Document 15
Asset Category – Modelling Overview
SPN

Asset Stewardship Report 2014

Ian Butler

Approved by Richard Wakelen / Barry Hatton

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Document History

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Preface

UK Power Networks uses Asset Stewardship Reports ('ASR') to describe the optimum asset management strategy and proposals for different groups of assets. This optimised asset management strategy and plan details the levels of investment required and the targeted interventions and outputs needed. Separate ASRs define the most efficient maintenance and inspection regimes needed and all documents detail the new forms of innovation which are required to maximise value, service and safety for all customers and staff throughout the ED1 regulatory period. Outline proposals for the ED2 period are also included.

Each DNO has a suite of approximately 20 ASR's. Although asset policy and strategy is similar for the same assets in each DNO the detailed plans and investment proposals are different for each DNO. There are also local issues which must be taken into account. Accordingly each DNO has its own complete set of ASR documents.

A complete list of titles of the ASR's, a summary of capex and opex investment is included in '**Document 20: Asset Stewardship Report: Capex/Opex Overview'**. This document also defines how costs and outputs in the various ASR's build up UK Power Networks 'NAMP' (Network Asset Management Plan) and how the NAMP aligns with Ofgem's ED1 RIGs tables and row numbers.

This ASR has also been updated to reflect the feedback from Ofgem on our July 2013 ED1 business plan submission. Accordingly to aid the reader three additional appendices have been added. They are;

1. **Appendix 1 – Efficiency benchmarking with other DNO's:** This helps to inform readers how UK Power Networks is positioned from a benchmarking position with other DNO's. It aims to show why we believe our investment plans in terms of both volume and money is the right answer when compared to the industry, and why we believe our asset replacement and refurbishment investment proposals are efficient and effective and in the best interest for our customers.

2. **Appendix 2 – Endorsements from EA Technology & SKM:** This section summarises the conclusions made by EA Technology relating to UKPN's HI processes

3. **Appendix 3 – Endorsement from SKM:** This section summarises the conclusions made by SKM relating to UKPN's HI processes

4. **Appendix 4 - UKPN observations relating to HI's following Ofgem feedback:** This section summarises UKPN's response to Ofgem's initial feedback on our HI's

All of the cost numbers displayed in this document are before the application of on-going efficiencies and real price effects.

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SPN – Modelling Overview

1.0 Executive Summary

This document identifies the significant enhancements UKPN has made to its earlier asset deterioration modelling capability, used since April 2012 to assess Health Indices (HIs). The enhanced modelling capability is currently being used to manage UKPN's risk-based asset condition replacement portfolio across all three licensed areas during DPCR5 and also RIIO-ED1. This novel and rigorous approach is essential, because the funding being requested in ED1 will still result in a substantial net ageing of UKPN's asset base. It is only possible to protect society and customers from severe service failures with rigorous asset end-of-life management, and modelling methods. The introduction of the new modelling approach represents a significant step change in UKPN's management of risk, targeting investment needs where they are required to deliver stable levels of service to customers.

The introduction of both the new modelling methodology and the data completeness, accuracy and timeliness (CAT) scoring process was a major step change in the approach to modelling asset deterioration. UK Power Networks, working in partnership with EA Technology, has a programme of further development for its modelling capability.

For the SPN region within UK Power Networks, there has been a consistent volume of HI4 and HI5 assets despite changing to the new models. A more noticeable change in the HI profiles is the volumes of HI2 and HI3 assets. The new methodology indicates a significant decrease in the volume of HI2 assets and a doubling of HI3 assets. This change in volumes of HI2 and HI3 assets is a result of the approach adopted by the reactive models, which assigned 70% of non HI1, HI4 and HI5 assets into the HI2 category.

The purpose of this document is to discuss the enhancements and the resultant HI profiles.

The key enhancement points to note are below:

- UKPN has introduced a step change in its approach to modelling asset deterioration, which is used to drive HI profiles and subsequent capital investment plans. This step change allows UKPN to use the most up-to-date advances in modelling capability to support asset health, asset criticality and asset risk in order to more efficiently and effectively manage the end-of-life risk of UKPN's asset base.
- The new Asset Risk and Prioritisation (ARP) models cover 84% of the HI reportable asset NLRE investment plan which equates to £180m, and builds on the established foundation of Condition Based Risk Management (CBRM). CBRM is widely used across the industry and benefits from EA Technology's extensive industry experience and field observations. We have engaged EA Technology to develop ARP to specifically target the requirements of RIIO.
- The CBRM approach had previously only accounted for 15% of the HI categories at UK Power Networks. CBRM was used during the formulation of the DPCR5 business plan. ARP has replaced CBRM and will be used for the remainder of DPCR5 and for developing the RIIO business plan for ED1.
- The new models use improved data and are driven by a significantly higher number of asset condition and defect points. This will benefit customers because UKPN is moving towards rigorous end-of-life management of very old and ageing assets. Assets can be safely managed to work closer to their actual point of failure.
- The new ARP models have gone through a very rigorous testing and calibration regime. This regime was specially developed and designed for the ARP models.
- Completeness, accuracy and timeliness (CAT) scores have been developed to assess and promote asset data quality and drive future data improvements.

- The new modelling capability has been developed to be dynamic, allowing models to be updated with asset data on a monthly basis – a function that could not be achieved through the CBRM approach.

- The new modelling approach developed to support ED1 condition-based asset-replacement volumes provides UK Power Networks with model asset criticality in addition to health.

- For some low-value assets, UKPN has developed simplified deterioration models, influenced by data quality and demonstrating better value for our customers.

- A dedicated team has been established within the Asset Management structure to continually develop UKPN's approach to asset health, risk and criticality.

In summary we have combined our leading decision support tool, ARP, with the experience of our senior asset engineers who have developed our investments plans. Ultimately our investment plan is developed utilising good engineering assessment and knowledge. This approach will ensure that our plans are robust and appropriate to maintain a safe and reliable service to our customers.

These significant enhancements to our modelling approach have resulted in a revised set of HI profiles based on enriched information.

All of the cost numbers displayed in this document are before the application of on-going efficiencies and real price effects.

2.0 Introduction

UKPN has been working with EA Technology to enhance and expand existing modelling techniques for establishing and managing asset health. The reason for these enhancements is to build upon the existing stewardship of an ageing asset base, incorporating asset risk and criticality. To enable the enhancements, UKPN has developed a new modelling approach that builds upon the long-established methodology of Condition Based Risk Management (CBRM); the new models are named Asset Risk and Prioritisation (ARP). ARP has the capability of using asset health, risk and criticality as a decision-making support tool to drive future investment interventions.

The development of ARP started in May 2011 and is split into a number of phases: Phases 1 and 2, which are now complete, saw the development and implementation of the new base modelling capability, and enabled criticality and risk to be modelled. Further phases will look at introducing a combined load and non-load modelling capability, the ability to trade off Opex and Capex investment decisions, and the impact and optimisation of investment to support a low-carbon SMART future. This is an ongoing project due for completion by 2015.

ARP modelling covers the majority of HI reportable asset groups. These are shown below with the previous modelling approach used to assess HIs.

Asset Category	Previous Methodology	New Methodology
LV OHL support poles	Reactive	ARP
HV OHL support poles	Reactive	ARP
HV switchgear (GM) primary	CBRM	ARP
HV switchgear (GM) distribution	CBRM	ARP
EHV UG cable (oil)	Condition Index	ARP
EHV switchgear (GM)	CBRM	ARP
EHV transformers	Condition Index	ARP
EHV OHL support poles	Reactive	ARP
EHV OHL support towers	Reactive	ARP
EHV OHL fittings and conductor	Reactive	ARP
132kV UG cable (oil)	Condition Index	ARP
132kV circuit breakers	Condition Index	ARP
132kV transformers	Condition Index	ARP
132kV OHL support towers	Reactive	ARP
132kV OHL fittings and conductor	Reactive	ARP

Table 1 – Summary of ARP models

The following table represents HI reportable assets that are not included in the scope of ARP. The HIs for these assets are calculated using newly developed alternative approaches.

Asset Category	Previous Methodology	New Methodology
LV switchgear and other	Reactive	Statistical Asset Replacement Model (SARM)
LV UGB	Reactive	Markov model
HV transformer (GM)	Reactive	Statistical Asset Replacement Model (SARM)
EHV UG cable (gas)	Reactive	Statistical Asset Replacement Model (SARM)
132kV UG cable (gas)	Reactive	Statistical Asset Replacement Model (SARM)

Table 2 – Summary of non ARP models

The two alternative modelling approaches, SARM and Markov, have been developed where the asset base is relatively small (e.g. gas-filled cables) or where we are looking to enhance our data quality to enable ARP models to be developed in the future.

UKPN has made substantial improvements to its asset data and asset risk management in all areas. The ARP process has now been deployed on all HI reportable assets where there are significant risks and expenditures involved.

3.0 Early Approach to Defining Asset Health

During 2008 and 2009, three different approaches were developed for deriving asset health. These were:

- Condition Based Risk Management (CBRM)
- Condition Index models
- Reactive models

3.1 CBRM Models

Historically, UKPN used the CBRM models, developed by EA Technology, to guide investment decision-making on non-load-related asset replacement. The CBRM modelling approach is widely used by other Distribution Network Operators (DNOs) and is widely viewed as an acceptable approach to modelling deterioration of assets to drive future investment plans and measure HI profiles. The CBRM models provided a Health Index (HI) as an output for individual assets, e.g. each unit of switchgear, with the Health Index being a measure of the overall condition of the asset and its probability of failure.

The HI was calibrated against probability of failure (POF). Within the model, a deterioration algorithm was applied that enabled the future condition and POF to be estimated. The deterioration and POF were developed by EA Technology, based on many years of experience and supported by field observations.

The HI was calculated on a scale of 0 to 10, with low values indicating good condition and high values indicating poor condition. The CBRM models applied to the following asset groups:

- HV distribution switchgear
- HV primary switchgear
- EHV switchgear

To accurately express the Health Indices of all our HV distribution, HV primary and 33kV switchgear as an output measure, as recognised by Ofgem, we used the same scale (1–10) as the CBRM Health Index tool, which was mapped to the HI output measures as follows:

Output measure	CBRM output
HI 1	0.5–1
HI 2	1–4
HI 3	4–6
HI 4	6–7*
HI 5	>7

Table 3 – CBRM HI Mapping

*The only exception to the above HI classification was for 11kV switchgear at distribution sites in SPN and EPN. We selected the band for HI4 as 5.5–7 (all other bands were unchanged). This was due to the distribution switchgear population in EPN and SPN being predominantly outdoor and more prone to environmental driven deterioration.

3.2 Condition Index Models

In order to establish a Health Index for assets not covered by CBRM, UKPN initially derived Condition Indices from limited available condition data. The Condition Index models were not as advanced as the CBRM models and only used asset age combined with condition assessment measurement data captured in Ellipse (UKPN's asset register) to determine condition indices and derive a Health Index. Factors such as environmental location, which can affect asset deterioration, were not considered in this methodology.

The decision to use the Condition Index model approach was based on the size of the set of condition measurements. Where the set of condition assessment measurements was small or the output did not show a correlation with our knowledge of replacement history, UKPN used a reactive methodology, which will be explained in the next section of this paper.

The following asset groups were covered by Condition Index models**:**

- **Transformers**
  EHV AND 132kV transformers
  132kV transformer

- **Switchgear**
  - 66kV switchgear (LPN only)
  - 132kV switchgear

- **Pressurised cables**
  - EHV FFC
  - 132kV FFC

3.3 Reactive Models

This methodology was used for asset groups where replacements were planned on a reactive basis from ad hoc condition assessments or long inspection cycles. The rate of deterioration was assumed to be reasonably constant (during DPCR5) and so could be based on historical projections.

For the assets covered by reactive models, the set of condition assessment measurements in Ellipse was too small to be used as a sample or the outputs of the condition assessment measurements were too small in comparison to our knowledge of condition-based replacement history. In the absence of sufficient credible data, this approach assumed that future asset replacement volumes planned for DPCR5 would be aligned to historical profiles.

The following assumptions were made with the application of this approach:

- DPCR4 additions are categorised as HI1 in year zero.
- The first two years of removals in DPCR5 are based on existing condition and historic projections and categorised as HI5 assets in year zero.
- The final three years of removals in DPCR5 are based on existing condition and historic projections and categorised as HI4 assets in year zero (and HI5 upon removal during the final three years of DPRC5).
- The remaining assets are split between HI2 and HI3.

Working to the assumptions listed above, this methodology would only assign assets as HI4 and HI5 that had been identified as requiring replacement during the DPCR5 period. Therefore, this approach would underestimate the total number of HI4 and HI5 assets on the network.

This methodology was applied to:

- Linkboxes
- LV switchgear (pillars, wall-mounted boards, fuses)
- LV poles
- HV poles
- 6.6/11kV transformer (GM)
- EHV gas cable
- 33kV tower line
- EHV and 132kV towers
- 132kV gas cable
- 132kV tower line (conductor)

With the exception of steel towers and gas cables, the reactive methodology was applied to low-value high-volume assets.

4.0 The Development of the ARP Models

The development of the ARP models within UKPN is a step change in the approach to consistent model asset deterioration, used to drive future condition-based investment. UKPN has implemented ARP across a greater proportion of the HI reportable asset categories. ARP is a consistent and structured process that combines asset information, engineering knowledge and practical experience to define future condition, performance and risk for network assets.

4.1 Method of Operation of the ARP Models

The first stage in the ARP process is to determine a numeric representation of the condition of each asset, known as a Health Index (HI). The HI of an asset combines information that relates to its age, environment, duty, specific condition and performance. This is to give a comparable measure of condition for individual assets in terms of proximity to end-of-life (EOL) and probability of failure (POF).

The ARP models use a rating of 1–10 to measure the current health of an asset.

Low values (in the range 0–4) represent some observable or detectable deterioration at an early stage. This may be considered as normal ageing, i.e. the difference between a new asset and one that has been in service for some time but is still in good condition. In such a condition, the POF remains very low and the condition and POF would not be expected to change significantly for some time.

Medium HI values, in the range 4–7, represent significant deterioration, where the asset's degradation is starting to move from normal ageing to processes that potentially threaten failure. In this condition, the POF, although still low, is just starting to rise and the rate of further degradation is increasing.

High values of health index (>7) represent serious deterioration, where degradation processes are so advanced that they threaten failure. In this condition, the POF is now significantly raised and the rate of further degradation will be relatively rapid.

ARP HI Scores Mapped to Ofgem HI Categories

ARP Score	Ofgem HI
0.5–1	1
1–4	2
4–6	3
6–7	4
>7	5

Table 4 – ARP HI Mapping

When deriving health indices, the following must be taken into account:

- The HI is built from available condition-related information and is intended to reflect an engineering assessment in a consistent manner.
- Once the existing HI has been established, the ARP models can predict the change in HI over time and future failure rates, and how these might be affected by different intervention strategies over specified lengths of time.

The detail of the HI formulation is different for each asset group, reflecting the different information and the different types of degradation processes. However, there is an underlying architecture, which is outlined below:

For a specific asset, an initial age-related HI is calculated using knowledge and experience of its performance and expected life, taking into account factors such as original specification, manufacturer, operating experience and operating conditions (duty, proximity to coast, etc).

Where condition information relating to specific degradation processes can be used to identify potential end-of-life conditions (i.e. oil test results for transformers), a separate factor is derived for each degradation process, calibrated by linking a defined condition to a specific HI value. This gives rise to a number of multipliers, one for each potential end-of-life condition. These are then combined to give a combined HI.

Additional information that is indicative of condition but cannot be directly related to specific degradation processes is used to create additional 'factors' that modify the basic age-related HI described above. Examples are factors relating to dielectric test results, fault/defect history and reliability issues associated with specific equipment types (e.g. different manufacturers).

4.2 ARP Asset Data – Completeness, Accuracy and Timeliness (CAT) scores

The ARP deterioration modelling approach that UKPN has developed to drive current and future asset condition-based investment programmes makes use of high-quality asset data collected across the business. To control and measure the quality of the data feeding into the ARP models, UKPN has developed an innovative data quality and control process. This is called our CAT scoring methodology, which measures data quality. The ARP models were developed as investment decision-making support tools. In order to use the models to their best effect, the data needs to be fully understood; this will influence the amount of expert judgement required to support the output of the models.

While the CAT score provides a measure of data quality for a specific moment in time, the detail behind the scores can be used to drive data quality. The CAT scores are updated on a regular basis. Currently, CAT scores are developed for the ARP models.

A summary of the results of the CAT scores:

- **Completeness Score** – indicates that data flow is reasonably good for the majority of asset groups; some gaps identified will be due to the time elapsed between data extraction from the source and ARP.

- **Accuracy Score** – demonstrates that the data accuracy is at an acceptable level, based on the inspector's personal experience and the knowledge of independent surveys undertaken by third party independent consultant SKM.

- **Timeliness Score** – places a good emphasis on maintenance and inspection operations of UKPN assets and highlights that the data is timely and up-to-date.

Data completeness is rising as enhanced processes collect high data through policy-driven inspection cycles. For new assets where risk of failure is low, it may be several years before data completeness scores rise towards 100%.

The current CAT scores for data supporting the ARP models are tabulated below.

<table>
<tr><th>ASSET CATEGORY</th><th>COMPLETENESS SCORE</th><th>ACCURACY SCORE</th><th>TIMELINESS SCORE</th></tr>
<tr><td>Grid & Primary Transformers</td><td>90</td><td>89</td><td>99</td></tr>
<tr><td>HV Primary Switchgear</td><td>71</td><td rowspan="5">89</td><td>97</td></tr>
<tr><td>Distribution Switchgear</td><td>62</td><td>97</td></tr>
<tr><td>22KV & 33 KV Switchgear</td><td>69</td><td>98</td></tr>
<tr><td>132KV & 66KV Switchgear</td><td>67</td><td>97</td></tr>
<tr><td>Steel Towers</td><td>68</td><td>N/A</td><td>94</td></tr>
<tr><td>Fluid Filled Cables</td><td>87*</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Wood Poles</td><td>60</td><td>N/A</td><td>47</td></tr>
<tr><td>Distribution Transformers</td><td>94</td><td>N/A</td><td>N/A</td></tr>
<tr><td>LV Switchgear</td><td>94</td><td>N/A</td><td>N/A</td></tr>
</table>

Link Boxes	65	N/A	100

Table 5 – CAT scores as of 8th February 2013

Source : Data Quality Report – data requirement file
ARP:
Z:\ARP Data requirement\ARP Data Quality Report Data Requirement

Non-ARP:
Z:\ARP Data requirement\Non-ARP CAT Score

Key

Green – Score of 85% or greater
Amber – Score of 65% or greater
Red – Score of less than 65%

*Fluid filled cable completeness score is based on fluid leakage rates.

The completeness scores for distribution switchgear and completeness and timeliness for wood poles must improve. The initial low CAT scores are due to the very large numbers of assets. This asset class will be one of the last to achieve good asset quality during the DPCR5 contract period. UKPN is able to tolerate this level of risk in DPCR5 because asset replacement has been guided by good data held on particular types and model of switchgear equipment known to age badly and be susceptible to failures in service. UKPN have the following initiatives underway in order to improve data quality:

- Inspection & maintenance activity on the assets by UKPN staff is undertaken using mobile devices. An enhancement has been developed and applied to the mobile software such that key asset attributes recorded in the asset registers are presented in a dedicated nameplate screen to the user as they record their work. The user is shown existing values to review against the asset which can be readily updated by entering a new value if found to be incorrect. To maintain / improve accuracy the new value is validated on entry (where appropriate). To aid completeness the user is alerted if the screen is exited with any attributes remaining blank i.e. having neither an existing or new value.

- A review of the way narrow-based Towers are managed in UKPN asset register was completed. A new inspection script has been introduced that is more relevant than the current pole script that is used for them, providing more specific asset condition information.

5.0 Model Comparisons and Outcomes

This section of the paper will explain firstly the common comparisons between the ARP models and the original models and will then continue to discuss specific comparisons between each modelling approach.

5.1 Common Enhancements

- The ARP models have been developed in partnership with EA Technology, building upon the already successful Condition Based Risk Management (CBRM) approach. The development of the reactive models was undertaken internally without the benefit of external expertise. The ARP approach is also hosted in an SQL environment, making it much more versatile and a more secure platform.
- The new models use improved data and are driven by a significantly higher number of asset condition and defect points. This will benefit customers as UKPN is moving towards rigorous end-of-life management of very old and aging assets. Assets can be safely managed to work closer to their actual point of failure.
- Environmental factors that influence asset deterioration, such as altitude and proximity to coast, are included in the ARP approach, but were not included in the Condition Index models.
- The ARP models assign an average age that is specific to each asset's make and model, whereas the original Condition Index model assigned a generic average age across all asset makes and models. This process increases the ability of the ARP approach to model more accurately how assets behave in the field, and also enables accurate modelling of assets with known defect types.
- The ARP models hold additional condition and defect point data, increasing the granularity of the model outputs.
- The ARP models enable UKPN to perform sensitivity analysis to explore multiple intervention scenarios leading to optimised condition-based investment plans.
- Alongside each of the ARP models sits a CAT score, which measures data quality. Implementing a CAT score encourages an understanding of data quality. CAT scores were not developed to score data quality for the original CBRM models. This is a significant step forward in our model development.

5.2 ARP Modelling Methodology versus the Original CBRM Modelling Methodology

The following section provides an overview of the ARP modelling approach.

- The ARP models use latest condition and defect data to model asset condition and future deterioration. The original CBRM models are based on asset data from 2008 and have not been repopulated with revised asset data. The original CBRM models required EA Technology to make modifications to the model and upload asset data from Ellipse. With ARP, each model has a dedicated UKPN asset engineer who is responsible for owning, understanding, maintaining and developing the models.
- The ARP models include advanced functionality over the original CBRM approach, enabling asset risk and criticality to be modelled in addition to asset health.
- The original CBRM models developed in 2009 are based on samples of assets within each HI reportable asset category. The worst affected asset category is the EHV switchgear model in LPN, where the original HI profile

is based on a sample size of 49% of the total asset population, which was then scaled up to align to the asset population. The philosophy of ARP is that the total population of assets is used.

- The original CBRM models used EA Technology's standard calibration settings, while the ARP models have been extensively calibrated and tested. UK Power Networks engineers and EA Technology experts jointly carried out the model calibration and testing as part of the ARP development. Taking into account the calibration and testing on the ARP models and the additional data points used in ARP, the ARP models more accurately model asset deterioration when compared to the original CBRM approach. Testing documents and sign-off documents are available on request.

- ARP modelling tool has gone through thorough data, methodology and software testing to ensure its reliability and accuracy. The current ARP models have gone through three stages of development, namely Excel modelling phase, ARP software Phase 1 and Phase 2.

- During initial ARP prototyping on Excel platform, UKPN has hosted numerous calibration sessions with EATL for asset owners to gain understanding of model methodology and calibrate the models with assistant from EA experts. The results produced by these calibration settings are then validated by UKPN engineers with their experience and expertise in the UKPN assets.

- After all the modelling methodologies were confirmed and signed off, Excel models were then developed into data server driven software during ARP software Phase 1 development.

- With improvement suggestions collected during phase 1 development, UKPN commenced Phase 2 of ARP development to further improve modelling methodology and software functionality.

The enhancements described above result in a more robust modelling of Health Indices.

5.3 ARP Modelling Methodology versus Reactive Modelling Methodology

The main differences between the ARP modelling approach and the original reactive model approach are summarised below.

- The original reactive models were developed where there was deemed to be insufficient asset and condition data to develop a more robust approach. The reactive models were developed in 2009, since when the business has undertaken significant data improvements that have enabled it to evolve an improved modelling methodology.

- The original reactive model used condition/defect data collected by inspectors in the field to identify potential future interventions, e.g. hammer testing on wood poles. Once the volumes of defective and suspect poles had been identified, these would have been programmed into the DPCR5 plan and mapped to a Health Index category. Any condition-based replacements programmed for years 10/11 and 11/12 were classified as HI5 and any condition replacements programmed for 12/13, 13/14 or 14/15 were classified as HI4. The volumes of HI4 and HI5s are those that were planned to be replaced for condition in DPCR 5 and mapped to table NL3 of the FPBQ.

- The ARP model provides a more rigorous approach to modelling deterioration that enables additional variables to be included, for example location, preservative and leaning pole factors. Therefore, the volumes of HI4 and HI5s generated by the ARP model are representative of the entire asset population for each asset category. This allows older critical assets to be managed much closer to their end-of-life than would otherwise be possible.

- The reactive approach did not assign an HI to each individual asset; hence it is not possible to accurately track asset deterioration other than at cohort level.

- The reactive models currently use data sourced from 2008. The ARP models have been linked to condition data captured in Ellipse via bespoke data output files that enable the ARP models to be refreshed with data on a monthly basis.

6.0 Markov Model

The Markov model is only used to model the deterioration of linkboxes. This approach was adopted because there is a reasonable sample of asset condition data. The decision to use the Markov model is a practical solution that demonstrates good value to customers. However, the data is currently insufficient to develop a more advanced approach, such as ARP. The linkboxes asset category has a reasonable population of condition data. The Markov model uses asset condition point data and operates on a scale of 1–4, which is in turn mapped to the Ofgem HI scale of 1–5.

The model calculates the projected annual volume of future replacements for a single asset type, in a single license area, from 2012 to 2041 using baseline condition ratings and probabilistic deterioration assumptions. It is intended for budgeting and does not identify specific assets to be replaced. It is designed for asset types that are difficult to inspect, where age is often unknown, and so other more sophisticated modelling approaches cannot be applied.

The model base case has been tested against historic data, to ensure it matches and reports the actual historic performance of these assets. The model also allows the impact of different policies and assumptions on service safety to be investigated. This process has been used to refine company asset policy and develop good value proposals for ED1.

7.0 Statistical Asset Replacement Model (SARM)

The SARM models are used on the asset categories where it is not possible or good value for customers to develop an ARP model. Assets modelled using the SARM methodology include LV switchgear; HV transformer; EHV UG cable (gas); and 132kV UG cable (gas).

The model identifies the volume of assets that will require replacement, driven by condition, over any given period of time. The model operates at cohort level and does not model deterioration on an asset-by-asset basis. At this current time, UKPN does not consider it to be cost-effective to capture the data required to support the development of full ARP models.

The model applies an asset-specific, user-defined, age-at-replacement profile to the current asset base in order to generate future annual replacement volumes. The age-at-replacement profile is defined by a mean value, and up to three alternative standard deviation (SD) values. From this, the model derives a normally distributed profile. This is applied to each (annual) cohort of purchases in order to project the volume and timing of replacements arising from those purchases.

This model does not make use of any asset condition data, but uses the SD values to model the variability that is known to exist in asset lives.

Underlying this methodology are broad assumptions, including:

- asset age and asset condition are correlated
- deterioration rates do not change
- maintenance/refurbishment policies do not change.

This bespoke model has been implemented using AIMMS (Advanced Interactive Multidimensional Modelling System) software, which is a multi-dimensional modelling software platform with optimisation capabilities – although these are not being used in this model.

The assets modelled by this approach are either low volumes (EHV and 132kV gas cable), low-value assets or distribution transformers (LV switchgear).

8.0 Average Asset Life

The table below summarises our approach to asset lives. The table compares the relationship between the average initial life and the average asset life. The average initial life is a point within the ARP models where deterioration and probability of failure starts to increase, and the average asset life is where the model assumes the asset has reached the end of its operational life. An asset within ARP with an age over the average initial life which does not have any condition or defect data assigned to it will be capped as an HI 3, however if the same asset has detrimental condition and defect data assigned to it, the asset will deteriorate to either and HI4 or an HI 5. The ARP models require condition and defect data to allow an asset to reach HI 4 or HI 5. Also an asset with an age less than the initial asset life with detrimental condition and defect data can be deteriorated to an HI 4 or an HI 5.

The statistical models do not have and average initial life and use the average model end of life to drive intervention.

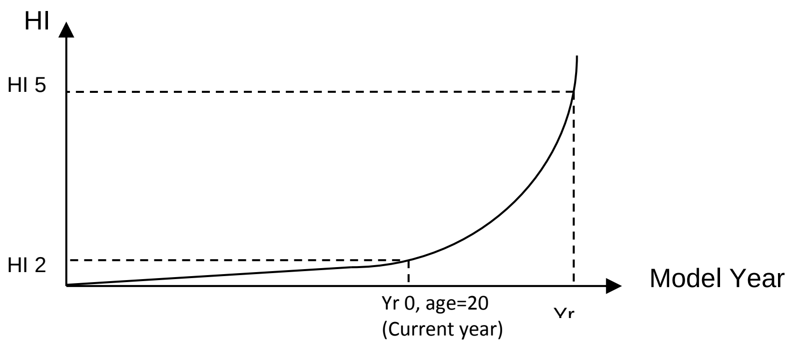
Asset	Average initial life	Average Asset Life
LV Network		
LV Switchgear	N/A	65
LV UGB	N/A	45
LV OHL support	55	70
HV Network		
HV switchgear (GM) primary	48	59
HV switchgear (GM) distribution	44	48
HV transformer (GM)	N/A	70
HV OHL Support	55	71
EHV Network		
EHV switchgear (GM)	51	60
EHV transformer	52	69
EHV cable (oil)	67	75
EHV OHL support poles	55	70
EHV conductor (tower line)	50	55
EHV Towers	N/A	83
EHV Tower painting	N/A	15
132kV Network		
132kV circuit breakers	43	49
132kV transformers	51	69
132kV UG cable (oil)	62	75
132kV conductor (tower line)	50	55
132kV Towers	N/A	88
132kV Tower painting	N/A	15

Table 6 – Asset Lives

Source ARP

The ARP initial life of an asset is derived from its manufacturer and model/type, the combination is mapped to a particular life span calibrated by asset engineers.

Average Asset Life represents the age when an asset reaches HI 5, it is an addition of Years to Reach End of Life and asset current age. Years to Reach End of Life is derived from model HI exponential degradation curve where asset reaches HI 5 from current year. The asset age is then combined with Years to Reach End of Life to generate modelled Asset End of Life.



Asset example
Age = 20 at Model Year 0, HI 2
Age = 60 at Model Year 40, HI 5
Average Asset Life = 20 + 40 = 60 years

Figure 1 – Average Asset Life

9.0 Criticality

As part of our new modelling capability, in addition to asset Health, we have built in the ability to model asset criticality. Asset criticality is a relative comparison of the consequences of failure within the Health index categories. The health index is the probability of failure of the asset. Asset criticality (consequence of failure) and health (POF) are calculated separately within the models; however they are combined to provide a measure of asset risk.

Each asset is placed in a criticality band, based upon the relative magnitude of the consequence of failure of the asset.

There are four criticality bands:-

- C1 – 'Low' criticality
- C2 – 'Average' criticality
- C3 – 'High' criticality
- C4 – 'Very High' criticality

The 'C2' criticality index band represents assets where the consequence of failure is approximately the same as the average consequence of failure for all assets in the same health index asset category. The other criticality bands are then calculated and expressed as a variation to the average consequence of failure per HI asset category.

The following criticality banding is used to define criticality:-

- C1 – less than 75% of the Average Overall Consequence Of Failure
- C2 – greater than, or equal to, 75% and less than 125% of the Average Overall Consequence Of Failure
- C3 – greater than, or equal to, 125% and less than 200% of the Average Overall Consequence Of Failure
- C4 – greater than, or equal to, 200% of average consequence of the Average Overall Consequence Of Failure

The criticality banding criteria aligns to the recommendations of the "Criticality Index Common Principles document dated 13th December 2012" which is an output from the Ofgem Criticality & Health Index working group.

The criticality bandings consider the consequences of failure of an asset in each of the following categories:-

- Network Performance consequence
- Safety consequence
- Environmental consequence
- Financial consequence of repair/ replacement

Examples of failure in each asset category:-

Consequence category	Consequence measure
Network Performance	IIS impacts for Distribution Assets, VoLL for N-1 assets
Safety	Valuation of Fatalities, Major and Minor Injuries
Environmental	Valuation of contaminant impacts and fugitive emissions arising from oil & SF6
Financial consequence of repair/ replacement	Cost to return asset to pre-fault availability

Table 7 – Asset Consequence Categories

For each asset the overall consequence of failure is the sum of the consequence of failure in the four categories stated above. The consequence of failure is measured in "modelled" £.

10.0 Innovation

Automated data refresh

Unlike conventional Excel modelling tools that require a manual data manipulation and refresh process that is susceptible to errors, ARP software uses SQL Server Integration Service (SSIS) to automate the data preparation process without any manual intervention. This ensures each model data refresh is generated with the exact same data process rules.

Automated Data Quality Reports

Every model output quality is reliant on input data quality. Automated Data Quality Reports (DQRs) are currently being constructed by UK Power Networks to provide Completeness, Accuracy and Timeliness (CAT) scoring for each ARP model. Upon completion, each ARP model data refresh would be accommodated by an auto-generated DQR to indicate its quality. These automated reports are set to be fully functional in April 2013. This allows asset engineers to understand the data behind the models and any historical data trends that could be relevant to model calibration. The CAT scores are currently manually generated.

Built-in data analysis functionality and reporting

Data analysis functionality and reporting have been built into the ARP models according to asset engineers' requirements. Built-in data analysis functions allow ARP users to view and analyse modelling results within the modelling tool, rather than copying and pasting them to external software such as Excel. This eliminates any possible human error during data transfer.

User-specified reports have been developed inside the models to generate asset-category-specific outputs. This ensures consistent model output reporting and improves the accuracy of results.

More capability

Most of the historical models only aimed to produce a Health Index. The transparency of ARP makes all of the calculation steps visible to users, while many of the intermediate calculation outputs provide useful results to users, for example ageing rate, probability of failure, and condition- and non-condition-related risk.

All the ARP models are based upon a core methodology, so outputs can be comparable across different asset categories. This allows users to make investment decisions by balancing risks across different assets categories.

Superior system

Most of the historical models are built upon Excel. Due to the limitations of the platform, Excel models have the potential to become unstable when dealing with large amounts of data/information. ARP's core engine is a database that has been built to handle a large amount of data, allowing high-volume asset categories to be modelled – something that was not possible with previous modelling capability.

ARP also incorporated secure log-in and strict administration systems. This has proven essential to systems containing sensitive utility network and customer information.

Sustainability

ARP has been developed based on the bespoke Condition Based Risk Management (CBRM) tool from EA Technology. UK Power Networks has established a partnership and ongoing maintenance contract to continuously maintain and improve ARP to ensure its modelling methodology and software is kept up to date.

10.1 Statistical Model Innovation

Statistical approach

With a data improvement programme driven by the CAT scores being introduced for certain low-value high-volume asset categories, such as distribution linkbox and LV pillar, UKPN has introduced statistical models. The statistical models have been developed in conjunction with our consultants, Decision Lab, who specialise in providing operational research solutions. All the statistical figures used within the modelling tools are documented and backed by source data and methodology to provide clarity and logic. In contrast to reactive modelling deployed in DPCR4 and DPCR5, it provides a more evidence-based approach

Superior system

The statistical models use AIMMS software as their core engines. AIMMS offers an all-round development environment for the creation of high-performance decision support and advanced planning applications to optimise strategic operations.

11.0 Results

The results of the change between the original and new modelling approach are displayed below. While the volume of HI4 and HI5 assets does not significantly change between methodologies, the output from the new models is based on better data quality delivering a more meaningful output.

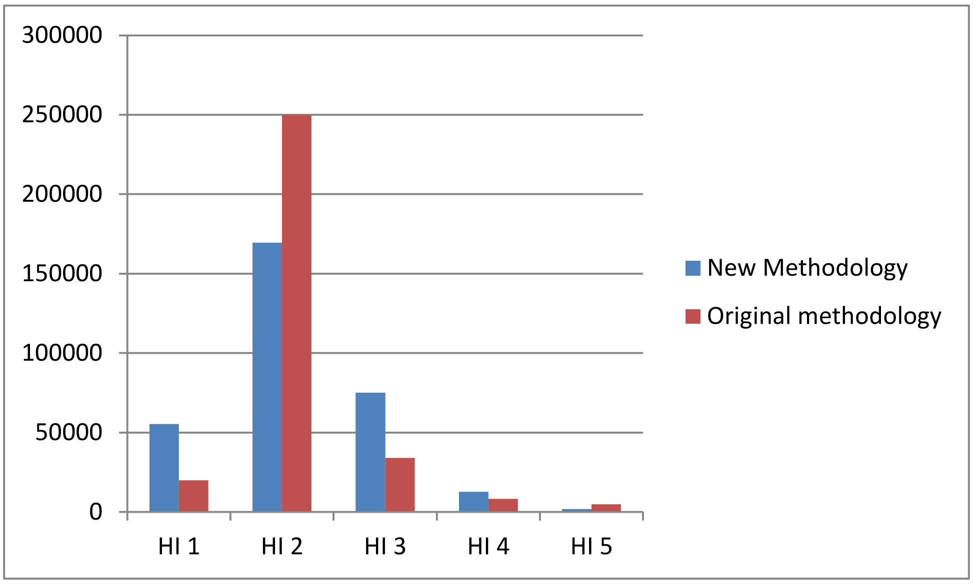


Figure 2 Forecast DPCR5 end position

The slight increase in HI 4 and HI 5 assets and subsequent decrease in HI 2 assets is due to the impact of the modelling of wood poles within ARP and is described in the text supporting Figure 11.2. The increase in HI 1 assets is again due to adoption of ARP modelling compared with the former reactive modelling methodology. Previously the reactive modelling approach only allowed assets up to 5 years of age to be recorded as an HI1 asset. The ARP models assign HI categories based on asset specific data rather just an age based rule which had been previously applied through the reactive methodology.

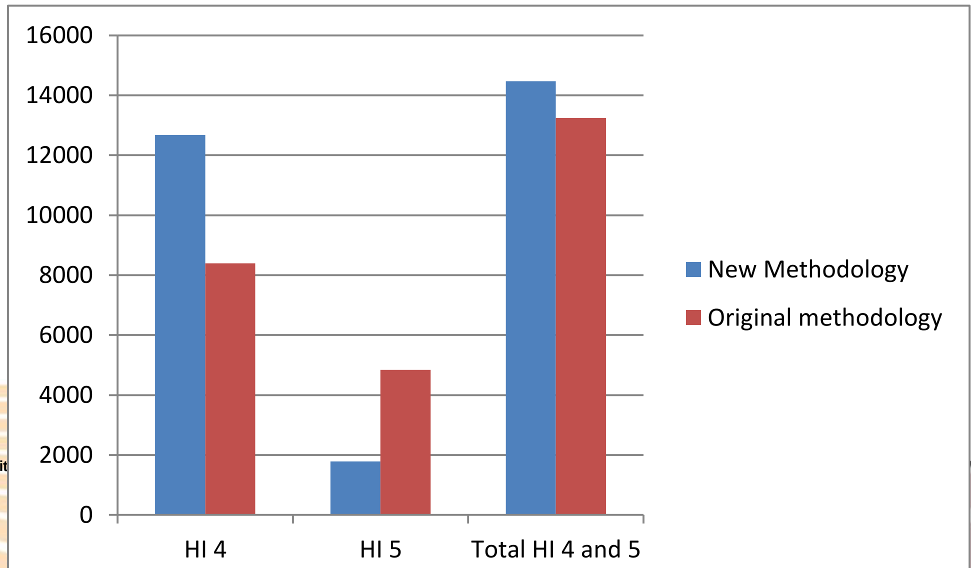


Figure 3 Forecast DPCR5 end position HI 4 and 5 assets

When analysing the volume of HI 4 and 5 assets the new modelling approach sees a slight increase when using the new modelling approach. There is a slight increase in the forecast volume of HI 4 and 5 assets and is due to wood poles and steel towers. All of these assets were previously modelled using the original reactive modelling approach which tended to place low volumes of assets (based on planned replacement volumes) in HI 4 and 5 with the majority of assets being placed in HI2. All of these assets are now modelled using our new ARP models which are robustly developed and tested and based on improved data which is significantly better understood

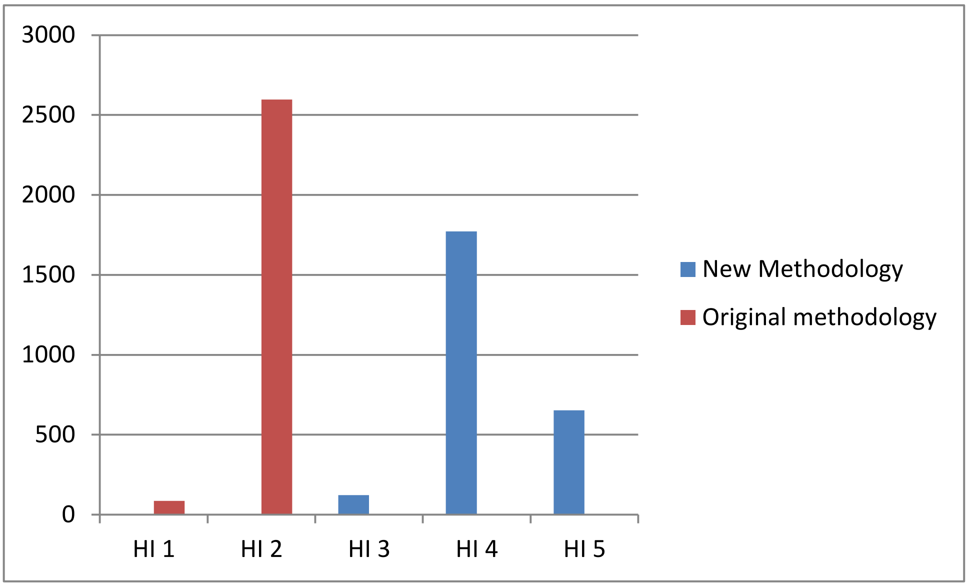


Figure 4 132kV Steel Towers forecast DPCR5 end position

Although when considered at a high level the change in model methodology does not significantly impact the overall volume of HI 4 and 5 assets, when analysed on an asset basis there are some significant changes. The graph below demonstrates such a change for 132kV steel towers where we see a significant increase in HI 3, 4 and 5 assets when we use the new modelling approach. The significant increase in HI 4 and 5 steel tower assets is due to the move from a reactive model to the ARP model to drive health indices. Using the original reactive modelling approach the first two years of removals in DPCR5 were categorised as HI5 assets. The final three years of removals in DPCR5 are categorised as HI4 assets. The introduction of ARP to model the health indices for steel towers is a much more robust approach, reliant on asset data with the volume of HI 4 and HI5 assets being driven by poles being classified as being suspect or defected assets.

12.0 Practical Application of ARP – Hastings Main

Investment drivers for switchgear can be split into two categories; internal condition and external condition. External condition factors include paint condition and corrosion of any part of the switchgear such as the bushings or the external bushings. On outdoor sites the condition of air insulated busbars and any concrete or steel support structures will also be considered. Internal condition factors include mechanism wear and circuit breaker trip times.
The purposed investment plan for 132kV switchgear in ED1 includes interventions on just one type of switchgear, the GEC OFA11. The are currently thirty three OFA11 circuit breakers on the network and with the proposed investment plan, twenty one will remain at the end of ED1.

Figure 5 - GEC OFA11 Bulk Oil Circuit Breaker

The GEC OFA11 is a bulk oil circuit breaker with a separate oil tank for each phase. In the SPN area, they are all located outdoors with air insulated busbars. A common issue that has been experienced with the breaker is corrosion on the bottom of the tank and the associated pipe work. The problem is caused by the difficulty in accessing the underside of the breaker for painting.

The 132kV circuit breakers located at Hasting Main are GEC OFA11 and due to be replaced in ED1 due to condition. The breakers on this site are all HI4 at the commencement of ED1 and degrade to HI 5 during ED1. The breakers are all 47 years of age. The following factors are considered in the ARP model contribute to the overall HI and the deterioration of the asset;

- Hastings Main is located right on the coast of the county of Sussex. The circuit breakers are located in an outdoor location and are subjected directly to the harsh coastal environment, which will increase the rate of deterioration of the assets and decrease the expected life.
- The 132kV circuit breaker model applies an increased probability of failure when the asst reached 46 years of age. The assets at Hastings are 47 years of age so the probability of failure has just started to increase.
- Since October 2008 there have been a total of 25 defects reported in Ellipse against these circuit breakers, the majority of which have been recorded against defective control cubical. This type of defect would result in moisture ingress increasing the risk of failure.
- The condition of external housing is rated at condition 4. Again this type of defect would result in moisture ingress increasing the risk of failure.
- In this instance the age, the environment, the volume and type of defects and the observed condition of the external housing all contribute to the overall HI of the asset.

Appendix 1: Average asset life benchmarking with other DNO's

At a company level the average asset lives applied by UKPN for HI related asset categories are 12% higher than the DNO average life. (as reported by DNO's in the July 2013 ED1 submission). The higher asset lives will result in a lower than average volume of HI4 and HI5 assets being reported. We use a world class asset degradation modelling tool developed in partnership with EA Technology. This use of this tool, along with good quality asset condition data, and an on-going commitment to ensure the required inspection and maintenance activities are carried out, means the design performance of assets can be maintained for longer than other DNOs. This means UKPN are adopting a potentially higher level of risk on the network by operating and managing its assets to perform safely and reliably for longer. The table below is a comparison between the average asset lives in SPN compared to the industry average asset lives.. The average lives in SPN are 12% higher than the DNO average life.

HI Category	All DNO average life	SPN average life	Delta
LV Switchgear	59.56	65	5.44
Linkboxes	N/A	45	N/A
LV Overhead Supports	61.25	70	8.75
HV Primary Switchgear	54.33	59	4.67
HV Distribution Switchgear	49.95	48	-1.95
HV Transformer (GM)	60.72	70	9.28
HV Overhead Supports	61.25	70	8.75
EHV Switchgear	52.20	60	7.80
Primary Transformers	59.16	69	9.84
EHV UG Cable (gas)	58.33	N/A	N/A
EHV Fluid Filled Cables	66.50	75	8.50
EHV OHL Support (towers)	83.75	83	-0.75
EHV OHL Support (poles)	61.25	70	8.75
EHV OHL Conductor (towers)	N/A	N/A	N/A
132kV CB's	49.99	49	-0.99
Grid Transformers	61.28	69	7.72
132kV UG Cable (gas)	56.67	N/A	N/A
132kV Fluid Filled Cables	65.25	75	9.75
132kV OHL Support (towers)	85.00	88	3.00
132kV OHL Conductor	N/A	N/A	N/A

(towers)			
Weighted across all HI categories	60.38	67.47	12%

Table 8 – SPN Comparison of Asset Lives (source DNO data share)

Appendix 2: Endorsement from EA Technology and SKM

20 January 2014

To Whom It May Concern

Letter of Endorsement The development of ARP with UK Power Networks Limited

EA Technology is happy to endorse UK Power Networks for their committed approach to improving their asset Health Index modelling capability by developing the Asset Risk and Prioritisation system.

EA Technology has worked with UK Power Networks to develop the Asset Risk and Prioritisation system, based on the EA Technology Asset Modelling Platform and Condition Based Risk Management (CBRM) methodology. In order to formalise the collaborative working arrangement and improve the knowledge transfer, UKPN & EA Technology signed a formal Partnership Agreement to foster a closer working relationship at the commencement of the ARP project.

From the commencement of the project in May 2011 UK Power Networks Asset Leads responsible for each asset group have been fully immersed in the process combining the optimum working environment of first hand distribution network experience with specialised modelling experience throughout the design, build, commissioning and testing of the Asset Risk and Prioritisation system.

This close relationship influenced the development of the ARP system throughout the project, some key examples are:

1. **Improved knowledge of asset degradation processes**
   UKPN asset leads worked closely with EA Technology to define the key degradation processes, and appropriate measurement points for these processes, for inclusion within the ARP models.

2. **Extension of modelling capabilities**
   With the development of ARP UKPN were able to expand their asset modelling capability to include their overhead lines assets and distribution plant in order to have a robust and consistent risk based prioritisation methodology covering the majority (78%) of their regulatory reportable asset base.

3. **Improved asset data**
   Throughout the ARP project UKPN have been focussed on improving the quality of the asset data which is used within their asset models. UKPN have specified bespoke data analysis capability within the ARP system to support this objective and have embraced automated IT data processes to extract data from their corporate data systems to the ARP system to improve data quality and consistency.

4. Ownership of the ARP models

From the commencement of the project UKPN asset leads took full ownership for their asset models and were involved from the specification stage for their models to ensure that their experience was reflected in the models and that they had a thorough understanding of the modelling methodology used for their assets.

5. Enhanced testing process

An enhanced testing process was specified by UKPN in order to ensure that the methodology employed in the delivered models mapped to the specifications and that the model outputs were built from the correct asset condition data and were combined correctly within the model.

Following delivery of the initial ARP system, UKPN have continued to work with EA Technology and are taking a global lead in asset deterioration modelling including the consideration of a combined load and non-load modelling capability and the impact and optimisation of investment to support a low-carbon SMART future

Yours faithfully

Robert Davis
Group CEO, EA Technology Ltd
t. +44 (0) 151 347 2460

Appendix 3 Endorsement from SKM

A separate independent assessment was undertaken in 2012 by SKM who undertook an audit of UKPN's HI process. This exercise was repeated in 2013, when SKM made the following comment;

"Based on the documentation provided and demonstration of the criticality index (CI) scoring algorithms, the system appears to be robust and meaningful. A limited test check of the ARP models examined key metrics and data points within the HI and CI scoring algorithms in addition to the various input and output data sources, and found no inconsistent results"

Source, RIIO ED1 Business Plan Assurance Audit (Health Indices), version 1.0, 17th June 2013

An audit on a sample of the condition points observed by UKPN inspectors was undertaken by SKM independent surveyors. The results observed by SKM found a 92% correlation between SKM and UKPN condition observations on site.

Appendix 4 UKPN observations relating to HI's following Ofgem feedback

Following feedback from Ofgem on our initial ED1 submission, relating to UKPN's HI's we have the following observations

- **UKPN has used a leading edge asset replacement model,** called Asset Risk & Prioritisation (ARP), developed in partnership with E Technology. The UKPN modelling approach is based on asset, age, condition and defect data and provide a "bottom up" view of the health of our assets

- **Quality of data feeding ARP has improved significantly**, and the introduction of the CAT score has been seen as an innovative approach to improving data quality.

- **We have combined our leading decision support tool, ARP, with the experience of our senior asset engineers** who have developed our investments plans. Ultimately our investment plan is developed utilising good engineering assessment and knowledge. This approach will ensure that our plans are robust and appropriate to maintain a safe and reliable service to our customers.

- **UKPN replaces assets on condition and not age,** and therefore no asset can reach a HI4 or HI5 without condition or defect data being recorded.

- **UKPN has applied by far the highest asset average lives** (12% higher on average), which has resulted in a risk based asset replacement plan and a consequential lower number of HI4 and HI5 assets when compared to industry averages.

- **UKPN has consistently reported lower volumes of HI4 and HI5** assets through DPCR5 and ED1, and we believe the numbers are right and appropriate given our definition of health and the average asset lives used.

- **There is no DNO agreed definition of Health Indices,** so it is perhaps not surprising that a range of values for the number of HI4 and HI5 assets occurs across the industry.