NGG Output Measures

Outline Proposals

10th July 2008

EXECUTIVE SUMMARY

TPA Solutions Limited has been engaged by Ofgem to develop a set of Output Measures for National Grid Gas NTS and to comment on the measures proposed by NGG. These measures must meet specific licence obligations placed upon NGG with reference to:-

- Asset Condition
- Asset Risk
- Asset Performance
- Asset Utilisation

The summary of the licence objectives, the NGG proposals, our comments on those proposals and any recommendations for amendments or additions to those proposals are given below.

Asset Condition

Licence Objective

To provide a measure of:-

- Condition
- Reliability
- Rate of deterioration
- Present and future performance

NGG Proposal

NGG believe that any measure of asset condition should be based on their 47 secondary asset groups and have proposed to provide a simple measure that reflects their assessment of Remnant Life, which in their definition equals Expected Life minus Current Age.

This Remnant Life is then used to create a matrix for each primary asset group which shows the number of secondary asset groups that will require some work (unspecified at this stage) in one of four categories.

- Within 2 years
- Within 2 to 5 years
- Within 5 to 10 years
- Within not less than 10 years

TPA Comments and Further Recommendations

For 1st April 2009

In order to achieve implementation of initial output measures for 1st April 2009 we believe that it will be necessary to adopt the NGG proposals as the starting point for an output measure of network condition using the same secondary asset groups. However in order to create a more meaningful measure for Ofgem it is important that the template produced provides a clear indication of the interdependencies and weightings of the different secondary components to show how this impacts on the primary asset. In its simplest form this could be a measure of the components criticality should it actually fail. For example it could be a classification which has the following descriptive elements.

1 – Single component failure will result in a major hazard

2 – Single component failure will result in complete failure of site to meet its design capability

3 - Single component failure will result in partial failure of site to meet its design capability

4 – Failure of component in combination with another component will result in a major hazard

5 – Failure of component in combination with another component failure will result in complete failure of site to meet its design capability

6 - Failure of component in combination with another component failure will result in partial failure of site to meet its design capability

7 – Failure of component has no immediate impact on design capability and doesn't create an immediate safety hazard.

8 – Failure of component results in no risk to primary asset.

As replacement decisions are based on many factors at the time that replacement is being considered it would be appropriate that NGG should identify asset health review policy documents. These should provide support to their calculations on remaining asset life. Of particular interest is the treatment of obsolete components. If these policies are not in place then the following data should be available to support the calculations of remaining life.

- Original design asset life and age of the asset
- Any test data to demonstrate current asset performance and level of deterioration
- Maintenance history and planned future maintenance strategy

The weightings applied within the Gas Asset Decision Support Tool (together with the methodology for developing the weightings) would also be useful as this provides an indication of the importance of an asset.

Following on from the last bullet we believe that in order to develop a fuller picture of the condition of any process critical NGG asset a more comprehensive set of measures is required that focuses on both replacement and maintenance. In most cases items for replacement that will appear under a Capex heading will be the 'big ticket' items such as compressors etc. The way that these items are maintained will have a crucial impact on the need for these major components to be replaced. Condition, and to a great extent Remaining Life are also dependent on maintenance. Correctly identified repair and maintenance (R&M) costs, which appear under Opex will be what keeps the system going and where the main effort and cost will lie. As it's not very often something completely new will be wanted it is probably not appropriate to link plant condition only with Replacement Costs.

What are required are output measures that go some way to identifying whether NGG's maintenance policy:-

- Is focused on asset reliability and consequence of failure
- Has defined regimes appropriate to the operating context of the plant
- Reflects latest thinking associated with maintenance
- Provides an auditable path to link maintenance routines to decision making about equipment.

We therefore propose two additional output measures.

- For each primary asset group a split by cost of the maintenance method used (Preventative/Predictive/Corrective).
- Identify against each secondary asset group the predominant maintenance method (Prev./Pred./C)

Post 1st April 2009

Assuming that asset records are sufficiently developed it could be possible to produce a much more comprehensive set of condition output measures along the lines we have described in this report. However in light of the discussion in this section on the importance of maintenance we believe that creating too many output measures linked to pure condition of the asset in the context of replacement may not be the most effective means of meeting the objectives of the licence conditions.

We believe that what is needed is a coherent set of policies and procedures, and output measures linked to these that are specifically tailored to delivering the requirements of the licence conditions on critical systems. The current short term proposals require significant development with a view to meeting the following objectives.

- Building on the recommendations for 1st April 2009, create a list that ranks the primary assets within the NTS and identifies the critical secondary components within those assets. This should take account of the location of the primary asset, interaction between components within a primary asset, interaction between primary assets (where appropriate), consequences of failure and probability of failure. Criticality does need to take account of the function of the primary asset, but it should also acknowledge the probability of failure should maintenance not be carried out. NGG have multi-junctions as their most critical primary asset. We believe that not all multi-junctions have the same criticality and that failure to maintain the critical assets on a multi-junction would lead to a total failure in a much longer time period compared to for example a compressor station. To assist in making the assessment of criticality some form of decision tree could be utilised (see Appendix 4 for an example). This will also assist in the assessment of the split between Preventative/Predictive/Corrective maintenance requirements.

The output measure that could be produced from this would be a list of critical primary assets and associated secondary components with their rankings in order of criticality and an indication for each component of the maintenance method (Prev./Pred./C).

- Develop a combined maintenance and replacement policy that is tailored to the criticality of the secondary components. This could result in different approaches for primary assets and will require constant updating to reflect the changing criticality of the primary assets as supply and demand patterns change.

The output measure for this could be the existence of an appropriate decision tree and detailed listing of the policies and procedures that have been completed compared to a target level. Ofgem would need to periodically verify that the procedures met the desired criteria. A further measure could be to provide a net present cost/value for each replacement project.

Post 1st April 2010

The development of measures that examine maintenance and replacement policy can be supplemented by some of the more focused condition output measures once it is clear what the critical components are and how they are maintained. So for example if a critical secondary component turns out to be a specific control system on a compressor station or stations then the fault history of that system will be of interest.

Asset Risk

Licence Objective

To provide a measure of:-

- Risk to reliability from asset condition of individual assets or their interaction

NGG Proposal

The proposal is that a traffic light system be adopted which identifies the risk profile of the current primary assets, aggregating the risk profile for all the secondary asset groups within that primary asset.

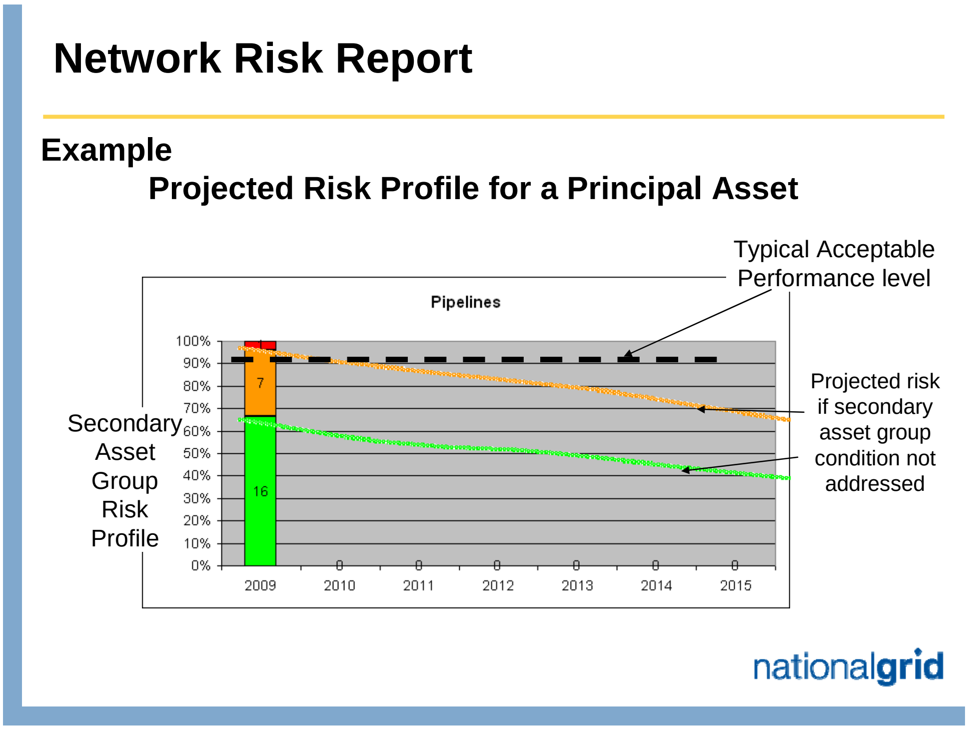
The risks that are incorporated into this measure cover Security of Supply, Safety, Environment and Fiscal. The basis for assessment of risk relies on compliance with various industry standards which are already reviewed by enforcement agencies HSE, EA and SEPA. The primary risk factor within each secondary asset group is identified and acceptance criteria assigned to this asset group.

The acceptance criteria used within the traffic light system are as follows:-

- **Green** Acceptable – Meets required standard for availability, reliability or capability
- **Amber** Cautionary - Only partially meets standard for availability, reliability and capability (nominally with 20% of gap from acceptable target)

- **Red** Unacceptable – Fails to meet the required standard for availability, reliability and capability (nominally greater than 20% gap from acceptable Target)

The numbers within each category are taken and the primary asset risk profile created as in the example below.



TPA Comments and Further Recommendations

NGG has proposed indicators of risk for Security of Supply, Safety, Environment and Fiscal. The Licence requirement is focused on the risk to the reliability of the pipeline system and therefore the output measures should address the impact that network asset condition and the interdependence between network assets has on reliability.

TPA has only focused on Security of Supply in developing output measures. It is therefore recommended that NGG develop a fault tree analysis for the whole network, using the methodology contained in this report in section 3 in order to assess the risk of loss of supply. It should include an assessment of the reliability of at least each primary asset group in delivering the 1 in 20 peak day capacity as a primary determinant of system reliability.

Asset Performance

Licence Objective

To provide a measure of:-

- Aspects of performance that impact on quality and cost of service

NGG Proposal

Proposed measures that NGG have suggested are:-

- Number of unplanned events where the operating pressure of a pipeline has been reduced to carry out a repair or investigate the condition of the pipeline.
- Number of unplanned events where the flow into the network from an Entry Point has been restricted because of an asset fault or failure.
- Number of unplanned events where the flow from the network at an Exit Point has been restricted because of an asset fault or failure.

TPA Comments and Further Recommendations

In addition to the measures proposed by NGG we recommend that measures which show the historical reliability and availability of the network are provided based on our suggested methodology and that more detail is provided for each NGG reported event to establish the duration, cause, location, impact and type of failure.

For reliability (R) this can be simply defined as:-

$$R_t = \frac{(t - d) \times 100}{t}$$

Where t = total operating period

d = unscheduled downtime (the period the equipment is down because it fails in service, or fails to start or fails whilst it is shut down because of the failure of one or more components contained within its taxonomy). It is measured from when the equipment shuts down, or when required work identified, until the relevant work is completed.

Availability (A) can be simply defined as:-

$$A_t = \frac{(t - (d+s) \times 100}{t}$$

s = scheduled downtime (the period the equipment is shutdown for planned routine work which is measured from the time it is shut down until it is made available again i.e. ready to start)

The main document (section 4) also shows a typical approach that can be used for collecting failure and repair data for the purposes of calculating availability of secondary assets which takes account of ease of maintenance.

Future development could include the publication of real time data on compressor performance and a mechanism to establish the underlying drivers behind the availability data, for example is reduced availability as a result of maintenance being less than planned.

It would also be very useful to establish how many near misses have occurred which don't show up anywhere. Indicators of the potential for this could be the level of spare components kept in stock or occasions when Control Centre staff don't get the level of response to control commands that they are use to.

Asset Capability

Licence Objective

To provide a measure of:-

- Level of network capability and utilisation, including entry and exit points

NGG Proposal

NGG is proposing to use some of the current tables that they report to Ofgem in the Annual PCR Reporting Pack (tables 5.1 to 5.6, 5.9 & 5.11).

TPA Comments and Further Recommendations

The measures proposed by NGG are not sufficient to meet the licence requirements and therefore we propose that a specific supply demand scenario is run which maximises the physical capacity of the network under a realistic supply demand pattern. We therefore propose that capability at entry and exit could be determined using the supply and demand distribution pro-rata to the TBE Base Case with no flow margin, all compressors working and demand diversity. The initial demand level to be the current forecast 1 in 20 peak day. This will provide a starting point, which can be added to by introducing standby compression and the reliability of the network under the two different sets of assumptions could be calculated to provide a comparison of the two modes of operation.

SECTION 1. INTRODUCTION

The following sections identify possible output measures for consideration by Ofgem for further development by NGG. These measures will address the following areas.

Asset Condition

Asset Risk

Asset Performance

Asset Utilisation

As part of the development of these measures TPA Solutions have started from first principles in order to develop an ideal set of measures that meet the Licence requirements in their entirety. It should be noted however that some of these measures are intended to be implemented in the medium to long term as a result of there being insufficient data held by NGG. These measures will be clearly identified in each section.

Each of the four areas will identify the summarised objectives of the output measures from the Licence requirements. In the proposals put forward by NGG at a meeting between NGG and Ofgem on the 9th May and in the final full written proposals published on the 29th May 2008.

It should be noted that although it is important to develop the output measures in such a way as to assess each area independently there is a need to develop an approach that allows cross-over between the areas.

Primary Asset Groups and Sub-groups

TPA Solutions have reviewed the complete system and have identified the following distinct asset groups which will be analysed in more detail in the four areas.

- Compressor
- Entry Point
- Pipeline
- Above Ground Installation
    - Exit Point
    - Multi-junction
- Telemetry

The main sub-groups (Secondary Asset Groups) are identified in Appendix 1.

Consideration could be given to break down the pipeline primary assets by area rather than individual pipes for example by maintenance area.

Licence Objectives

To provide a measure of:-

- Condition
- Reliability
- Rate of deterioration
- Present and future performance

TPA Analysis

The most crucial aspect of developing comprehensive measures for Asset Condition is the ability to identify each individual asset which should be tagged and recorded in an asset register in a unique way. This will then permit a full history to be maintained of that assets maintenance record, fault history, repair time and replacement and refurbishment record. From this information it would then be possible, if desired, to develop output measures that are specific to each critical component of the network.

NGG have advised that they only have a partial asset record, however we will outline what would be an ideal approach based on the assumption that over time this asset record could be provided at a level consistent with meeting the Licence objectives to its full extent.

Network Condition - General

When reviewing the various primary asset groups, it is important to establish their importance to the network and how these assets have performed to date. TPA believes that although compressor stations have a lesser importance than say entry points or multi-junctions, their history of poor performance compared to all other primary assets raises their criticality level. They are the asset group with the most moving parts, the most sub-groups and the most things that could fail and that actually do fail. Discussions with NGG revealed that they don't really consider compressors to be a critical asset but they do rate the multi-junctions as the most critical, because a failure at one of these sites could result in the loss of supply to a large area, whereas a compressor outage would lead to limited or no supply loss depending on the standby arrangements.

Clearly there are justifications for either being critical as they both have an impact on the network, albeit significantly different, but the probability of failure is not addressed by the simplified assessment of criticality. This issue is addressed further in the risk section.

We have identified (Appendix 1) what we have considered are the key secondary assets that are indicators of the condition (and reliability) of the primary asset. NGG have provided a list of secondary asset groups (47 in total) that they consider are the key indicators of the condition of the primary assets (see Appendix 2). There is a significant difference in the approaches. We believe that many of the assets listed do provide an indication of the condition of the network, but that the approach taken by NGG includes what we consider to be many tertiary asset groups. These are assets that might ultimately lead to failure of the system in combination with another event or events, but don't have a direct material impact on system risk when they fail, and in some cases only create a problem with risk combined with two or more events. Examples of this are most civil assets, acoustic cladding and fuel gas metering. Clearly catastrophic failure of some assets, as opposed to simply failing to perform its intended function, could result in a safety risk but this is not something that is separated out in the NGG proposals.

Asset groups have also been included which we don't believe NGG NTS have sufficient examples of to warrant inclusion e.g. odorisation plant. We had assumed that these are almost entirely in the control of GDN's with possibly some examples at terminals where direct supplies to local networks are provided St.Fergus, Theddlethorpe, Bacton and at some direct connects. There are also questions of materiality and detail which should be addressed ultimately. Some relatively small components are sometimes critical to the operation of some primary assets, but would be missed from an asset list at this level. We appreciate the difficulty in getting a balance between practicality and materiality, but reliability of the whole system is based on identifying the weakest links.

We believe that any approach which dilutes the relative impacts of different components in the interests of providing a simple solution should be avoided if possible.

TPA Output Measure Options

Our primary objective when examining the development of appropriate output measures is to create measures that meet the objectives within this section of the Licence.

Condition

There are many ways in which the condition of an individual asset can be measured or assessed.

- Assessment of ageing using time dependant failure rates
- Remaining life of component (expressed as a percentage of design life)
  - Function of design life, design characteristics, level of maintenance and operating conditions
  - Some components will have effectively an infinite life others limited by pressure and thermal fatigue, corrosion and wear
  - Only influences risk if close to zero
  - Incorporate testing data to extend/reduce life e.g. noise levels, boroscopic inspections
- Availability history (for definition of availability see section 4)
- Historical expenditure (on for example CP)

To provide comprehensive coverage of all critical components does require full asset records for those components and as stated above a detailed asset base at component level. This does not exist in its entirety at the moment but could be built up from day 1 and form part of a medium to long term solution.

As a guide to assessing true asset life a simple design performance model could be created, which would use the design performance of the piece of plant or component when it was installed and then map current performance against the original design. This is data that should be readily available. The level of degradation can then be established to assess the need for "do nothing", upgrade or complete replacement. This should reduce or defer the need for replacement due to obsolescence if a piece of plant was, say, 20 years from needing replacement or repair. Theoretically, complete replacement of certain plant could be deferred indefinitely if refurbishment brought the item back to year 0 of its asset life. This zeroing of plant is something that NGG already incorporates into their processes.

Examples of specific tests that could be used to establish asset condition are:

- Pressure drop and flow across a line valve – increases in pressure for the same flow over time could indicate problems with the valve
- Time taken for a valve actuator to close and open a valve – if this time remains within a specific band then it doesn't need replacement
- Compressor exhaust stack temperature creep – generally this is something that cannot be recovered beyond certain limits so replacement is necessary beyond these limits. Simple noise measurement provides a good indicator of worsening condition

We are aware that BG Group adopts the principles outlined in this report for their assessment of remaining asset life.

Reliability

We address reliability under section 4 which examines Network Performance.

Rate of Deterioration

In order to provide a quantifiable measure this requires a combination of:-

- Historical and forecast maintenance expenditure
- Effectiveness of maintenance to reduce failures
- Time dependant failure rates
- Need a clearly defined starting reference point

Some possible measures that could be considered:-

- Planned maintenance cost versus actual
- Availability divided by maintenance cost
- Remaining asset life with forecast maintenance versus remaining asset life without any maintenance

Present and Future Performance

We address this area under Network Performance.

Other Measures

As part of our analysis we considered some focused measures that could be used as complimentary to the primary measures of condition. Examples of this are shown below, but some of these could be more useful as measures of risk and performance.

Pipelines

- Failures due to corrosion
- Interference incidents resulting in pipe damage

- CP and surveillance expenditure Actual as %age of Forecast
- % fatigue life (for pipes with pressure cycling)

Compressors (see Appendix 3 for more details)

- Vibration – increasing levels indicate wear
- Noise from cabs and stacks – increasing levels indicate need for replacement
- Start reliability – indicators of reliability of control systems which can be compared against historical levels when sites manned
- Run reliability
- Mean time between trips
- Trip duration
- Equivalent running hours versus planned running hours
- Performance
    - Head vs flow
    - Efficiency vs flow
- Maintenance cost per fired hour

AGIs

- Failures due to corrosion
- Actuator operating times

Telemetry

- Communication downtime
- Data errors
- Command response

Maintenance Strategy

One of the things that this report implies is the importance of the NGG Maintenance Strategy. This affects many things, from opex through to life expectancy of the equipment. For example, what is the balance between Preventive (scheduled) and Predictive (condition monitoring, testing, etc) maintenance and how have these decisions on this split been arrived at?

The importance of understanding the Maintenance Strategy is that it may provide the key to how much further work needs to be done to identify *critical components* - an issue that underlies almost all of this report. In an ideal world, a Maintenance Strategy would be based on a 'bottom up' analysis, usually Failure Mode and Effects Analysis (FMEA) which would have identified the (smallest) critical components and therefore how they would be dealt with, either in terms of redundancy (sparing etc) and/or maintenance in the overall strategy.

There could be a case for developing an output measure related to Maintenance Strategy which attempts to address the impact of the strategy on the condition of the asset and hence the need for replacement. An indicator of an effective maintenance strategy is the decision making process that is applied when carrying out maintenance. Under the previous studies carried out as part of the TPCR, NGG indicated that they had adopted PASS 55 which is a "Specification for optimised management of physical infrastructure assets." NGG identified that the predominant strategy is (Planned) Preventative Maintenance. Predictive Maintenance, where an asset is maintained or replaced based on its condition rather than a pre-determined regular frequency, has become increasingly used by NGG. Corrective Maintenance (fix on failure) is something that appears to be rarely used by NGG.

The relative proportions of these three primary maintenance strategies can vary considerably depending on the industry, but an output measure that could be used to compare with other similar operations could be to simply provide the split either in man-hours or cost between the three primary maintenance methods – Preventative/Predictive/Corrective. A further development could be to identify against each secondary asset group the predominant maintenance method (Prev./Pred./C).

Other comparators could simply be maintenance or controllable opex costs as a percentage of capital spend/asset value. This information can be derived from various gas industry sources including FERC, regulatory reporting and company accounts from similar businesses.

NGG Proposed Output Measures

As stated above NGG believe that any measure of asset condition should be based on their 47 secondary asset groups and have proposed to provide a simple measure that reflects their assessment of Remnant Life, which in their definition equals Expected Life minus Current Age.

This Remnant Life is then used to create a matrix for each primary asset group which shows the number of secondary asset groups that will require some work (unspecified at this stage) in one of four categories.

- Within 2 years
- Within 2 to 5 years
- Within 5 to 10 years
- Within not less than 10 years

An example is shown below.

	Primary Asset -Entry Point					
Secondary Asset Groups	**Unit**	**No of Asset groups where work may be required within 2 Years**	**No of Asset groups where work may be required within 5 ears but not less than 2 years**	**No of Asset groups where work may be required within 10 years but not less than 5 years**	**No of Asset groups where work may be required within not less than 10 years**	**Total No of Assets Groups**
Above Ground Pipe Coating	**Site**					
Acoustic cladding	**Site**					
Below Ground Pipe Coating	**Site**					
Cathodic Protection	**System**					
Civil assets - access	**Site**					
Civil assets - buildings/enclosures	**Site**					
Civil assets - drainage	**Site**					
Civil Assets - ducting	**Site**					
Civil assets - pipe supports	**Site**					
Electrical - including standby generators	**Site**					
Electrical - safe shutdown (UPS etc)	**Site**					
Filter / Scrubbers	**Site**					
Fire and gas detection	**Site**					
Fire Protection	**Site**					
Fiscal metering	**Streams**					
Flow or pressure regulator including measurement	**Streams**					
Fuel tanks & bunds	**Units**					
Gas analyser	**Units**					
Locally Actuated Valves	**Units**					
Network Control and Instrumentation (telemetry, pressure, flow and temperature)	**Sites**					
Pig Trap	**Units**					
Preheaters	**Units**					
Process valves (remotely operated valves)	**Units**					
Safety valves (remotely operated valves)	**Units**					
Security	**Site**					
Slam shut system	**Units**					
Station process control system	**Site**					
Vent system	**Unit**					

The proposal by NGG is partially consistent with the Licence objectives, in that it provides an indication of the current state of all the different secondary asset groups. It doesn't however provide a clear measure with regard to the reliability of the secondary or primary assets and hence the network as it does not provide any indication within the condition analysis itself of the criticality of the different components, the extent of work that might be needed, the interdependence of components and what would happen if maintenance procedures were changed. All these things would be addressed in the NGG assessment at the time work is needed, but Ofgem would have to question nearly every entry to make its own judgement on what the figures really mean. The issue of criticality could be addressed by some weighting applied to each asset group, but this only works well if all the individual components in the group could have the same weighting.

One aspect that may not have been addressed is the asset groups that need frequent attention. So for example if work is required every five years, does this measure show this? This is where some reference to design (or expected) life would give a clearer indication. Maybe this could be addressed by NGG providing Ofgem with the analysis behind the numbers in the table?

Examples of questions that would be needed to draw out anything more meaningful could be:-

- If this asset were to fail, what would be the consequences of failure now/within 2 years/2 to 5 years…..?
- How many asset groups need work doing every 2 years/2 to 5 years?
- Of the number of asset groups requiring work within the next 2 years. How many will be re-lifed/replaced/partially replaced/re-assessed?
- For each asset category how many are likely to need replacement due to statutory legislation?
- For each asset category, what has been the fault history?
- Which asset categories are interdependent?
- Etc….

We believe that the approach taken by NGG to this area, although relatively straightforward in approach, simplifies things too much. It provides only limited information to Ofgem and the rest of the industry to allow them to judge the condition of the network, without extensive further questioning. A longer term objective should be to develop a much more focused and informative set of output measures that identifies the most critical components and provides a clear indication of material system impacts and likely actions that will be required going forward. This should ideally be dealt with at the secondary asset level, by individual component.

As stated above, NGG have indicated that they are intending to develop a complete asset record, therefore the requirement to record all the necessary data for a comprehensive fault history should already be part of those records.

Comparison between TPA and NGG Methodologies

In principle the approaches are similar. We agree that current processes should be adopted wherever possible, but it is also important that Ofgem are assured that the licence objectives are being met. The NGG proposals do provide some measure of asset condition, but we are unable to provide a comprehensive evaluation of the output measure provided by them as it is clear from the information provided that this is only one part of the picture when NGG are considering asset replacement. The replacement decision is made when the time comes to consider an asset for replacement, by when many factors could have changed.

One area of specific note is the treatment of obsolescent assets. Why is it necessary to consider an asset for replacement across the board just because it is obsolete when either its fault history suggests that no component has failed in service or that it poses minimal risk to the reliability and safety of the network? Surely there could be a more cost-effective strategy, for example by having spare new components ready to be used should a failure occur. We acknowledge that this may not be appropriate for components where replacement times are lengthy.

We note from the NGG response on electricity output measures that a greater level of detail is provided relating to asset condition and would be more reassured by the gas proposals if it could be confirmed that this level of detail exists within the gas area. Examples of this could be as follows.

- Individual asset group health indices linked to remaining asset life and the underlying methodology used to determine these. For example NGE quote a procedure TGN (AR) 4 for electricity. Is there a comparable procedure for gas or is it addressed in the Decision Support Tool GADST?

- Historic health indices – is there enough information to calculate these for gas as is shown for some assets in electricity?

- Technical asset life – NGE have specific definitions for technical asset life and how data, information, knowledge and modelling is used to derive the technical asset lives for certain assets (e.g. as contained in PS(T) EPS 12.7 and TGN(AR) 7. Does the equivalent exist for NGG assets?

<u>NGG Costs</u>

We assume that if complete asset records and fault history will be collected in order to assist in the establishment of the expected life range for the secondary asset groups that development of any of the TPA alternative output measures, should this be pursued, would be minimal.

TPA Recommendations

<u>For 1st April 2009</u>

In order to achieve implementation of initial output measures for 1st April 2009 we believe that it will be necessary to adopt the NGG proposals as the starting point for an output measure of network condition. However in order to create a more meaningful measure for Ofgem it is important that the template produced provides a clear indication of the interdependencies and weightings of the different secondary components to show how this impacts on the primary asset. In its simplest form this could be a measure of the components criticality should it actually fail. For example it could be a classification which has the following descriptive elements.

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The weightings applied within the Gas Asset Decision Support Tool (together with the methodology for developing the weightings) would also be useful as this provides an indication of the importance of an asset.

Following on from the last bullet we believe that in order to develop a fuller picture of the condition of any process critical NGG asset a more comprehensive set of measures is required that focuses on both replacement and maintenance. In most cases items for replacement that will appear under a Capex heading will be the 'big ticket' items such as compressors etc. The way that these items are maintained will have a crucial impact on the need for these major components to be replaced. Condition, and to a great extent Remaining Life are also dependent on maintenance. Correctly identified repair and maintenance (R&M) costs, which appear under Opex will be what keeps the system going and where the main effort and cost will lie. As it's not very often something completely new will be wanted it is probably not appropriate to link plant condition only with Replacement Costs.

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Assuming that asset records are sufficiently developed it could be possible to produce a much more comprehensive set of condition output measures along the lines we have described in this section. However in light of the discussion in this section on the importance of maintenance we believe that creating too many output measures linked to pure condition of the asset in the context of replacement may not be the most effective means of meeting the objectives of the licence conditions.

We believe that what is needed is a coherent set of policies and procedures, and output measures linked to these that are specifically tailored to delivering the requirements of the licence conditions on critical systems. The current short term proposals require significant development with a view to meeting the following objectives.

- Building on the recommendations for 1st April 2009, create a list that ranks the primary assets within the NTS and identifies the critical secondary components within those assets. This should take account of the location of the primary asset, interaction between components within a primary asset, interaction between primary assets (where appropriate), consequences of failure and probability of failure. Criticality does need to take account of the function of the primary asset, but it should also acknowledge the probability of failure should maintenance not be carried out. NGG have multi-junctions as their most critical primary asset. We believe that not all multi-junctions have the same criticality and that failure to maintain the critical assets on a multi-junction would lead to a total failure in a much longer time period compared to for example a compressor station. To assist in making the assessment of criticality some form of decision tree could be utilised (see Appendix 4 for an example). This will also assist in the assessment of the split between Preventative/Predictive/Corrective maintenance requirements.

  The output measure that could be produced from this would be a list of critical primary assets and associated secondary components with their rankings in order of criticality and an indication for each component of the maintenance method (Prev./Pred./C).

- Develop a combined maintenance and replacement policy that is tailored to the criticality of the secondary components. This could result in different approaches for primary assets and will require constant updating to reflect the changing criticality of the primary assets as supply and demand patterns change.

  The output measure for this could be the existence of an appropriate decision tree and detailed listing of the policies and procedures that have been completed compared to a target level. Ofgem would need to periodically verify that the procedures met the desired criteria. A further measure could be to provide a net present cost/value for each replacement project.

Post 1st April 2010

The development of measures that examine maintenance and replacement policy can be supplemented by some of the more focused condition output measures once it is clear what the critical components are and how they are maintained. So for example if a critical secondary component turns out to be a specific control system on a compressor station or stations then the fault history of that system will be of interest.

Licence Objectives

To provide a measure of:-

- Risk to reliability from asset condition of individual assets or their interaction

TPA Analysis

TPA acknowledge that it is difficult to develop clear and simple quantitative measures for network risk, however we believe that the approach adopted by NGG only partially addresses the subject. We started our analysis by trying to answer the question - What is risk?

In its simplest assessment there are two primary aspects – safety and security of supply. The primary safety requirement is about minimising catastrophic failure resulting in gas release, or major supply disruption that triggers either a local or national gas supply emergency. For safety it is about meeting the needs of the Safety Case and other legal obligations.

The primary issue with regard to security of supply is about ensuring that the network is capable of meeting 1 in 20 peak day demand [pending review of Safety Case obligations regarding security of gas supply]. In addition from a commercial perspective it is about the risk of not meeting demand for entry/exit capacity on any day. In this context we believe there are some factors that need consideration.

- What does the NTS Safety Case say about ensuring security of supply?
- System is not 100% reliable and not meant to be
- It is quantifiable in this respect by reference to probability of failure (related to 1 in 20 peak day obligation)
- Current risk is that the system is expected to fail if weather and demand conditions exceed those which form the basis of the 1 in 20 peak day demand – in its simplest interpretation theoretically once every 20 years
    - What has been the past and future risk profile?
    - What is the relevance of:-
        - Baseline levels versus peak demand (Entry baseline = 9144 GWh/d – 1 in 20 Peak demand = 5944 GWh/d)
        - Entry baseline levels versus exit baselines (9144 vs 8000 (excl.IUK))
        - Forecast supply levels versus demand
- What happens to the risk profiles if key infrastructure/components fail?
- How does exit reform change the profile given commercial access to firm load shedding?
- Shipper interruption
- What additional provisions are made to mitigate the risk of failure?

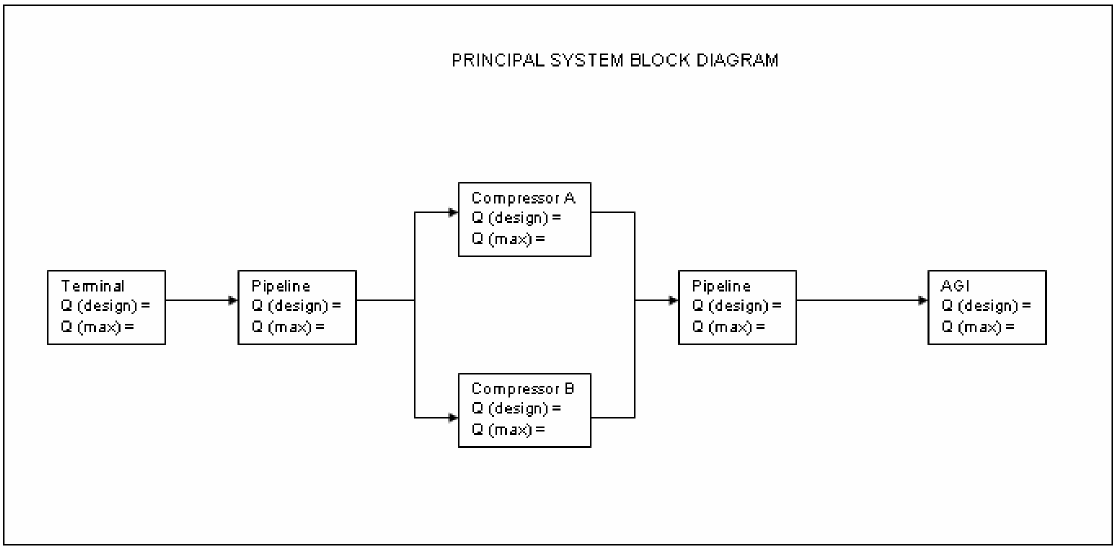
- Flow Margin/Operating Margins/Diversity

Any output measure related to risk should address the following:-

- Probability of failure
  - Catastrophic failure
  - Loss of supply
  - Both are quantifiable
  - Strike action e.g. Grangemouth
- Linked back to reliability/availability of individual components
- Related to over/under supply situation
- Provision of a system wide fault tree analysis
  - AND/OR gates would identify interdependencies in failure mode (see example below)

Fault Tree Analysis

The principal systems within the NTS can be represented by the block diagram shown below. We have excluded Multi-junctions but these could easily be included.



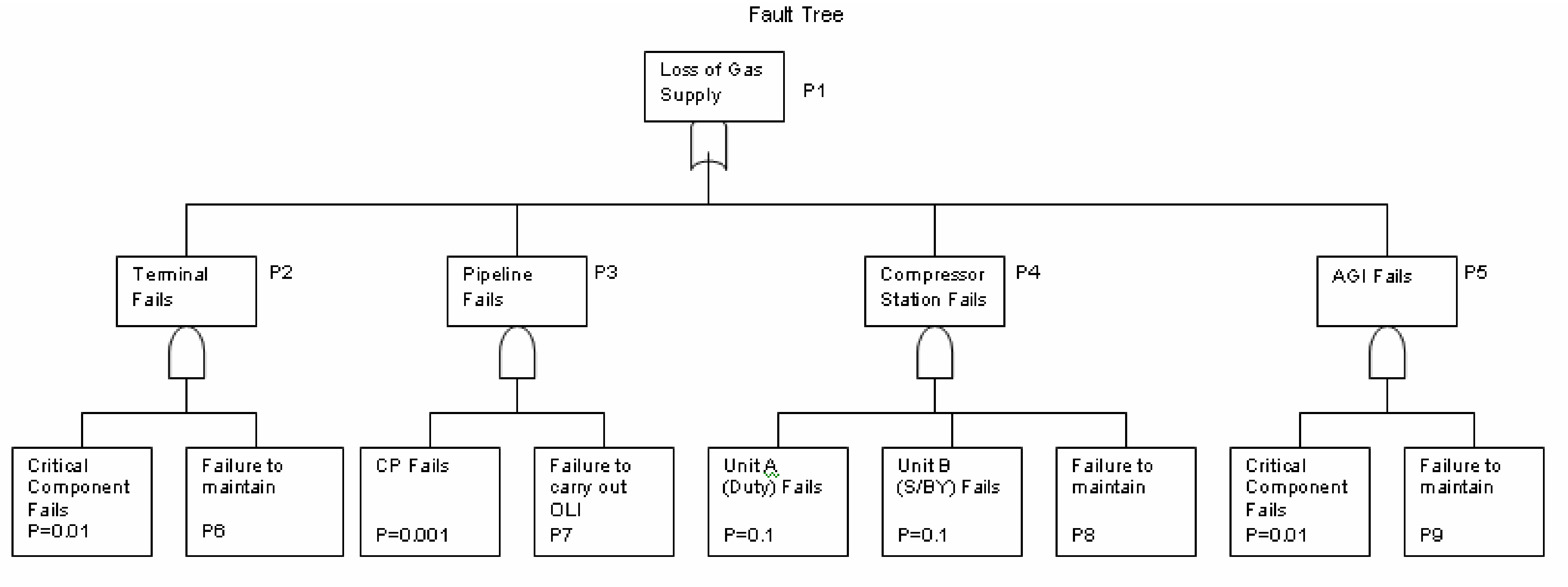
An expanded version of this could be used to identify where spare capacity exists by representing all of the primary assets on one complex diagram. This could show a comparison of the design capacity of each asset with the maximum expected throughput (for example under the Base Case supply, 1 in 20 peak day demand conditions).

It is important to distinguish between spare capacities which exist in particular streams i.e. over sizing and where this is provided as a 'standby' or redundant stream as this affects the probability of failure to provide gas.

Potential bottlenecks will also be highlighted. For example, the capacity at the terminal may exceed that of the pipeline system down stream, thus effectively constraining the terminal operation, and so on further down the line.

Either version of the diagram can be used to create a fault tree to assess the impact of maintenance and plant redundancy on the probability of losing the gas supply or failing to deliver 1 in 20 peak day capacity. An alternative that could be modelled is to test the impact on off-peak exit capacity provision, to assess the impact of outages during maintenance periods. But this could require multiple scenarios to provide a meaningful measure given that maintenance will be taking place across the summer under many different supply and demand conditions.

The analysis below starts with the simplified fault tree and probability of a loss of gas supply based on the probability of failure of specific assets. A starting point for assessment of a baseline probability could be to take the loss of 50 mcmd of supply availability which is similar to an offshore loss that could occur. This could be varied where there is a known supply surplus such that the figure could be 50 mcmd + current surplus. Examining supply impacts though is more of a commercial issue, given that there is no obligation on NGG to ensure that sufficient supplies are available to meet a specified standard.


Fault Tree
Loss of Gas Supply
P1
Terminal Fails
P2
Pipeline Fails
P3
Compressor Station Fails
P4
AGI Fails
P5
Critical Component Fails
P=0.01
Failure to maintain
P6
CP Fails
P=0.001
Failure to carry out OLI
P7
Unit A (Duty) Fails
P=0.1
Unit B (S/BY) Fails
P=0.1
Failure to maintain
P8
Critical Component Fails
P=0.01
Failure to maintain
P9

The principal assets appear in the order shown a number of times in the NGG network and hence many of these could be produced for discrete sections of the network. The top event, namely loss of gas supply occurs if any of the principal assets fail. The probability of this loss occurring will be significantly dependant upon maintenance and equipment sparing (or redundancy).

The probability of loss of supply can be estimated for a number of scenarios, and these can be compared. For example where there is an over or under supply situation, this can be reflected in the analysis.

The following assumptions are made in the fault tree based on standard risk ratings. The probability of a critical component failure at a terminal or at an AGI is 1 in 100 (0.01). The probability of CP failure is 1 in 1000 (0.001). The probability of a compressor unit failing to start is 1 in 10 (0.1). The probabilities are multiplied at an AND gate and added at an OR gate.

A number of cases can be considered in which the impact of the failure to carry out the relevant maintenance (preventive or predictive) can be assessed. These are P6 to P9. These cases, with the corresponding change in the probability of the top event (P1) occurring are shown in the table below. The calculations also show the effect of removing a spare compressor.

Case	P6	P7	P8	P9	Unit A	Unit B	P1	P1(case n)/P1(case 1)
1	0.1	0.1	0.1	0.1	Yes	Yes	3.10×10^{-3}	1
2	0.1	0.1	0.1	0.1	Yes	No	1.21×10^{-2}	3.9
3	1	1	1	1	Yes	Yes	3.10×10^{-2}	10
4	1	1	1	1	Yes	No	1.21×10^{-1}	39
5	0.1	0.1	1	0.1	Yes	No	1.02×10^{-1}	32.9

Case 1 assumes that the probability of failing to carry out the relevant maintenance/inspections is 1 in 10 and that duty and standby compressors are available. This is the base case, against which the other probabilities can be compared.

Case 2 assumes that no spare compressor is installed, and that maintenance is carried out subject to the base case probability.

Case 3 assumes that no maintenance is carried out at any of the assets, but that a spare compressor is installed.

Case 4 assumes that no maintenance is carried out at any of the assets, and that no spare compressor is installed.

Case 5 assumes that maintenance is not carried out at the compressor station and that there is no spare compressor.

Clearly, other cases can be calculated – such as failure to maintain only one of the other assets i.e. terminals, pipelines or AGIs.

Installation of electric compressors could easily change the picture across the network as more is known about their reliability. To illustrate this if the electric compressors are proven to be more reliable than gas – Unit A (Duty) Fails becomes 0.01 or maybe even 0.001 – P1 becomes 2.2 x 10^{-3} or 2.1 x 10^{-3} respectively.

Electric without standby with a probability of failure of 0.01 - P1 = 3.1 x 10^{-3} same as gas with standby. Electric with standby generation would probably bring reliability back to the same level as that with a standby unit and at lower cost.

If failure frequency data was available then P1 could be expressed as a frequency of failure rather than a probability of failure.

Given the increased interdependence of gas and electricity networks and the fact that certain types of failure on one system can have a negative impact on the other system, consideration should be given to assessing risk across both networks jointly.

NGG Proposed Output Measure

The proposal is that a traffic light system be adopted which identifies the risk profile of the current primary assets, aggregating the risk profile for all the secondary asset groups within that primary asset.

The risks that are incorporated into this measure cover Security of Supply, Safety, Environment and Fiscal. The basis for assessment of risk relies on compliance with various industry standards which are already reviewed by enforcement agencies HSE, EA and SEPA. The primary risk factor within each secondary asset group is identified and acceptance criteria assigned to this asset group.

The acceptance criteria used within the traffic light system are as follows:-

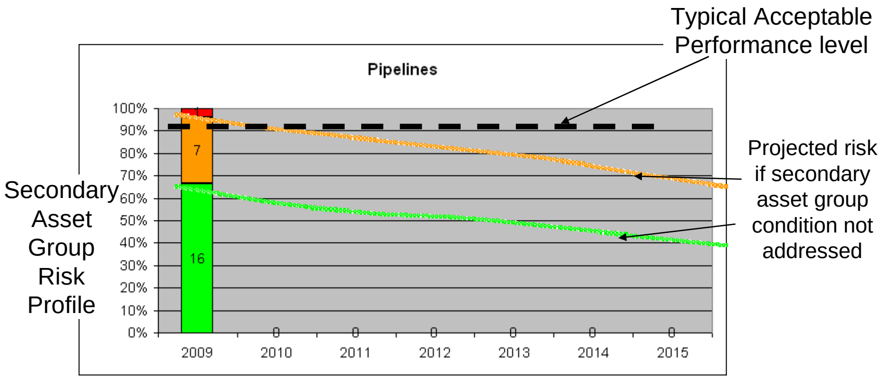
- **Green** Acceptable – Meets required standard for availability, reliability or capability
- **Amber** Cautionary - Only partially meets standard for availability, reliability and capability (nominally with 20% of gap from acceptable target)
- **Red** Unacceptable – Fails to meet the required standard for availability, reliability and capability (nominally greater than 20% gap from acceptable Target)

The numbers within each category are taken and the primary asset risk profile created as in the example below.

Network Risk Report

Example

Projected Risk Profile for a Principal Asset



nationalgrid

The difficulty with adopting this approach is that it incorporates too wide a collection of risks and there is no indication of the relative weightings of their contribution to system risk. Furthermore some of the risk factors included in the assessment relate to meeting safety and statutory obligations, which failure to meet would have other consequences for NGG than an affect on the reliability of the system. NGG have also stated that although there are international standards adopted by NGG, these need not be complied with if it can be demonstrated that safety, security of supply and environmental standards are maintained or improved. So failing to meet a specific standard is clearly not an indicator of system risk, if an alternative approach can be adopted.

We believe that this part of the Licence is an area where the intention of the Licence condition has not been addressed. This is about the risk to the reliability of the pipeline system and should address the impact of network asset condition on reliability and the interdependence between network assets. The NGG proposal provides no clear quantifiable measure of reliability and doesn't address the interaction between primary asset groups.

We would therefore recommend the adoption of some form of fault tree analysis for the whole network, which should include an assessment of the reliability of at least each primary asset group in delivering the 1 in 20 peak day capacity as a primary determinant of system reliability. Fault tree analysis is something that is widely used in safety related risk assessments across many industries from road accident assessment to military applications.

Comparison between TPA and NGG Methodologies

The fundamental difference in the approaches is that NGG encompass four elements of risk (safety, security of supply, environment and fiscal) whereas TPA have focused on the risk associated with the ability for NGG to meet its obligation to provide 1 in 20 peak day capacity. We acknowledge the four risk areas are important and that measures can be developed around those, but the specific requirement of the licence is to provide a measure of the level of risk to the reliability of the network taking account of interdependent assets. We believe our proposal for the development of fault tree analysis and to test it out primarily on their ability to meet the 1 in 20 peak day obligation and some other scenarios provides a better indicator of network risk in this context.

At the very least the NGG output measures give no indication of the impact of interdependency between asset groups.

<u>NGG Costs</u>

Costs for developing the fault tree analysis should be low as this should only involve producing a relatively simple spreadsheet and populating it. Once set up it could be updated very easily.

TPA Recommendations

It is recommended that in addition to the measures proposed by NGG a fault tree analysis is developed for the whole network, using the methodology contained in this report. It should include an assessment of the reliability of at least each primary asset group in delivering the 1 in 20 peak day capacity as a primary determinant of system reliability.

SECTION 4. ASSET PERFORMANCE

Licence Objectives

To provide a measure of:-

- Aspects of performance that impact on quality and cost of service

TPA Analysis

Performance means different things to different users

- DN's need to meet their 1 in 20 peak day requirements
- DC's need max capacity when they want it to minimise commercial risk

100% reliability is not essential and certainly not at any cost.

We believe that network performance can be measured quite simply by reliability and availability. But to refine this further needs an acknowledgement of the cost of that performance level. This could be for example a cost per unit of asset group throughput. This is something that can be benchmarked internationally.

In its simplest form reliability can be defined as the probability that a system, primary asset or component (below primary asset level) will operate without failure for a prescribed period under specified conditions of operation.

At the highest level reliability (R) can be simply defined as:-

$$Rt = \frac{(t - d) \times 100}{t}$$

Where t = total operating period

d = unscheduled downtime (the period the equipment is down because it fails in service, or fails to start or fails whilst it is shut down because of the failure of one or more components contained within its taxonomy). It is measured from when the equipment shuts down, or when required work identified, until the relevant work is completed.

An alternative approach is to use Availability which is defined as the proportion of time the system, primary asset or component is commissioned and ready for operation.

At the highest level availability (A) can be simply defined as:-

$$At = \frac{(t - (d+s) \times 100}{t}$$

s = scheduled downtime (the period the equipment is shutdown for planned routine work which is measured from the time it is shut down until it is made available again i.e. ready to start)

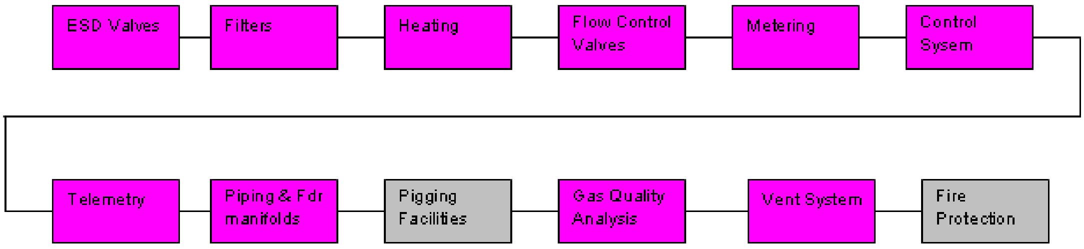
At the component level Reliability, Availability, Maintainability (RAM) analysis can be performed.

In the case of the NTS the assets must be able to operate with a high level of online availability (at least at peak demand times), but the assumption that this is 100% is not guaranteed unless the average availability of all components is 100%.

Availability is a function of reliability and maintainability and is therefore calculated using a combination of failure rates and corrective (or repair times).

It is convenient, although simplistic, to represent a principal asset by a series of blocks. An Availability Diagram for an NGG terminal (network entry) facility could look something like that shown below. The operational i.e. production critical components (shaded pink) and associated failure and repair data can then be tabulated.

I



For the system to operate with an overall availability of a minimum of 99% (for example) the average availability of each production critical component, in a 12 component system must be equal to $0.99^{1/12}$ = 0.99916. In practice, distributing the availability equally around the plant would not be logical. A method is required that parcels out the availability so that the more complex parts, which are likely to be the least reliable are assigned a relatively low availability target, while the simplest parts are given higher availability.

The figure above is illustrative only i.e. does not show where duplication or components in parallel exist, so can be misleading in the sense that as shown would underestimate actual availability. Terminal specific drawings would reflect exactly what is in place at each location.

The table below shows a typical approach to collecting failure and repair data.

Critical Component	**Failure Mode**	**Mean Failures / 10^6 hours**	**MTTF (yrs)**	**Data Source**	**MTTR (hrs)**
ESD Valves					
Filters					
Heaters					
FCVs					
Metering					
Control System					
Telemetry					
Gas Analysis					
Vent System					
ANO					

Based on data from the table above, the table below calculates how quickly a component can be maintained:

Component	**Failures λ / yr**	**Tc (hours)**	**λ. Tc**
ESD Valves			
Filters			
Heaters			
FCVs			
Metering			
Control System			
Telemetry			
Gas Analysis			
Vent System			
ANO			
$\Sigma\ \lambda =$		$\Sigma\ \lambda\ Tc =$	

The corrective time (Tc) which is the weighted average repair time for the secondary asset group is calculated as follows:

$Tc = \Sigma \lambda \cdot Tc / \Sigma \lambda$

$Availability = 1 - (\lambda \cdot Tc) / 8760$

Current Performance

A relatively simple measure of the current performance of an asset is to utilise something like Overall Plant Effectiveness (OPE) which is defined as:-

Availability x Performance Rate x Quality x 100

Where

$$\text{Performance Rate} = \frac{\text{Actual Op. Time x Output}}{\text{Required Op. Time}}$$

$$\text{Quality} = \frac{\text{Actual Output}}{\text{Expected Output}}$$

This is designed to accommodate circumstances whereby failures cause partial loss of capacity and not just on/off.

Future Performance

This is essentially current performance taking account of the rate of deterioration on asset groups using simulation.

Possible measures could be to monitor component availability versus maintenance expenditure (plus possibly replacement and major overhaul costs). Alternatively examine operational performance over time. This would mainly be relevant to compressor stations where intermittent operation affects start-up reliability. A more hands-on approach could be to monitor major moving parts continuously against design criteria e.g. work and flow parameters and vibration levels. This could provide useful information on the current state of compressors and their deterioration over time. This is already done by NGG but is kept in house and could possibly be added to the data made available on their website. This will involve incurring some material costs, particularly if the monitoring information is not currently collected in near real time. General Electric for examples offers a remote monitoring service for compressor installations. For more detail on compressor condition assessment see Appendix 3.

NGG Proposed Output Measure

NGG already produce a number of reports on network performance.

HSE – "Major Hazards Safety Performance Indicators in the UK Onshore Gas and Pipeline Industry" report includes

- Maximum Operating Pressure Excursions
- DN Inlet Pressure Excursions below 38 Barg
- Gas Quality TFA Advice Instructions

EA/SEPA Network Review includes

- Running Hours per Site/ Unit and Emissions to Atmosphere

- Prediction of Future running Hours

OFGEM – Annual Price Control Review Report includes

- Compressor Running Hours
- No of Incidents

Proposed measures that NGG have suggested are:-

- Number of unplanned events where the operating pressure of a pipeline has been reduced to carry out a repair or investigate the condition of the pipeline.
- Number of unplanned events where the flow into the network from an Entry Point has been restricted because of an asset fault or failure.
- Number of unplanned events where the flow from the network at an Exit Point has been restricted because of an asset fault or failure.

Comparison between TPA and NGG Methodologies

The NGG measures could be useful, however we believe that these should be combined with the use of reliability and availability measures as outlined above. These measures on their own don't give a very clear picture of real performance as they are only indicative of loss of service but do not quantify the impact. Further information would need to be sought for each event. This should include more detail on the incident, with as a minimum the duration, cause, location, impact and type of failure being provided. It would also be useful to see an age profile of failed components to understand if it is old or new ones that are failing.

<u>NGG Costs</u>

The only material costs that could be incurred, should this measure be adopted, is that of collecting and making available near real time compressor data.

TPA Recommendations

In addition to the measures proposed by NGG we recommend that measures which show the historical reliability and availability of the network are provided based on our suggested methodology and that more detail is provided for each NGG reported event to establish the duration, cause, location, impact and type of failure.

Future development could include the publication of real time data on compressor performance and a mechanism to establish the underlying drivers behind the availability data, for example is reduced availability as a result of maintenance being less than planned.

It would also be very useful to establish how many near misses have occurred which don't show up anywhere. Indicators of the potential for this could be the level of spare components kept in stock or occasions when Control Centre staff don't get the level of response to control commands that they are use to.

SECTION 5. ASSET CAPABILITY AND UTILISATION

Licence Objectives

To provide a measure of:-

- Level of network capability and utilisation, including entry and exit points

TPA Analysis

The concept of asset capability relies heavily on the ability to identify physical capacity of the asset. Once this is determined then utilisation is relatively simple to calculate. Capability may be different to design capacity as operational conditions will be different to the original design basis. In order to create an appropriate set of measures it is important to provide a clear set of rules for calculating capability. Many scenarios have been considered in the past for modelling the network, but for the purposes of this study we do not consider it is necessary.

There are many examples of margins being incorporated into the design of the NTS (flow margin, OM, standby compression and non-diversified demand). It is therefore proposed that some of these provisions should be taken out to arrive at what could be considered the maximum capability of the network.

We therefore suggest that capability at entry and exit could be determined by establishing the maximum physical capability of the current network, using the supply and demand distribution pro-rata to the TBE Base Case with no flow margin, all compressors working and demand diversity. The initial demand level to be the current forecast 1 in 20 peak day. This should not incur any material costs as this is something that could be incorporated into the analysis already carried out for Ofgem.

This will provide a starting point, which can be added to by introducing standby compression and the reliability of the network under the two different sets of assumptions could be calculated to provide a comparison of the two modes of operation.

These capabilities can then also be compared against booked capacities, peak usage and baselines.

As an additional simple measure utilisation could be calculated using the following simple formula.

% Utilisation (U)

$$Ut = \frac{(t - (d+s+st) \times 100}{t}$$

st = standby (available but not running), all others as per availability equation above.

NGG Proposed Output Measure

NGG only propose to use some of the current tables that they report to Ofgem in the Annual PCR Reporting Pack (tables 5.1 to 5.6, 5.9 & 5.11). Unfortunately these don't tell the full story as there is no indication of physical capacity and therefore the TPA proposed suggestion for capability should be added to the pack, either in aggregate or ideally by individual entry and exit point. Further refinement could be to identify the capacity of all the primary assets.

Compressor running hours should be adjusted to reflect effective running hours taking account of the operating conditions of the compressors as this will give a more accurate assessment of the compressors lifespan. Running inside or outside specific operational parameters can increase or reduce remaining life. This may be more appropriate as a measure within Network Condition. The types of parameters that would be of significance are operating pressures and temperatures with there being an ideal design condition, and operating above or below these design levels will reduce or extend the actual running hours required between major overhauls.

Comparison between TPA and NGG Methodologies

NGG are proposing using existing regulatory reporting arrangements to meet this objective. TPA do not agree that this provides sufficient information to meet the licence requirement and propose an approach that seeks to establish physical capacity under a tightly defined scenario.

<u>NGG Costs</u>

The TPA proposal should not incur any material costs as this is something that could be incorporated into the analysis already carried out for Ofgem.

TPA Recommendations

The measures proposed by NGG are not sufficient to meet the licence requirements and therefore we propose that a specific supply demand scenario is run which maximises the physical capacity of the network under a realistic supply demand pattern. We therefore propose that capability at entry and exit could be determined using the supply and demand distribution pro-rata to the TBE Base Case with no flow margin, all compressors working and demand diversity (scenario A). The initial demand level to be the current forecast 1 in 20 peak day, but increased pro-rata to meet maximum supply and storage deliverability. This will provide a starting point, with an alternative scenario (B) which allows for standby compression at sites that currently have this facility. The reliability of the network under the two different sets of assumptions could be calculated to provide a comparison of the two modes of operation.

A proposed template for this measure is provided below.

	Scenario A	**Scenario B**
Reliability		
Entry Point Capability		
St.Fergus		
Etc…..		
Exit Point Capability		
Bacton AGI		
Etc…..		

APPENDIX 1. TPA SECONDARY ASSETS

Compressor Main Components

- Gas Turbine/Electric motor
- Power Turbine (compressor)
- Valve and actuator
- Filter
- Heater (fuel gas)
- Pressure/flow control
- Metering
- Pig Trap
- Pipework
- Blow-down system
- Control and instrumentation
- UPS
- Compressor auxiliary components
    - Cab
    - Stack
    - Fire and gas system

Entry Point Components

- Valve and actuator
- Filter/Slug catcher
- Heater
- Pressure/flow control
- Metering
- Pig Trap
- Pipework
- Relief system
- Control and instrumentation

Pipeline Main Components

- Pipework
- Pipeline Auxiliary Components
    - Cathodic Protection
    - Inspection

AGI Main Components

- Valve and actuator
- Regulator
- Heating
- Control and Instrumentation

Telemetry Main Components

- Transmitter/Receiver
- Communications
- Computer

APPENDIX 2. NGG SECONDARY ASSETS

	Primary Assets				
Secondary Asset Groups	**Entry Point**	**Pipeline**	**MultiJunction**	**Compressor**	**Exit Point**
Civil assets - drainage	Yes	Yes	Yes	Yes	Yes
Civil assets - access	Yes	Yes	Yes	Yes	Yes
Civil assets - buildings/enclosures	Yes	Yes	Yes	Yes	Yes
Civil assets - pipe supports	Yes	Yes	Yes	Yes	Yes
Fuel tanks & bunds	Yes	Yes	Yes	Yes	Yes
Electrical - including standby generators	Yes	Yes	Yes	Yes	Yes
Electrical - safe shutdown (UPS etc)	Yes	Yes	Yes	Yes	Yes
Filter / Scrubbers	Yes	Yes	Yes	Yes	Yes
Fire and gas detection	Yes	Yes	Yes	Yes	Yes
Fire Protection	Yes	Yes	Yes	Yes	Yes
Major River Xing's	N/A	Yes	N/A	N/A	N/A
Network Control and Instrumentation (telemetry, pressure, flow and temperature)	Yes	Yes	Yes	Yes	Yes
Pig Trap	Yes	Yes	Yes	N/A	Yes
Below Ground Pipe Coating	Yes	Yes	Yes	Yes	Yes
Locally Actuated Valves	Yes	Yes	Yes	Yes	Yes
Process valves (remotely operated valves)	Yes	Yes	Yes	Yes	Yes
Acoustic cladding	Yes	Yes	Yes	Yes	Yes
Civil Assets - ducting	Yes	Yes	Yes	Yes	Yes
Cathodic Protection	Yes	Yes	Yes	Yes	Yes
Impact protection (N2 Sleeves)	N/A	Yes	N/A	N/A	N/A
Markers	N/A	Yes	N/A	N/A	N/A
Above Ground Pipe Coating	Yes	Yes	Yes	Yes	Yes
Security	Yes	Yes	Yes	Yes	Yes
After coolers	N/A	N/A	N/A	Yes	N/A
Air intake	N/A	N/A	N/A	Yes	N/A
Exhausts	N/A	N/A	N/A	Yes	N/A
Boundary Controllers	N/A	N/A	N/A	Yes	N/A
Cab ventilation	N/A	N/A	N/A	Yes	N/A
Compressor	N/A	N/A	N/A	Yes	N/A
Flow or pressure regulator including measurement	Yes	N/A	Yes	Yes	Yes
Gas analyser	Yes	N/A	Yes	Yes	Yes
Gas Generator	N/A	N/A	N/A	Yes	N/A
Fiscal metering	Yes	N/A	N/A	N/A	Yes
Fuel gas metering	N/A	N/A	N/A	Yes	N/A
Odorisation Plant	N/A	N/A	N/A	N/A	Yes
Power turbine	N/A	N/A	N/A	Yes	N/A
Preheaters	Yes	N/A	Yes	Yes	Yes
Station process control system	Yes	N/A	Yes	Yes	Yes
Unit control system	N/A	N/A	N/A	Yes	N/A
Recycle line & valve	N/A	N/A	N/A	Yes	N/A
Starter motor	N/A	N/A	N/A	Yes	N/A
Vent system	Yes	N/A	Yes	Yes	Yes
Electrical variable speed drive	N/A	N/A	N/A	Yes	N/A
Non return valve	N/A	N/A	N/A	Yes	N/A
Slam shut system	Yes	N/A	Yes	Yes	Yes
Safety valves (remotely operated valves)	Yes	Yes	Yes	Yes	Yes
Civil assets - bridges	N/A	Yes	N/A	N/A	N/A

APPENDIX 3. CONDITION ASSESSMENT OF COMPRESSOR STATION COMPONENTS

INTRODUCTION

The need to assess the condition of plant and equipment on a compressor station can be due to the following requirements:

- Performance of the gas compressor and driver (gas turbine or electric motor) in their ability to deliver the required flow and pressure required by the operator.

- To ensure that the complete station and hence all the individual components are reliable enough to be able to start and come on line when required and to be able to run the station for the required number of hours

- Maintain the integrity of the plant to ensure that it is always operating in a safe manner and does not present any hazard when operating to any personnel or its surrounding environment

From the above it can be seen that the condition of plant and equipment operating on a gas transmission system has to satisfy a number of criteria which are all inter-related. Hence the condition of major components like the gas compressor, the gas turbine or electric motor driver and also the unit and station control systems need to be monitored accurately and continuously to ensure that all the desired objectives of performance, reliability and safety are achieved.

COMPRESSOR STATION COMPONENTS

A typical gas compressor station operating on a gas transmission system will have the following components or functions:-

a. Gas compressor

b. Gas turbine or electric motor driver

c. Unit and station control systems

d. Station Inlet and outlet valves

e. Pressure and flow control

f. Flow metering

g. Pig Traps

h. Compressor cab and exhaust system

i. Fire and gas system

j. Blow down system

k. Filters and/or scrubbers

l. heating system

A number of the components and systems listed above, whilst all essential to the safe and efficient running of the compressor station, can be classified as being static systems whose condition does not deteriorate significantly. Once installed these static components and systems should last the life time of the compressor station if maintained regularly. However, the gas compressor, its driver, the control system and the gas turbine exhaust system do deteriorate due to the nature of the operation. Therefore it can be stated that the components inside the compressor cab and the control systems are the most critical on a compressor station whose condition can deteriorate over time and requires monitoring. These components can now be considered individually.

GAS COMPRESSOR

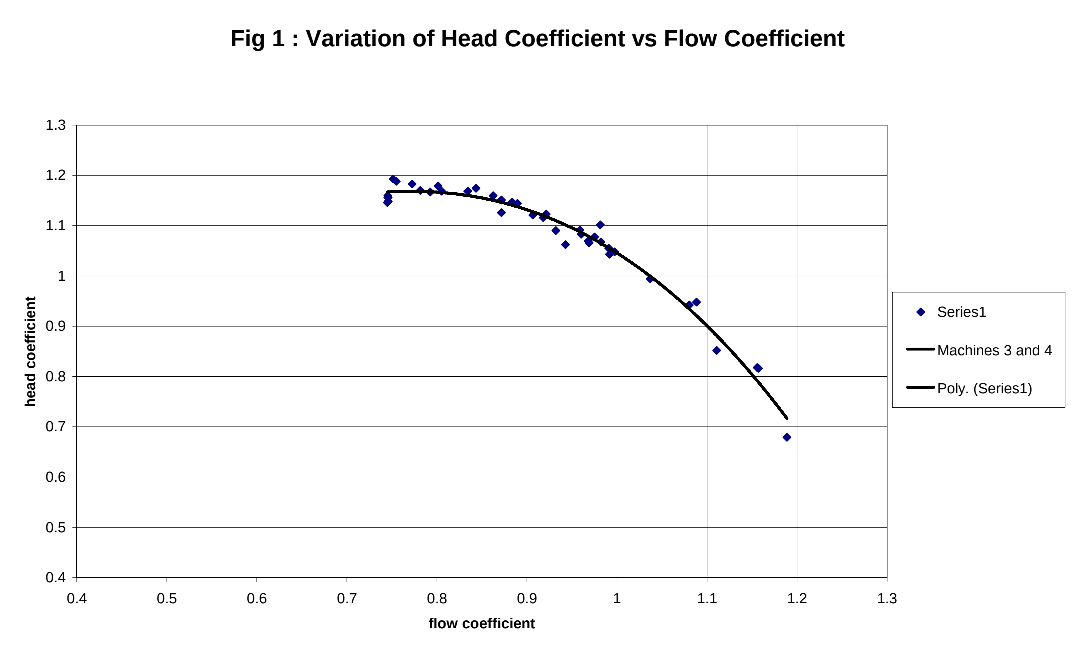
All the gas compressors operating on the National Gas Transmission System are centrifugal machines and most are single stage operation. They are relatively simple in design having an impeller which can be of the overhung or between bearings design. The most critical section of the machine is the rotor system which contains the impeller, bearings and shaft seals. The condition of the rotor system is usually continuously monitored using vibration monitoring and analysis equipment. Operating on clean dry natural gas it is very rare to find any damage to the gas compressor internals. However, problems can occur due to high vibrations which may require new bearings and shaft seals.

Generally, a gas compressor designed for operating on clean dry gas does not experience any major problems. The most unreliable aspect of the gas compressor as stated above is the rotor system which can create reliability problems due to high vibrations due to bearings and shaft seal wear. However, these should be monitored continuously and timely intervention can prevent any major damage and unreliability problems.

The thermal performance of the gas compressor can also be monitored continuously and compared against the actual design to ensure that no internal degradation is occurring.

Figs 1 and 2 below show how the condition and performance of the actual machine can be continuously monitored by plotting the non dimensional work done by the machine as a function of the flow and also the variation of efficiency as a function of flow. These two characteristics of the machine will also show if the instrumentation used for measuring the performance and condition of the machine is functioning correctly or not.

A gas compressor is usually designed for a range of flow and work conditions which are required by the operator. If, however, these conditions change due to supply and demand, then the internals of the compressor can be redesigned which requires a new rotor system only. It does not require a new compressor. This is the usual practice.



For the centrifugal compressor therefore it can be concluded that:-

1. The condition of the machine can be monitored continuously to ensure that its performance and integrity are within the design requirements.

2. The only item that requires replacement is the rotor system which may need to be replaced due to a change in the work and flow required from the impeller.

3. The major cause of unreliability in a centrifugal compressor operating on a gas transmission system is trips due to high vibrations and shaft seals malfunctioning.

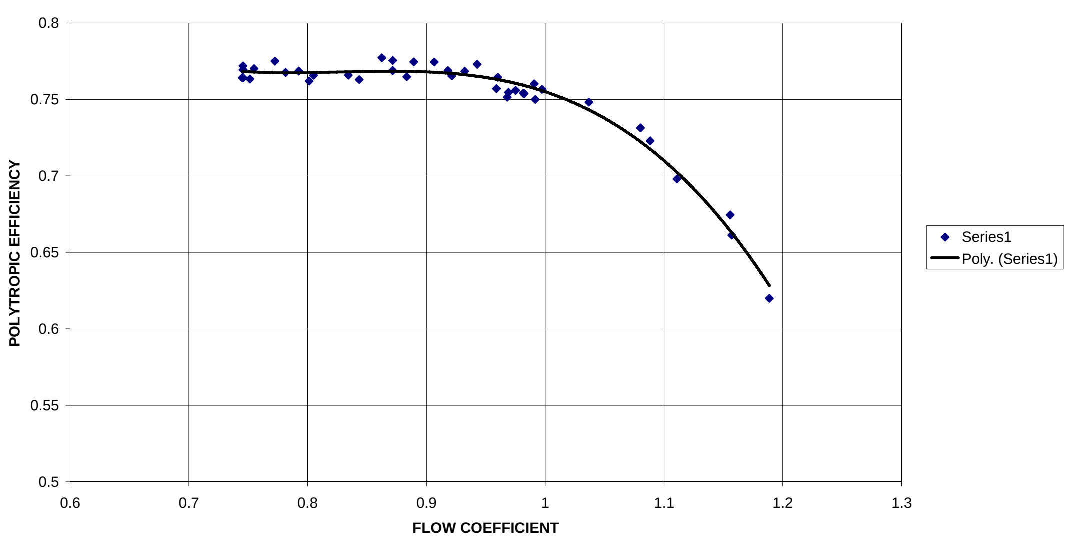
4. The compressor performance measures can therefore be stated as:-

   a) Measure of the work and flow parameters against the expected design requirements.

   b) Operating efficiency of the machine.

   c) Start and run reliabilities which are both affected principally by the rotor vibration characteristics.

Fig 2 : POLYTROPIC EFFICIENCY Vs FLOW COEFFICIENT



GAS TURBINE (COMPRESSOR DRIVER)

Unlike the gas compressor and in particular aero derivative gas turbines are more complex and much more prone to failure. The reliability of these gas turbines is also affected by the operating mode of the compressor station. Where machines are continuously brought on line and run for short periods before being taken off line then it is likely that there will be higher levels of unreliability and a higher level of internal component degradation compared to machines that are brought on line and left to run continuously for long periods of time.

The major components of a typical gas turbine operating on the UK National Gas Transmission System are:

- Air inlet and filtration system
- Axial compressor/s
- Combustion chamber
- Axial turbine
- Power turbine
- Control system

Fig 3 shows the layout of the above components in a 3 shaft gas turbine system.

Major Components of a Gas Turbine Engine System

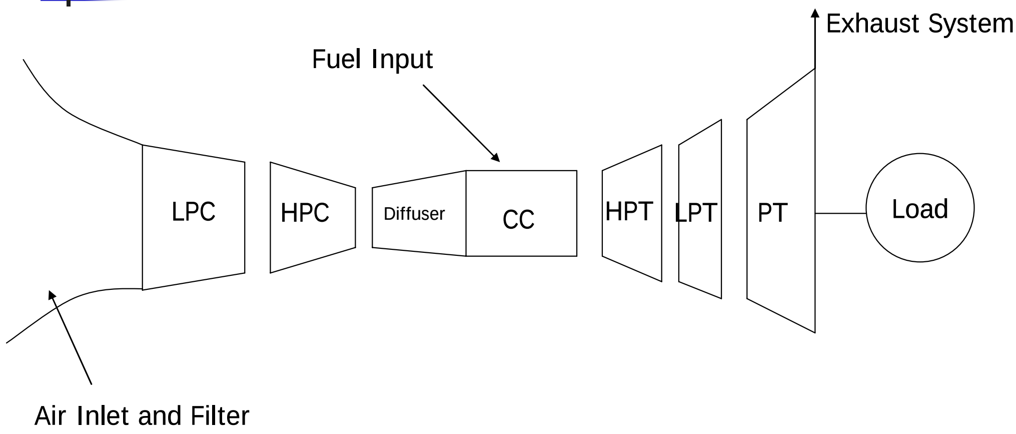


Fig 3: Typical Layout of a 3 Shaft Gas Turbine System

Unlike the gas compressor which operates in a clean and dry environment, the gas turbine operates under much more arduous conditions. The failure or underperformance of any individual component will have a detrimental impact on the performance of the whole gas turbine system.

As demonstrated with the gas compressor it is possible to monitor the actual performance and degradation of the complete gas turbine system by comparing it with the original design parameters. The actual performance of each section of the machine can be plotted and compared to the expected performance and this can be done using on line systems. From this analysis decisions can be made regarding the need to refurbish the machine, replace individual sections or a complete replacement. Similar to the gas compressor the mechanical integrity of the unit is usually monitored using vibration measuring equipment and software which provide details regarding the health of the gas turbine rotor systems.

The usual practice for a gas turbine is to carry out a refurbishment of the gas generator system between 18000 to 24000 running hours and 50000 running hours for the power turbine. These running hours, however, will depend on how the gas turbine has been operated. The above values are typical if the machine is operated at the design point. The running hours may be extended if the machine is operated at below the design point or reduced if it is operated above the design point.

The key point to note from the above is that it is crucial for an operator to monitor the operation of the gas turbine system on line continuously. This approach will provide accurate decision making data which is objective rather than subjective.

The areas of unreliability in a gas turbine system as described above are:-

1. High vibrations of the rotor systems
2. Problems in the combustion system due to fuel quality
3. Degradation of components due to high metal temperatures
4. Ignition problems at start up
5. Flame failures

The need to replace a gas turbine on a compressor station will usually be due to:

- Insufficient power to meet the gas compressor work and flow parameters
- A serious component failure in the front end of the gas turbine such as the low pressure axial compressor which results in damage throughout the complete gas turbine system right the way through to the power turbine.

Whilst it may be difficult to anticipate a significant change in the flow conditions which may require more power and hence the need to replace a gas turbine, it is definitely possible to avoid catastrophic failures by monitoring the gas turbine continuously. Another option which may be available to increase the power output without the need for the complete replacement of the gas turbine is to re-rate it and carry out more regular major overhauls.

It can be concluded that for the gas turbine:

- Its condition and performance can and should be continuously monitored
- It is the most sensitive component on a gas compressor station
- The key performance indicators are mean time before failure, efficiency and start reliability and maintenance costs per fired hour

GAS TURBINE EXHAUST STACK

Gas turbine exhaust stacks are required to exhaust the combustion products away safely into the atmosphere and also to reduce the noise of the combustion system as they exit the power turbine. These stacks operate in a harsh environment as they operate between high exhaust temperatures exiting from the power turbine into low temperatures in the atmosphere. They are therefore subjected to thermal cycling which will eventually degrade the insulating capacity of the system and hence lead to a decrease in performance and increased noise. Increased noise levels have an impact on the local environment due to noise pollution.

The condition of the exhaust as stated above is quite easily determined by measuring the noise being emitted at a certain distance and compared against the allowable levels for the station.

INSTRUMENTATION AND CONTROL SYSTEM

Instrumentation and control system failures are a major source of unreliability of any process plant operation. One method of increasing the reliability is to design in additional redundancy. However, this will lead to additional capital costs and also possible increases in maintenance activity.

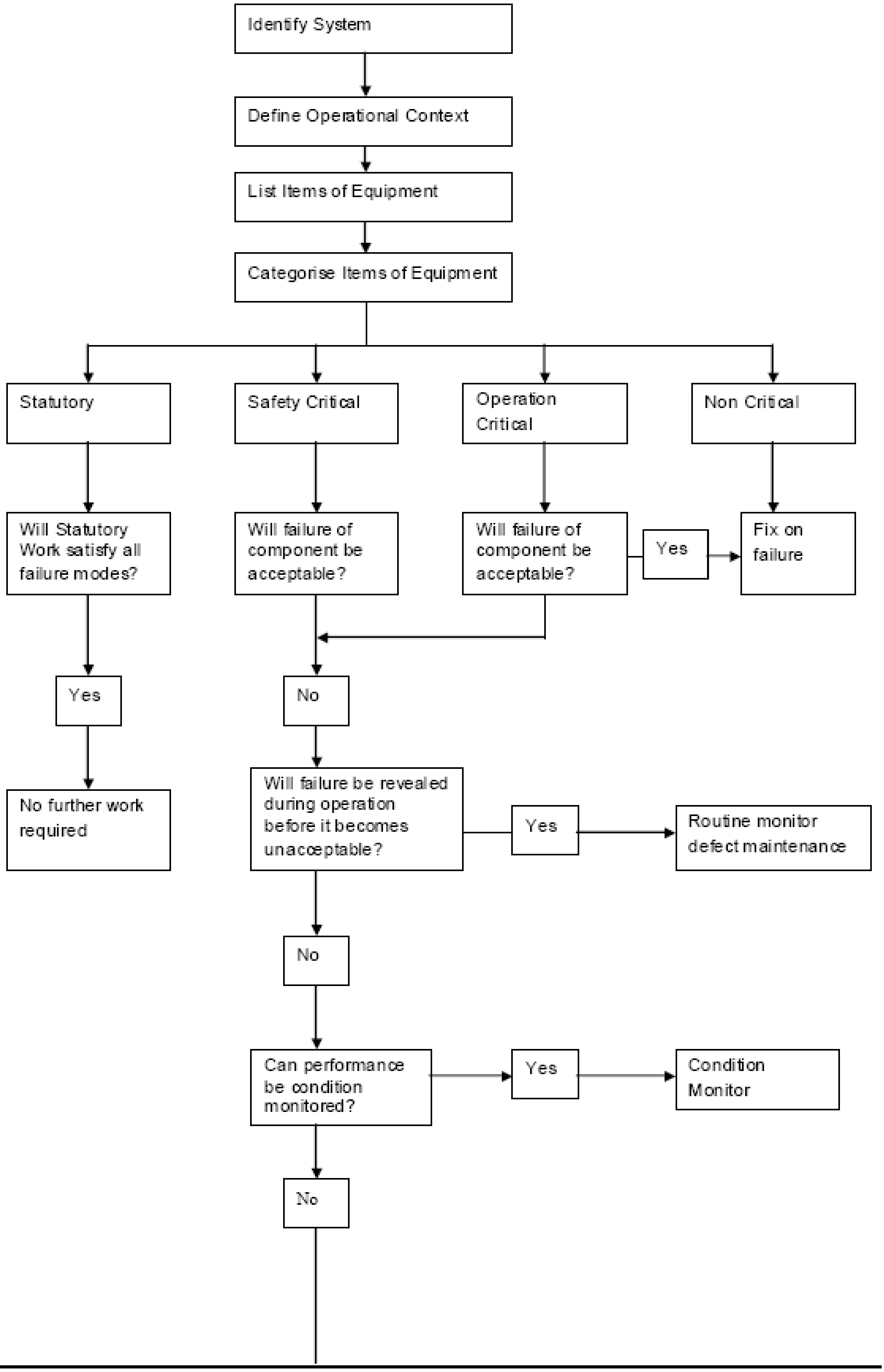
It is very difficult to increase the reliability of an existing control and instrumentation system other than to increase the maintenance activity. The reliability of the control and instrumentation is a key aspect of the design and specification at the initial phase of the project. To increase the reliability of the equipment operating on the UK's National Gas Transmission System it to evaluate the existing designs and consider a gradual replacement of the older equipment which may also be affected by obsolescence and the lack of spare parts availability.

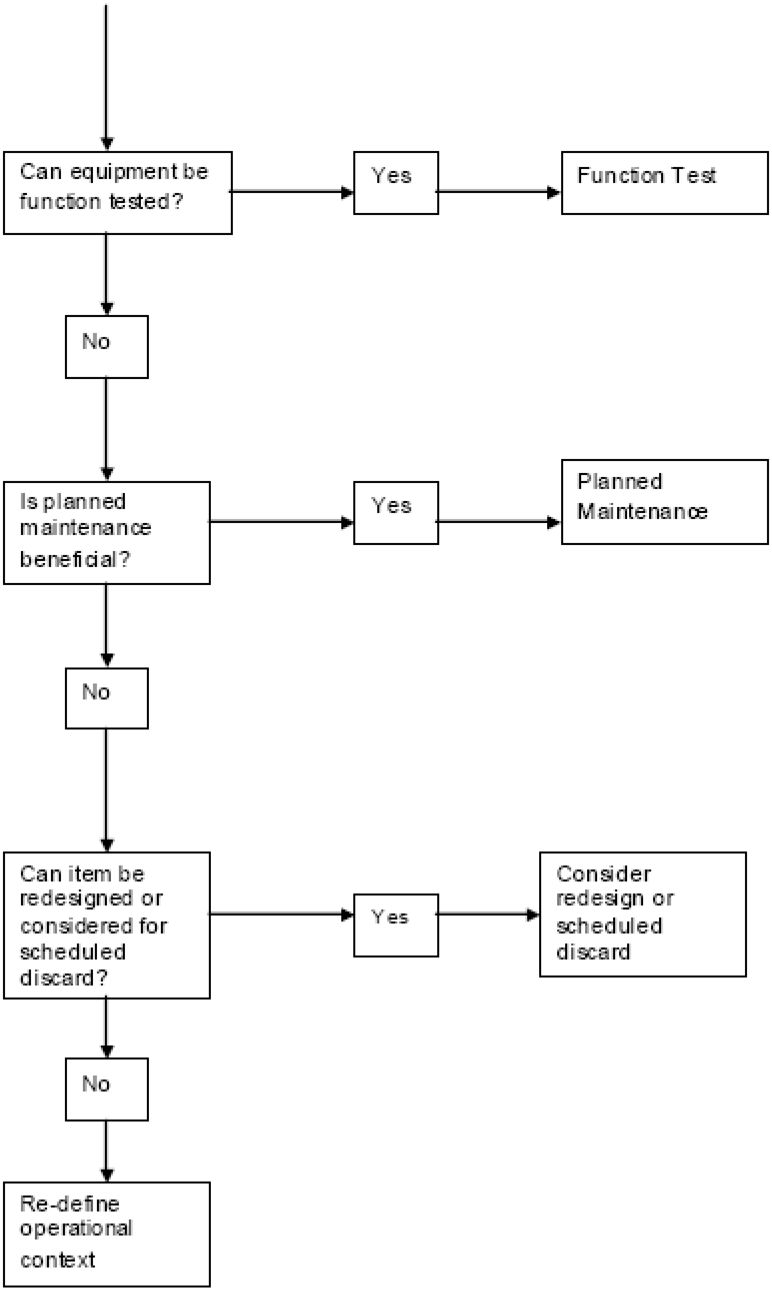
CONTINUOUS MONITORING OF PLANT AND EQUIPMENT

In summary it can be seen from the discussion above that to establish objective measures for condition and performance measurement of plant and equipment on a process plant, it is essential to maintain a system of measurement and recording which monitors the plants operating parameters continuously.

To achieve meaningful measures of reliability and condition, the measurement and recording system needs to be calibrated against the performance of the plant and equipment when it is new, or has been refurbished and re-zeroed. Only in this way can objective measures be established against which the plant's performance can be measured in the future.

APPENDIX 4. MAINTENANCE ALGORITHM




Can equipment be function tested?
Yes
Function Test
No
Is planned maintenance beneficial?
Yes
Planned Maintenance
No
Can item be redesigned or considered for scheduled discard?
Yes
Consider redesign or scheduled discard
No
Re-define operational context