Calculating a Health Index to make decisions on Asset Replacement

Simon Blake       Durham University

Mathematical Methods in Reliability Research: Expert Judgment

Strathclyde University, 31 August 2012
Problem: Optimising replacement programme

- Fleet of 1200 large primary transformers
- Most installed in 1960s
- 70 year expected lifetime
- So replace 20 per year
- But bulge expected
- Deterioration rates vary
Replacement Considerations

- High capital cost (around £0.5M) per transformer
- Long lead time (1-2 years)
- Older transformers have higher power losses
- Older transformers less robust at taking extra load
- Could lose 20000 customers for 8 hours (penalty cost £1.6 M)
Typical deterioration curve

But what does 100% or 0% mean in terms of $\lambda$?

And what factors determine $T$ and $T^*$?
Factors affecting T and T*

- Location (coast, elevation, pollution)
- Loading (emergency, cyclic, average)
- Manufacturer and type (known problems)
- Actual fault history (usually nil: $\lambda \approx 0.004$)
- Observed external condition (inspections)
- Internal condition (laboratory analysis of oil, dissolved gases and insulation)
Health Index as measure of condition

- $H$ on a scale from 0 (=100%) to 10 (=0%)

- Supposedly related to $\lambda$ according to

\[ \lambda = ke^{cH} + \lambda_0 \]

where $k$ and $c$ are determined by data and/or ‘expert judgment’ e.g. $\lambda(10) = 10 \lambda(4)$

So $H$ can be considered as a logarithmic function of $\lambda$
Fault rate as function of Health Index

![Graph showing the relationship between Fault Rate and Health Index. The graph indicates an increasing trend, with a label for the Non-condition related fault rate at a Health Index of 10.](image-url)
Health Index as a function of time

H is considered to vary with t according to

\[ H = H_0 \cdot e^{B(t-t_0)} \]

- What should H be at \( t = 0 \)?
- What factors determine rate of deterioration B?
- How should present value affect future expectations?
Deterioration Curves, with different doubling times
30 year actual, worse than expected
Options for updating deterioration curve
Who are the experts with the judgment?

- Theorists (types of model to select)
- Consultants (selecting the actual model)
- Asset Engineers (determining parameters)
- Maintenance Engineers (assessing asset condition)
- Managers (how to use the results)
How loading affects ageing rate B

- Base value $B=0.0343$ takes transformer from $H = 0.5$ to $H = 5.5$ in 70 years

- Multipliers for $B$ based on bands of average loading (as % of rating):

<table>
<thead>
<tr>
<th>band</th>
<th>multiplier</th>
<th>% of transformers</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 65</td>
<td>1.00</td>
<td>61</td>
</tr>
<tr>
<td>65 – 90</td>
<td>1.14</td>
<td>31</td>
</tr>
<tr>
<td>90 – 106</td>
<td>1.31</td>
<td>6</td>
</tr>
<tr>
<td>Over 106</td>
<td>1.50</td>
<td>2</td>
</tr>
</tbody>
</table>
How location affects B

• Bands are of distance from coast
  (0-10 km, 10-25 km, over 25 km) and
elevation (0-200m, 200-400m, over 400m)
and corrosivity (external database)

• These give composite multipliers of
  1.00 (no transformers)
  1.09 (17%)
  1.21 (55%) and
  1.33 (28%)
Sensitivity to value of B

• Minimum value actually occurring (0.0373) goes from $H=0.5$ to $H=10.0$ in 80 years

• Median value (0.0426) takes 70 years

• Maximum value (0.0683) takes 44 years

Is this a realistic range? How could we tell?
Effect of value of B on 1965 cohort

- H values for 44 transformers at t=50 range from 4.21 to 9.89

- Replacing at H=8.0 would spread replacement from 2012 to 2030

- Case study presented at CIGRE transformer conference, May 2012
Complex rules for incorporating condition

- Analysis of 5 separate dissolved gases
- Each band scores 0, 2, 4, 10 or 16
- Weighted in ratio 5:3:3:3:12
- Modified by ratio to previous reading
- Combined with other analyses (insulation, oil) to give multiplier from 0.7 up to 1.25
- External condition (worst of 4 factors) provides further multiplier from 0.9 to 1.3
Effect of incorporating condition

![Bar chart with various categories and their corresponding number of transformers. Categories include:
- over +2.0
- +1.5 to +2.0
- +1.0 to +1.5
- +0.5 to +1.0
- 0.0 to +0.5
- -0.5 to 0.0
- -1.0 to -0.5
- -1.5 to -1.0
- -2.0 to -1.5
- below -2.0

The number of transformers ranges from 0 to 150.]
Expert Judgment: Disadvantages

- With many experts, complex rules develop, difficult to understand or explain.

- Can introduce unintended bias e.g. with granularity of bands.

- No theoretical justification e.g. $\lambda$ is an exponential function of $H$, which is itself an exponential function of $T$. 

Expert Judgment: Advantages

• Enables hard-to-quantify experience and judgment to be incorporated into a mathematical model

• Incorporating it wins support of the experts

• Probably produces an effective ranking, even if there are structural offsets
Conclusion

We need to use expert judgment as one factor in our model to prioritize the replacement of large transformers.

But how can we make it more user-friendly, more justifiable, and more reliable?

Your input would be appreciated.