial Solution Attempts

The loss of the production flowlines prompted an urgent review of suitable systems of repair to the affected pipeline areas and those with a predicted wall thickness below calculated acceptance criteria.

Andrew Palmer & Associates (APA, now part of the Penspen Group) undertook several investigations into the cause, nature and resolution of the corrosion problems. [(1), (2), (3)] The initial attempts at a solution to the areas with unacceptable defects involved the use of propriety epoxy external collars. A programme of corrosion inhibition was also commenced by BP in order to minimise the internal corrosion rate.

4.3 Implications of Initial Solution Attempts

The start of inhibition within the crude production pipelines has limited wider implications for the environment and LTO issues and it was principally a fully self-contained 'solution'. However, the use of inhibition carried with it an associated commitment to absorbing the substantial operating cost it carried. It was also accepted that even with inhibition there was a probability that some corrosion would continue albeit at a greatly reduced rate.

The adoption of epoxy collar repairs to the pipelines had several environmental and LTO implications. Due to the number of repair sites a succession of excavations were required down the length of the pipelines. The reinstatement of such areas became increasingly problematic due to a combination of factors including the poor, low grade soil and from 2000-2001 the unfortunate occurrence in the United Kingdom (UK) of an outbreak of Foot and Mouth Disease (FMD). The latter event led to several excavation and reinstatement sites being left open awaiting an appropriate time for re-entry after access to farmland was prohibited to reduce FMD transmission.

4.4 Further through wall defects, April 2000

Just as progress with epoxy collar repairs had become held up due to FMD issues in early 2000, a through wall defect in the 10" crude production pipeline was detected. This resulted immediately in the shutting in of this pipeline and the diverting of production to the other two crude oil production pipelines.

This defect was ultimately dealt with by alternative means, not part of this paper's discussion. However, the occurrence invigorated the need to search for a suitable long term solution that would also alleviate the need for the numerous and disruptive incursions into land that the epoxy collar repairs had caused to date.

This situation was the prime mover behind the inception of the project.

5 EVOLUTION OF A PROJECT

5.1 Project Business Drivers

The business drivers for the project were as follows:

- A requirement to actively manage all corrosion issues associated with the flowlines.
- The requirement and need to inhibit the production pipelines.
- The need to pig the infield flowlines to monitor the state of internal corrosion and the associated costs in lost production, pigging operations etc.
- The request from consultation bodies for a ‘one-hit’ solution to the internal corrosion problems to avoid the future need for pipeline excavation.

5.2 Project Organisation

A core project team of BP and Penspen personnel was established with the principal members being:

- Design and Engineering – principally Penspen resources
- HSE – including LTO issues
- Planning – schedules and cost control
- Extended Team – operations, procurement, sub-surface etc.

This team called on other further resources as the project developed and as situations arose.

5.3 Project Vision and Mission Statements

To act as the twin focii for the project team. The following statements were formulated for the project.

Project Vision

Operation of the Wytch farm pipeline infrastructure until end of field life without integrity issues.

Project Mission

To deliver a well site to Gathering Station pipeline system with design life beyond 2020, which will not require excavation interventions and allow non-obtrusive integrity monitoring.

5.4 Initial Options

At the kick-off meeting for the project the participants at the meeting drawn from all the project stakeholder bodies produced during a 'brainstorm' session a suite of options and associated questions for the resolution of the internal corrosion problem. These included:

- *What is minimum number of lines that need replacing?*
- *Possibility to include multi-phase metering to negate use of oil test lines – could free them up for other duties.*
- *What production are we targeting?*
- *Use insert liners.*
- *Need to discuss other less expensive options than just new pipeline.*
- *What about state of the smaller lines? Will need to address all lines to see if they fall into the project scope.*
- *Consider getting rid of the smaller lines.*
- *Consider large bore coil tubing.*
- *Consider plastic lines.*
- *Directionally drilled lines.*
- *Consider tunnel instead of directional drill.*
- *Do nothing and just abandon the 10" line. Bring on test lines – convert test lines to production lines.*
- *Use water injection line for production.*
- *Shut down low producing sites.*
- *Insertion techniques.*
- *Take up the old lines and using the same routes, insert new lines.*
- *Temporary by-pass pipe.*
- *Drill wells from Gathering Station.*
- *Tanker in Poole Harbour.*
- *Coating lines instead of using liners.*
- *Rail tankers from F/M site.*
- *New 12" line and than abandon old ones.*
- *Route line down access road.*
- *Relocate GS.*
- *Improve well site water separation.*

- *Pipe well site water to wellsites for injection.*
- *Sub-sea line in Poole Harbour – use Coflexip.*
- *Epoxy shells on every joint – internal cement lining.*
- *Use large line to decrease pressure drop.*
- *Larger water injection line.*

Environmental Issues:

- *Produce evidence of review of options in environmental statement in the planning application. Can be on basis of cost.*
- *New pipelines must be buried. Myth or fact?*
- *Corrosion issues have to be mitigated against into any new pipeline.*
- *Area in question is not highly populated.*
- *Need to demonstrate submitted route is the lowest risk route.*
- *Some of the area will have no issues but other parts are congested and will have several issues.*
- *Work alongside existing live lines – along roads with utilities lines.*
- *Create heath land in the forest in exchange for a route.*
- *Security worry for above ground lines (terrorism/vandalism).*
- *Check the local plan – see if lines must be buried or not.*
- *Build an easy-open trench and insert the lines.*
- *Can't interfere with access on bridle paths. Problems with even temporary closure.*

5.5 Project Selection Criteria

The same kick-off meeting also developed the outline of what an ‘ideal’ solution would combine vis à vis the controlling constraints summarised in Table 3. The selected option from either new build of refurbishment should be the best fit with this ‘ideal’

AREA	MUST HAVE	LIKE TO HAVE
Programme	Speed of solution	
Environment	Minimal environmental intrusion Need to demonstrate the consideration of a number of options in Environmental Statement (ES) No interruption to bridle path etc. access	Benefits to environment Win-win reinstatement
Health & Safety	Safe during installation, operation and abandonment Minimal effect on existing pipelines	
Integrity	100% certainty of no leakage or spills	Ease of integrity monitoring
Operations and Maintenance		Minimal Interference to production Low maintenance
Construction	Good constructability	
Cost	Economically justifiable	
Client Image / Reputation		Enhance reputation Innovation

Table 3: Project Selection Criteria

5.6 Project Scope Definition

Early consideration was given to the question of which pipelines should be included as part of the scope of work for the project.

The project developed and utilised a pipeline scope decision tree based on the potential corrosivity of the pipeline environment to add pipelines to the field of investigation. See figure 2.

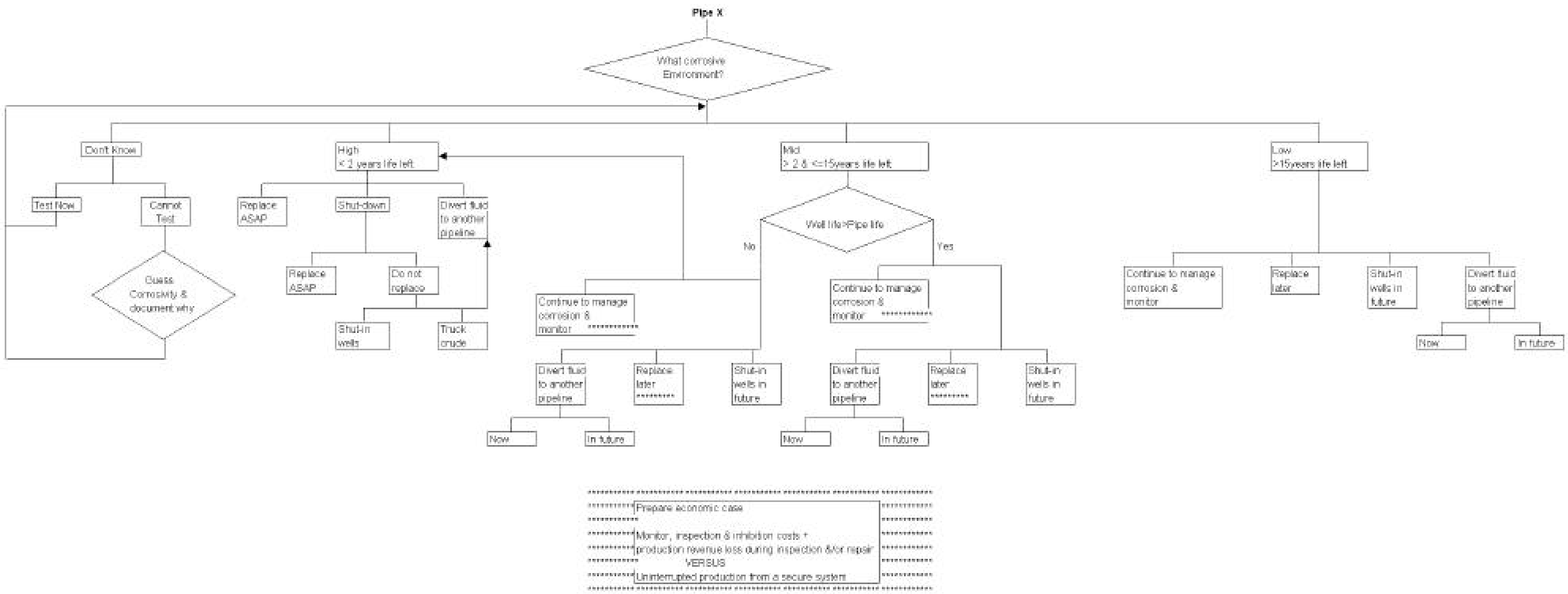

Figure 2 Pipeline scope selection tree

Other issues to be factored in included knowledge of independent projects such as new power cable supplies to be run to wellsites. The obvious economies of scale or potential to re-use redundant pipes made available by the project required the inclusion of such other projects within the project scope.

The project scope therefore included a necessary element of redundancy. This was on account of the programmed period allotted to the development of Project Options and the timing of inter-related activities such as future pigging runs. The data required now in order to refine and reduce the scope could not be obtained and hence it was necessary to include several ‘redundant’ scope items up to a point later in the project development where they could be safely discarded.

5.7 BP Capital Value Process (CVP)

It is important to situate the consideration and development of this project within the controlling project management development tool utilised by BP, termed the Capital Value Process (CVP). [8] Each project is developed through the following sequential stages:

- Appraise
- Select
- Define
- Execute
- Operate

This project was conducted through the ‘select’ phase.

At the end of each stage there is a deliberate ‘stop’ placed, termed in the CVP process a ‘gate’ through which the project must pass successfully prior to proceeding to the next stage. Controlling the gate is a gatekeeper who, although independent of the project has been kept informed of progress, issues and other points. At the ‘gate’ stage an additional independent check can be prescribed in the form of a ‘Peer Review’. Such a review requires the assembly of discipline experts drawn from within or without the company whose selection is principally based upon what detailed experience, overview and criticism they can add to the project and in this way either endorse or reject the Project Team recommendations.

A peer group review was used on this project.

The ‘select’ phase of the project was programmed to last approximately four months, from June to September 2001 inclusive.

6 Development of Potential Solutions

6.1 Results of initial option appraisal

From an assessment of the kick-off meeting options against the selection criteria the numbers of potential options were quickly reduced and then further grouped into two distinct families of options as follows:

- New Build Options
- Existing Pipeline Refurbishment Options

6.2 Process Considerations

Of primary importance to the consideration of any option was what wellsite flows the pipelines would be required to carry in the future.

The inherent variability of all future projections and, especially those concerning wellsite forecasts lies unconformably over the need to use accurate flow data to size pipelines.

The project ran pipeline sizing models using PIPESIM™ for four different wellsite production scenarios. The succession of results prompted further discussion and challenge to the predicted crude, water and gas flows to end of field life.

Process modelling was of critical importance in feeding back to option assessment the minimum required cross-sectional pipeline areas to flow the predicted quantities of product.

The importance of best quality wellsite forecast data and accurate iterative modelling cannot be overstated, as it directly affects the range of available options that can be considered thereafter. An example of this was the consideration of loose-fit liners in the existing crude production lines. The loss of cross-section due to a combination of pulling tolerance and liner wall thickness was sufficient to eliminate this as a possible rehabilitation option.

The major system constraints were diagnosed through meetings with operational staff in order to establish the critical pressures at wellhead and station points. It was important that the proposed solution did not lead to a rise in pressure that would choke flow from the wells. The effects of rehabilitation and new build options were checked against this and other benchmark data. Base case and multiple sensitivity studies were conducted to test the initial results of the analysis.

The base case results of process calculations revealed the following requirements for cross-sectional areas and pressures to flow the wellsite forecast volumes.

Pipelines	**From/To Wellsites**	**Process Results**
New Production Lines	K/L to F/M	6" min, 8" recommended
	F/M to G.S	16" min.
New Water Injection Lines	G.S to F/M	12" base, 8" option 1
	F/M to K/L	10" base, 8" option 1
Refurbish Existing Lines (12"/10"/6")	No liner	F/M at 13.46 barg
	Structural liners	F/M at 25.86 barg
	Non-structural liners	F/M at 14.87 barg

Table 4: Base Case Results of Hydraulic Analysis

6.3 New Build Options

From an examination by helicopter, foot and mapping information together with an assessment of environmental information conducted jointly with the project team environmentalist the following route options for new pipelines were consolidated:

Option 1: Direct route for a single pipeline using HDD to maximum extent.

Option 2: Using existing right of way to greatest extent.

Option 3: New route to south of wellfields through pine plantations etc.

These options are shown in Figure 3.

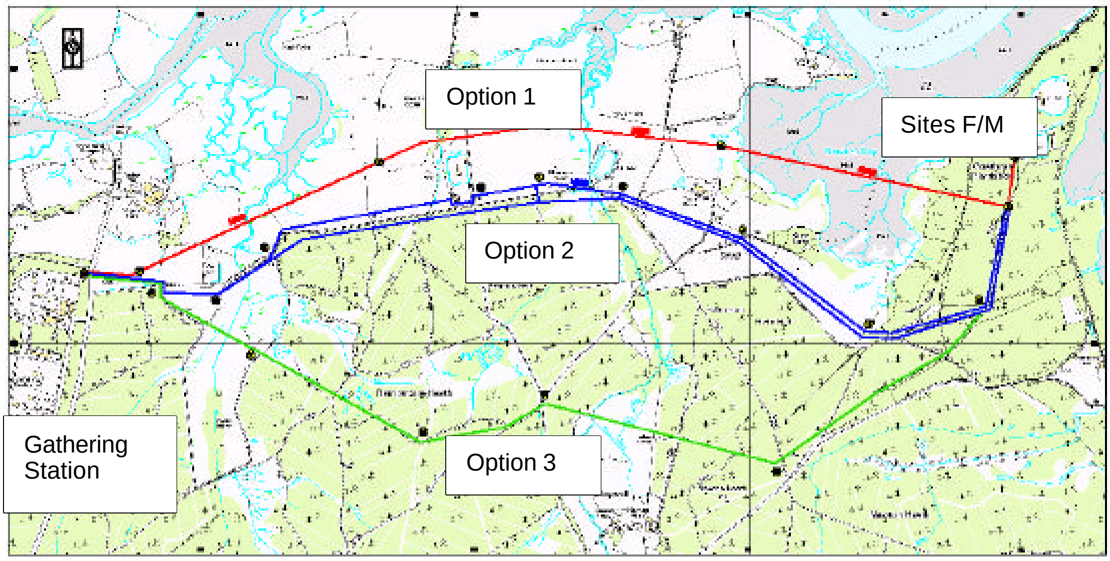

Figure 3 New Build Options

The summary advantages, disadvantages and outstanding issues are given in Tables 5, 6 and 7.

Advantages	• Reduced visual and environmental • Reduced visual and environmental impact upon completion
Disadvantages	• Only suitable for a single pipeline up to 16" diameter • Access for heavy plant at entry drilling location • Long laydown areas for preparing pipe strings • Risk of drilling mud escaping to environment • Risk of failure to complete • Only internal monitoring possible • Mud recycling facilities required.
Outstanding Issues	• Need to replace water pipelines • Ground conditions and requirement for site investigation

Table 5: Option 1 - Northern Route Using HDD

Advantages	• No limit to number of pipelines • Little 'new' disturbance to environment • Reduced land take, thus few problems and cost associated with land negotiations • Above ground pipeline easily maintained and monitored
Disadvantages	• Existing pinch points will become very congested • Close to some occupied buildings • Possible problems if water pipeline converted to high pressure gas line • Lines will require removing on decommissioning
Outstanding Issues	• Reaction of planning authorities to above ground pipelines • Also HSE and English Nature reactions • Permanent land take required for above ground pipelines

Table 6: Option 2 - Adjacent to Existing Pipelines

Advantages	• More than 1 pipeline could be laid • Part of route might be above ground (Goathorn Peninsular)
Disadvantages	• 'Unknown' environmental issues may arise • New wayleaves/easements required for most of route • Archaeological survey required • Not possible to tie into intermediate well site A, D and X
Outstanding Issues	• Reaction of landowners • Need for HDDs at Wetland Areas

Table 7: Option 3 – Southern Route

6.4 Refurbishment Options

The options considered were as follows:

- Non-structural cured in place (CIP) liners.
- Semi-structural CIP liners.
- Non-structural coatings.
- Close-fit polymeric liners.
- Loose-fit 'pipe-in-pipe' systems using glass reinforced epoxy (GRE) or flexible pressure pipes.

The following table numbers 8-12 inc. summarise the investigations and conclusions concerning each of these systems and their suitability for this project.

Advantages	• No discernable advantages
Disadvantages	• Need to clean pipe internals • Need to bond liner to pipe • No structural strength of liner • Reliant on existing (host) pipe integrity • No track record of O&G industry use • Can collapse due to external hydrostatic load • Gas build-up between liner and pipe
Outstanding Issues	• By inspection deemed unacceptable • Not considered further

Table 8: CIP Liners

Advantages	• Track record of use in oil and gas pipelines • Minimum loss of internal cross-section due to this coating • Intelligent pigging still possible after coating • Minimum new material requirements
Disadvantages	• Need to clean pipe internals • Need to achieve good coating adhesion for method of work • Use of cleaners, solvents and acids to effect cleaning of existing pipe (environmental impact) • Reliant on existing pipe integrity • No structural strength of coating • Specialised process and limited number of contractors • If coating less than 100% effective, possible loss of containment
Outstanding Issues	• By inspection not considered further

Table 9: Non-Structural Coatings

Advantages	• Speed of solution – pipe prefabricated only needs to be installed • Small excavations at c. 3 locations only • Established technology • High integrity (pressure retaining) new pipe within existing pipe • Long pull length (2,000m) reduces need for pit excavations • Pipe material has good anti-corrosion properties • Innovative use of flexible pipe technology
Disadvantages	• Size and weight of reels will involve major transport and environmental issues • Gas permeation through pipes to annulus will require gas venting • Need for flanges and tees to be in steel for connection to existing pipework • Installation work in close proximity to existing lines • Production downtime during installation • Possible risk of liner becoming struck • Intelligent pigging of existing pipe will be no longer possible • Very expensive liner • Very significant reduction on cross sectional area • Will need hot bends and tees to be removed • Existing line needs to be cleaned
Outstanding Issues	• Traffic plan and transportation issues for reels • Location of hot bends and number

Table 10: Loose fit (flexible) liners

Advantages	• GRE pipe has high corrosion resistance • High integrity (pressure retaining) new pipe within existing pipe • No requirement to weld • No gas permeation issues
Disadvantages	• Need to remove all hot bends, tees • Need to assume host pipe is straight and level • Any bends, tees etc. need to be in steel • Doubts over suitability of jointing system pressure capability and design life • Short pipe lengths (6.1m) that have to be assembled into pipe strings • Loss of pipe cross-section due to pulling tolerance and pipe WT • Loss of existing pipe wall to intelligent pigging examination • Transport of pipes via containers to site • Pull length and pit numbers dictated by existing pipe geometry.
Outstanding Issues	• Joints • Installation problems • Throughput requirements for production profiles

Table 11: Loose fit (pipe-in-pipe) systems

Advantages	• Proven technology • Small excavations for pits at 500-800m • Compared to new build, less environmental disturbance • Significantly less cost than comparable new build options • No new pipe proliferation, work is in existing right of way • Quick installation possible; 4 days downtime quoted for 4km x 12" pipeline • For water injection pipelines good track record of use • For crude lines, alternative liner materials available • For grooved/ribbed liner possible avoidance of need to vent every 500-800m
Disadvantages	• For application in crude gas pipelines liner material needs special consideration • Gas permeation through liner requires venting; this will raise environmental/safety issues • Hot bends, tees need to be removed • Any internal weld beads > 3mm will need to be removed • Will involve excavations and work around existing pipelines • Production downtime for pipeline to be lined • No inherent structural strength in liner – relies on host pipe for pressure retention
Outstanding Issues	• Numbers and locations of hot bends • Assessment of weld penetration >3mm • Use of grooved/ribbed liners

Table 12: Close-fit liners

7 PROJECT MANAGEMENT APPROACHES

7.1 Scope Redundancy

Due to the finite period of the 'select' phase of the project, the large number of constraining issues and the considerable number of unknowns concerning current state of corrosion plus pigging information from future runs, there was a need to ensure that all possibly relevant items were considered at the outset to allow exclusion at a later date, if appropriate.

Examples of this approach on this project included:

- Inclusion of seawater/produced water injection pipelines within the project scope.
- Consideration of rehabilitation using rigid pipe-in-pipe system.
- Review of changes to current operational regimes.

7.2 Loose/tight approach to detail

The programmed period for the 'select' phase meant that there was insufficient time to consider all options and all issues in equal detail. However, the need for sufficient detail on certain important issues such as process, liner design, wall thickness and installation, new pipeline route definition etc. meant that these items were considered in depth.

Of note on this project were the following examples of detail approach:

Project Area	Requirements
Process-flow considerations and pipe cross-section requirements.	'Tight' level of detail required due to derived considerations of pipe diameter, liner design implications etc.
Liner Information (loose fit)	'Tight' level of detail required concerning wall thickness, pulling tolerance, liner internal diameter and roughness
Construction Methodology – Rehabilitation	'Tight' level of detail required concerning pit size and depth for rehabilitation works.
Construction Methodology – New Build	'Tight' level of detail required for Horizontal Directional Drill (HDD) planning concerning pull lengths, laydown areas and ability to stop and start pulls.
Cathodic Protection and Instrumentation & Control	'Loose' level of detail required to assess general implications of the range of rehabilitation and new build options.

Table 13: Examples of project approach to detail

8 PROJECT DEVELOPMENT

8.1 New Pipeline Options

The project team discerned the apparent advantages particularly to the environment of Option 2, paralleling the existing pipeline easement.

Innovative approaches to the construction of discrete sections of the pipeline route were conceptualised and included in the overall proposals for the route in order to mitigate environmental constraints. These included:

- Use of above ground sections of new pipeline where existing flora would hide the view.
- Burying above existing pipelines and raising existing ground level.
- Installing alongside existing road embankment and extending embankment to cover.
- Using short HDDs to cross SSSI wetland areas.

8.2 Rehabilitation Options

From the first review by the Project Team of acceptable rehabilitation options for the project, it was evident that these options would reduce to:

- Close-fit liners
- Loose-fit liners
    - Flexible pipe in pipe
    - Rigid pipe in pipe

8.2.1 Close Fit Liners

Progress in the evaluation of this rehabilitation option was made quickly by testing probable roughness and wall thickness in the process models to confirm that the option met acceptable pressure and flow criteria.

Key areas that required more investigation and definition remained. They were:

8.2.1.1 Pulling Lengths, Number and Sizes of Pits

Although the typical values were known, more definition of the exact layout and configuration was required prior to presentation to environmental and other bodies.

8.2.1.2 Existing Pipe Weld Penetration

Information from close fit lining contractors indicated that excessive weld penetration 3.2mm (total measured across the diameter) would be unacceptable to the liner during installation. Clarification received from a lining construction contractor confirmed that this applied only for new build pipelines and could increase to 6.3mm (¼") approximately for existing pipelines. This removed a key concern about the need for (a) excessive downtime to locate and cut out excess weld penetration areas (b) the effect of the corresponding increase in excavations to the point where disturbances approached again that of a new build option.

8.2.1.3 Hot Bend Numbers and Location

The issue of hot bends and the need to remove them to facilitate liner installation and prevent short pulls or pull-away of the liner from the pipe wall becomes a significant consideration in an environmentally sensitive area. Fortunately most hot bend locations were adjacent to well head sites which would minimise disruption. Other bends were located adjacent to environmentally sensitive SSSI areas. For these areas it was proposed to use and site the send and receive pits to double up as bend replacement pits.

8.2.1.4 Liner Material Selection

The crude oil product temperature at 55-60°C combined with the presence of hydrogen sulphide and CO_2 signalled that liner material selection would require special attention. This is on account of the migration of entrained gas through the liner to the liner/ pipe internal wall annulus. Any operational shutdown and product evacuation thereafter carries a concomitant risk of liner collapse. This phenomenon is exacerbated where the liner is subject to the mechanically weakening effects of high temperatures and sour environment.

The project therefore investigated the possible first use and application of the 'safety liner' concept under development using 'Rilsan® B PA-11' polyamide (nylon). The liner utilises external grooves to permit annulus gas migration over far greater distances and thus avoid the need for intermittent above ground gas venting at installation pit locations.

8.2.2 Loose-Fit Liners

8.2.2.1 Flexible Pipe System

Flexible pipe systems were investigated by meetings with suppliers to discuss rehabilitation of the existing production pipelines. The principle advantages were:

- Long pull lengths achievable (up to 2km).
- Inherent structural integrity of the flexible pipe providing additional security against loss of containment.
- Proven technology and installation methods.

The significant issues requiring further investigation and consideration included:

- Flow limitations of flexible pipe due to the pulling tolerance and liner wall thickness
- Transportation of the very large and heavy flexible pipe coils which were estimated as up to 157T for 2000m x 8.66" ext. diameter. Typical reels would measure in excess of 7m diameter and 3m width.
- Cost – flexible pipe systems are expensive.

8.2.2.2 Rigid Pipe-in-Pipe Systems

Rigid pipe insertion systems in Glass Reinforced Epoxy (GRE) were investigated. Significant design issues were identified concerning the suitability and size of proprietary jointing systems. When combined with the loss in diameter due to installation tolerances and the need to remove hot bends etc. this option was not considered further.

9 TESTING THE PROJECT CONCLUSIONS

9.1 Assessment by Core Team

The core Project Team conducted an internal review of their work and utilised a bespoke spreadsheet to guide the analysis process and introduce a degree of objectivity into the choice process.

The spreadsheet used as a basis the project selection criteria in Table 3 developed at the kick-off meeting but enhanced to focus on the perceptions of 'Chance of Success' and 'Business Impact' of each principal option. These items were defined as:

Chance of Success - A spreadsheet calculation derived from project team assessments of the factors deemed to belong to the set affecting the success of the option e.g. feasibility, risk, constructability etc.

Business Impact - A spreadsheet calculation derived from project team assessments of the factors deemed to belong to the set affecting the success of the business impact of the options e.g. HSE, economic, integrity.

An example of the spreadsheet selection tool in given in Figure 4 and the results of this analysis are given in Table 14

	Option		
	Do Nothing	New Pipeline	Refurbished Pipeline (Close-Fit)
Chance of Success	78%	59%	49%
Business Impact	23%	75%	76%

	New Pipeline Route Options		
	Route 1	Route 2	Route 3
Chance of Success	52%	53%	53%
Business Impact	84%	78%	75%

Table 14: Project Team Conclusions for Main Project Options

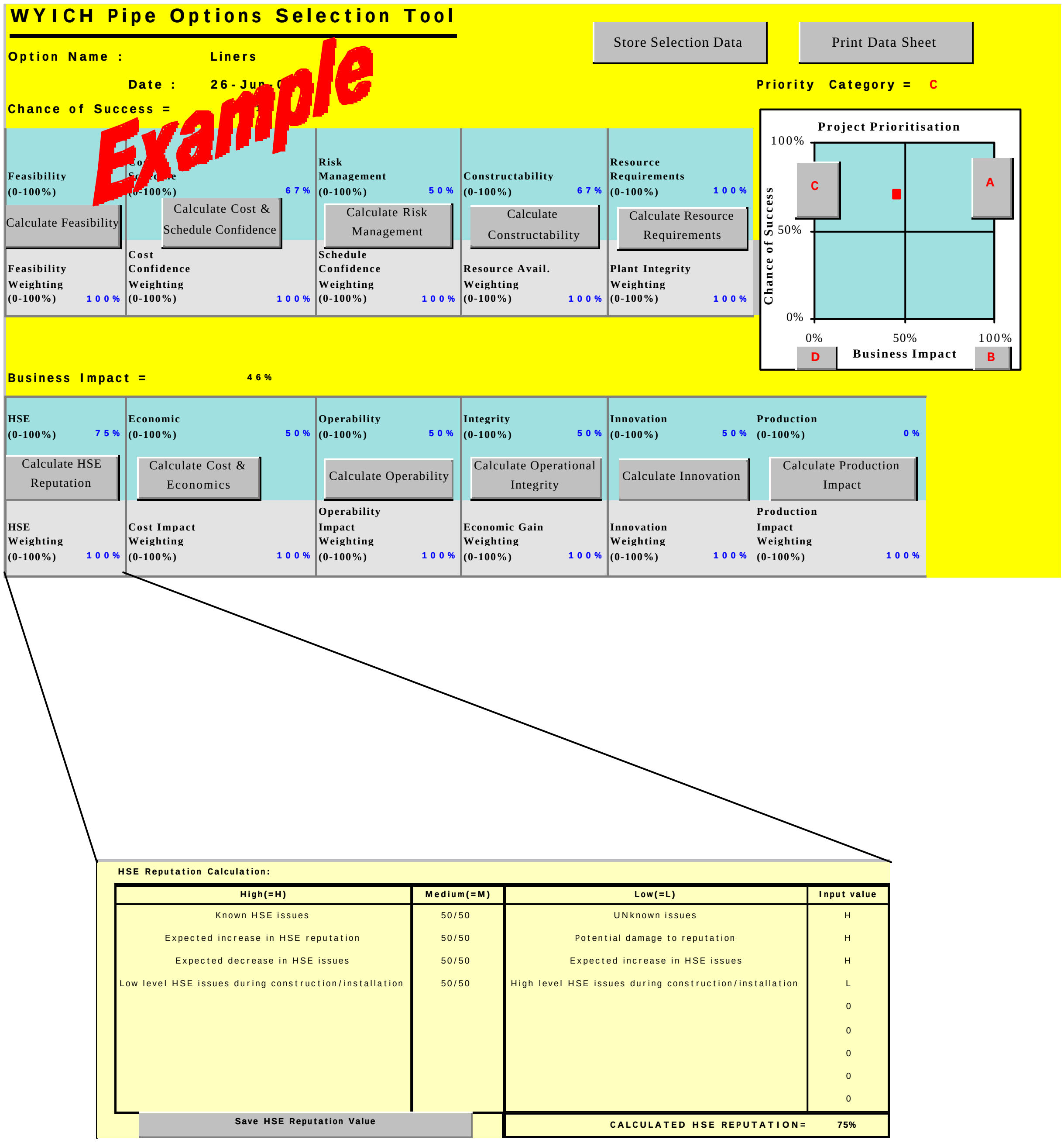

Figure 4 Example of Spreadsheet Selection Tool

9.1.1 Refurbished Pipeline – Close- Fit

The lower than expected chance of success value for close-fit lining of pipelines was ascribed to the following factors:

- Concern about internal weld penetration and the need to remove areas of excess detrimental to the lining operation and the effect of this work on shutdown times and the environment.

- Liner collapse and venting of gas issues – the possibility of liner collapse and required actions to remove and re-install together with the need to either vent gas at pit locations or adopt the 'safety liner' grooved liner concept to allow gas migration over greater distance to safe areas such as wellheads.

- Carrier pipe integrity – the introduction of a liner within the host pipe removes the possibility of intelligent pigging of the host pipe hence its condition becomes hidden. A separate concern was raised about the possibility of corrosion occurring within the annulus and pipe internal wall due to the trapping of water and gas. This concern was neutralised during the project Peer Review meeting.

9.1.2 New Pipeline

The Chance of Success and Business Impact of the three potential routes were submitted to analysis by the same spreadsheet with discussion by the Project Team.

Once again the differentiation between the alternative routes was extremely small with route option 2 thought by the team to be preferred but actually coming a narrow second to route option 3.

The principal reason for this was the concern over working in close proximity to live pipelines and the business and environmental impact should any damage occur.

9.2 Assessment by Peer Review

After review and assessment by the team, a formal presentation was made to a Peer Review Group. This group was formed from individuals nominated by the project team based on their knowledge of specialist areas of expertise or other important oversights that they might bring. For example, an inspector from the Health & Safety Executive was invited to participate as a Peer Review Member. The Peer Review Group comprised these areas of expertise:

- Installation of close fit liners within oil pipelines.

- Construction operations within fragile environments.

- Design and application of non-metallic materials including 'safety liner' concept for close fit liners.

- Inspection and integrity of pipelines (HSE).

- Decommissioning of infield pipelines.

- Environmental considerations for pipelines.

There was therefore a very good fit of experience with the key identified areas of the project.

This led to good feedback and endorsement that:

- Do nothing was not an option.

- Close-fit lining was the preferred rehabilitation option.

- For new build, route option 2 was preferred.

The Peer Review presented the following challenges to the Project Team to address prior to the adoption of a close fit lining solution:

- Demonstrate life of field capabilities for lined systems.

- Education process for Project Team and Operators.

- Education process for BP management and regulators.

- Development of integrity assurance plan for lined pipelines for field life.

- Make use of extensive technical expertise within BP.

- Holistic evaluation of the changes to the chemical program which will arise.

- Understand and evaluate failure modes and consequences.

- Re-instatement.

Additional recommendations were made to pass through the 'gate' at the end of the 'select' phase as follows:

- Consultation with BP Underground Technology Group to get technical assurance for life of field issues.

- Contact Canadian regulators and end users to gain familiarity with lined pipelines.

- Accelerate and complete intelligent inspections of other pipelines.

- Evaluate effect of step change in chemical inhibition on the rest of the facilities/wells.

- Consider contracting strategy using preferred supplier/best in class.

- Re-visit risk matrix and decision making tool.

10 CONCLUSIONS

From the description of the site, constraints, pipeline history and work undertaken in this project, the following conclusions may be inferred:

- In project locations where there are an abundance of constraints the *prima facie* assumed advantages of refurbishment above new build can be subsumed within the detailed consideration of environmental and LTO issues.

- During the conceptual stage of consideration of available options it is imperative to examine in detail certain key issues identified by the project team to exhaust the likelihood of later problems manifesting. Examination in detail must be selective and focussed solely on the key issues to ensure conformance to project timescales.

- In order to keep open as many potential engineering solutions to a suitable time within the conceptual phase when they can be assessed, it is sometimes necessary to include within the project scope items that later on can be discounted.

- When faced with selecting options from a multi-criteria project there is a need and benefit to be gained from using a team of independent 'peers' to audit, commend or reject the project teams conclusions.

11 ACKNOWLEDGEMENTS

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