XII DBMC
International Conference on Durability of Building Materials and Components
PORTO - PORTUGAL, April 12th-15th, 2011

Condition-Based Service Life Prediction and Planning in Practice

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ABSTRACT

This paper looks at service life prediction and planning based on a combination of condition assessments and the application of a service life prediction methodology using the stochastic Markov Chain with Neuro-Fuzzy Artificial Intelligence (Service Life Prediction Beyond the 'Factor Method' - 11DBMC Best Paper Award) to quantify changes in condition over time.

The model, which considers the seven modifying factors of the 'Factor Method' for service life prediction as well as the age and current condition of the building or component to calculate changes in condition over time, enables the calculation of typical degradation curves for a variety of building and component types in various physical and operational environments. These curves are used to predict the remaining service life, assess the effectiveness or appropriateness of the current maintenance regime or level, do life cycle planning and develop pro-active strategies to prevent premature failure or reduced service life.

The application of the service life prediction methodology in combination with condition assessments is illustrated with four case studies on an active learning environment building, a university campus and four multi level office buildings.

KEYWORDS

Condition assessment, Service life prediction curves.

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1 INTRODUCTION

The objective of this paper is to illustrate the use of a condition-based service life prediction methodology to provide asset managers with better-informed options and strategies.

A Service Life Prediction model [McDuling et al 2008] is used to predict changes in condition over time and produce Service Life curves for a building or component. By plotting the assessed current condition of the building or component on these curves, the remaining service life can be predicted and better informed asset management options and strategies can be developed.

The Service Life Prediction model is based on a combination of the Markov Chain and Neuro-Fuzzy Artificial Intelligence, and the seven modifying factors of the 'Factor Method' [ISO 15686-2:2001] for service life prediction, as well as the age and current condition of the building or component to quantify changes in condition over time.

This application of condition assessments in combination with service life prediction is illustrated with three case studies.

2 CONDITION ASSESSMENTS

A five-point colour-coded rating system is used to assess the percentage of the asset in each condition category as illustrated in Table 1 below.

Table 1. Condition assessment criteria.

Rating	*Condition*	*Action Required*	*Assessment (Total = 100%)*	*Maintenance Type*
5	Excellent	Preventative Maintenance	% of asset in Condition 5	Normal Maintenance
4	Good	Condition-based Maintenance	% of asset in Condition 4	
3	Fair	Repairs	% of asset in Condition 3	Backlog Maintenance
2	Poor	Rehabilitation	% of asset in Condition 2	
1	Very Poor	Replacement	% of asset in Condition 1	

Assessing the percentage of the asset in each condition category enables the quantification of the extent of maintenance backlog and development of condition profiles as illustrated in Fig. 1 below.

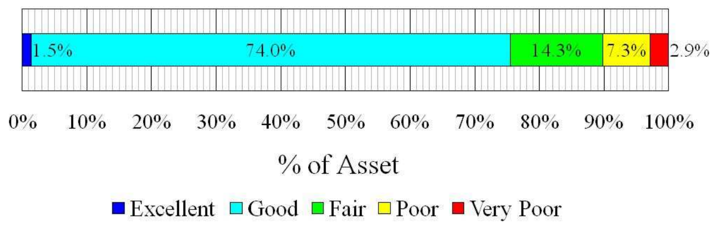


Figure 1. A typical condition profile, showing the percentage of the building in each condition category. The extent of maintenance backlog amounts to 24.5%.

The average assessed condition of the profile in Fig. 1 is 3.64 ('Fair'). If a single rating was applied the building's condition would be assessed as 4 ('Good') and the small percentages in Condition 1 ('Very Poor': 2.9%) and 2 ('Poor': 7.3%), with higher levels of associated risk, would not be visible to decision-makers and consequently overlooked.

3 SERVICE LIFE CURVES

A Service Life Prediction model [McDuling et al 2008] is used to quantify changes in condition over time and produce Service Life curves for a building or component. The model is based on a combination of the Markov Chain and Neuro-Fuzzy Artificial Intelligence, the seven modifying factors of the 'Factor Method' [ISO 15686-2:2001] for service life prediction, as well as the age and current condition of the building or component to quantify changes in condition over time [McDuling 2006].

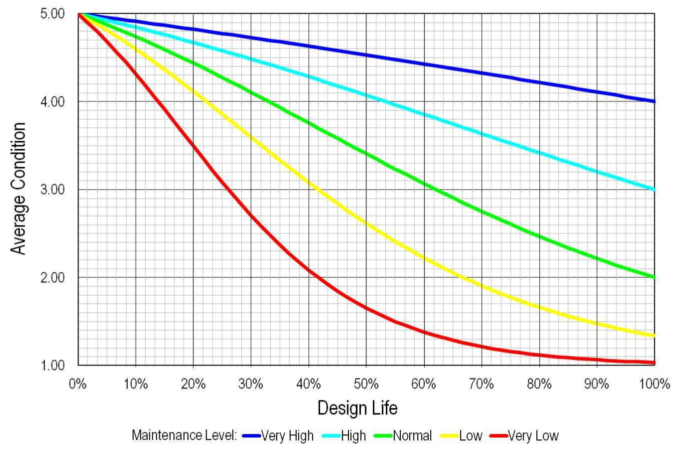


Figure 2. Generic service life curves showing the predicted change in average condition over the design life of the asset for various levels of maintenance, assuming high quality (4) of material/fabric and work execution, a high level (4) of design, slightly aggressive (3) external and internal climates and a less favourable (4) to slightly aggressive (3) operational climate using a rating scale similar to the condition rating scale in Tab. 1.

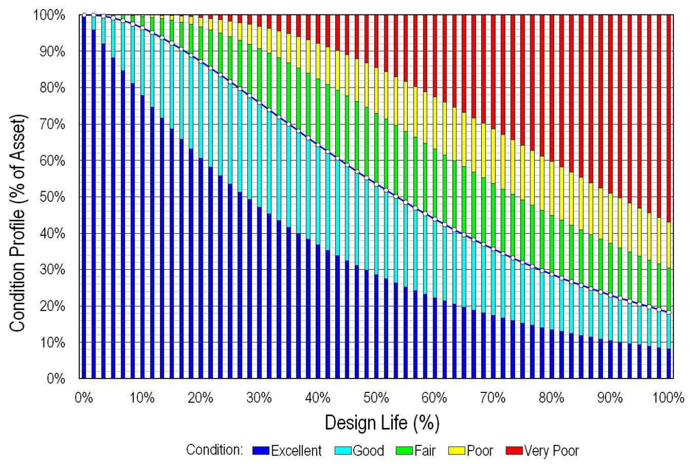


Figure 3. Predicted changes in the condition profile over the design life of an asset. The area below the blue curve represents the percentage of the asset in 'Excellent' and 'Good' condition.

According to De Sitter's Law of Fives [Vanier 2000], backlog maintenance (repairs, rehabilitation and replacement/renewal) can cost 5 to 25 times more than normal maintenance. The objective of strategic asset management is therefore to maximise the area below the blue curve (i.e. the percentage in 'Excellent' and 'Good' condition requiring normal maintenance) within limitations. The area above the curve represents the percentage of the asset requiring backlog maintenance.

The generic service life curves in Fig. 3 are used to develop asset management strategies by changing the horizontal axis to a time scale and selecting the appropriate design life of the building or component, condition threshold and rehabilitation or renewal strategy as illustrated in Fig. 5 below.

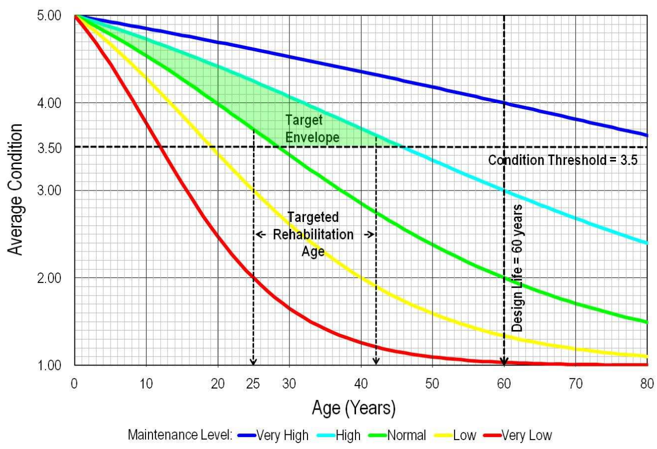


Figure 4. Service life curves illustrating condition threshold, target envelope and targeted rehabilitation age assuming a design life of 60 years.

The condition threshold is the minimum acceptable condition, while the target envelope is defined by the area between two maintenance level curves and the selected condition threshold, as illustrated by the shaded area in Fig. 5 above.

The appropriate maintenance strategy is determined by the decision to rehabilitate or renew the building during its design life or not (investment strategy) and the selected condition threshold. The objective of a strategy not to rehabilitate or renew the building during design life is to achieve a service life that exceeds the design life. The type of asset, design life, degradation and preservation factors [ISO 15686-2:2001] and obsolescence need also to be considered.

Depending on the condition threshold selected, a strategy not to rehabilitate or renew the building during its design life will require a higher maintenance level at a higher maintenance cost compared to a rehabilitation strategy. A higher condition threshold requires a higher level of maintenance at a higher cost during the asset's service life.

In the event of a rehabilitation strategy, a higher condition threshold means a shorter service life and requires an earlier or possibility more than one refurbishment during the asset's design life, but at a lower cost per refurbishment. This could be a good strategy for investment portfolios where retaining high profile tenants prepared to pay for premium accommodation is an objective, or where technical, functional or financial obsolescence could be a consideration.

A lower condition threshold means a longer service life and will require later or no refurbishment, but at a higher refurbishment cost. If the building condition is allowed to deteriorate below the threshold, the risk of losing existing or failure to attract new tenants increases.

To prevent that the average condition of the building deteriorate beyond the condition threshold, planning for the rehabilitation should ideally start two to three years before the condition reaches the threshold level. By doing regular and consistent condition assessments and plotting the assessed condition on the service life curves, maintenance planners can get early warning and start their planning in time before the condition has a negative impact on the performance of the building.

4 CASE STUDIES

4.1 Active learning environment building (Australia)

The first case study looks at a 26-year-old active learning environment building with an aggressive operational environment where students are trained in building trades such as bricklaying, plastering, tiling and stone masonry. The building has a large industrial/factory area as well as offices, lecturing rooms and ablution facilities. It has a gross floor area of 8,375 m^2 and an estimated replacement cost of Au$ 11,900,000. The assessed average condition of the building is 3.64

The required maintenance budget, as shown in Table 4 below, is based on the assessed condition of the building and a maintenance cost model, which is aligned with De Sitter's Law of Fives [Vanier 2000] and based on the estimated replacement cost of the building or component. This methodology is similar to the parametric approach of NASA to estimate deferred maintenance [NASA 2003].

Table 2. Condition-based maintenance budget (Au$) required.

	Normal Maintenance			
	Preventative Maintenance (Condition 5)	Condition-based Maintenance (Condition 4)	Allowance for Unplanned Maintenance	**Total for Normal Maintenance**
Assessed Condition*	1.45%	74.04%		75.49%
Budget Required	$ 148,773	$ 176,240	$ 89,264	$ 414,277
% of Budget Required	9.51%	11.26%	5.70%	26.47%
	Backlog/Deferred Maintenance			
	Repairs (Condition 3)	Rehabilitation (Condition 2)	Replacement (Condition 1)	**Total for Backlog Maintenance**
Assessed Condition*	14.34%	7.31%	2.86%	24.51%
Budget Required	$ 341,306	$ 435,102	$ 374,145	$ 1,150,553
% of Budget Required	21.81%	27.81%	23.91%	73.53%
	Estimated Total Maintenance Budget Required			**$ 1,564,830**

* % of building in each condition category weighted based on estimated replacement cost.

Table 4 illustrates the consequences of backlog maintenance and De Sitter's Law of Fives: 24.51% of the total building requires backlog maintenance, which amounts to 73.53% of the total budget required.

4.1.1 Maintenance Options

Option 1 provides for the allocation of available funds to the maintenance categories based on the ratio of budget required per category to total budget required (as shown in Table 4 above), i.e. 9.51% of the available budget is allocated to preventative maintenance. This method, the 'Balanced Approach', ensures that funds are also allocated to Preventative Maintenance and not just Backlog Maintenance. If an amount of $650,000 is allocated based on the 'balanced approach' the average condition will improve to 4.20, which is on the top end of the target envelope in Figure 6 below, i.e. it will take $650,000 allocated based on the 'balanced approach' to change the condition from the bottom to the top of the target envelope. This will increase the current estimated remaining service life from two years to 12 years.

Option 2 provides for the eradication of all Condition 1 ('Very Poor') and Condition 2 ('Poor') and requires $809,247. This will improve the average condition to 3.97 and the estimated remaining service life of nine years.

Option 3 provides for the eradication of all maintenance backlog and will require $1,150,553 to improve the condition to 4.26, and will add 12 additional years to the estimated remaining service life.

Option 4 provides for total refurbishment, which will require $1,277,245 to improve the average condition to 4.79 and extend the estimated remaining service life to 24 years.

4.1.2 Option comparison

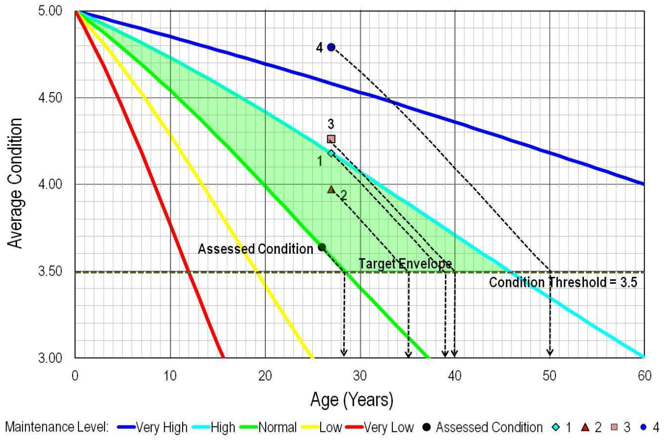
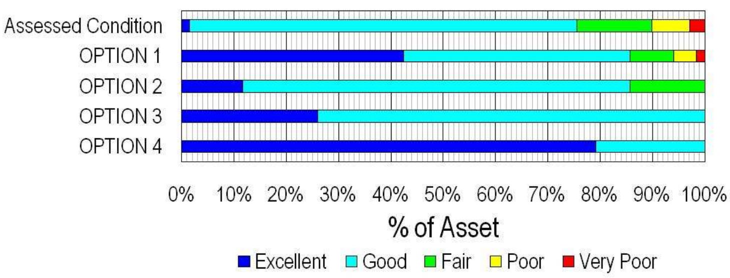


Figure 5. Average assessed condition of an Active Learning Environment Building with predicted changes in condition for four maintenance options assuming continuation of the current maintenance regime.

Table 3. Option Comparison.

Option and Strategy	Budget required (Au$)	Additional Service Life (years)	Cost per additional Service Life year	Condition	% Improve-ment in condition	Cost per 1% improve-ment in condition
1. Balanced budget allocation	$ 650,000	10	$ 65,000	4.20	15.38%	$ 42,250
2. Eradication of 'Poor' & 'Very Poor"	$ 809,247	7	$ 115,607	3.97	9.07%	$ 89,262
3. Backlog eradication	$ 1,150,553	12	$ 95,879	4.26	17.03%	$ 67,549
4. Total refurbishment	$ 1,277,245	22	$ 58,057	**4.79**	31.59%	$ 40,428

Graph 1. Predicted change in condition profile for various options.



From Fig. 6 the estimated Remaining Service Life is two years.

4.2 Six academic hospitals (South Africa)

This case study of six academic hospitals in South Africa illustrates the value of regular and consistent condition assessments. The condition assessments were undertaken between 1996 and 2005.

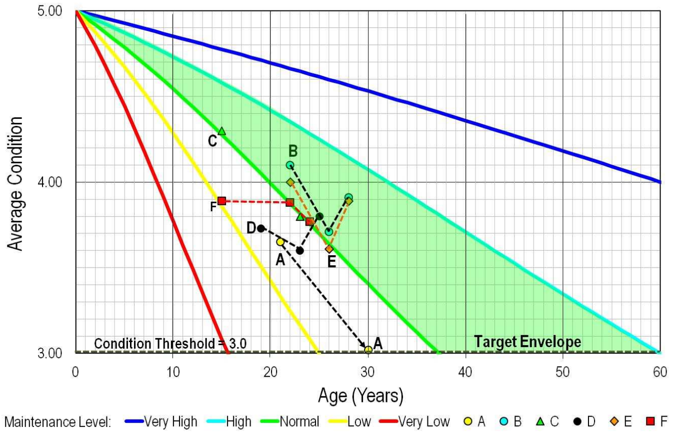


Figure 6. Six Academic Hospitals.

Hospital A illustrates the consequences of too long intervals between condition assessments and has reached the end of its service life only 30 years after it has been commissioned. The maintenance level of this hospital was clearly too low and there was no change in the maintenance regime after the first assessment. In contrast, Hospitals B, D, E and F clearly showed a positive reaction to the condition assessments by the improvement in their condition to fall within the target envelope. In view of the growing demands created by changes in medical and nursing technology and the risk of obsolescence, Hospital C and F may have better maintenance strategies.

4.3 University campus (Australia)

The average condition and age of two sets of university buildings are shown in Fig 1 below. The first set of buildings, numbered from 1 to 26, is academic buildings with a condition threshold of 3.5 and a target condition envelope between Normal and High Maintenance Levels. The second set of buildings, numbered from 27 to 51, is student accommodation with a condition threshold of 4.0 and a target condition envelope between High and Very High Maintenance Levels.

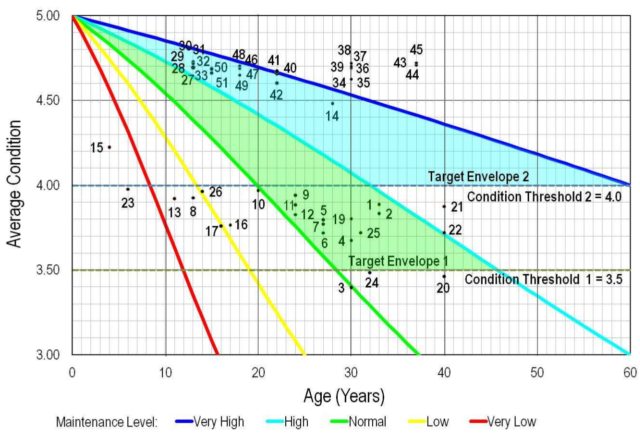


Figure 7. Average condition and age of buildings on a university campus.

4.3.1 Building Set Number 1 – Academic buildings

Although building numbers 1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 19, and 22 and 25 all comply with the condition and maintenance targets, their remaining service life varies between three and eight years, and a strategic review of these buildings should be undertaken as soon as possible. The average condition of building numbers 3, 20 and 24 are below the condition threshold of 3.5 and should have been already rehabilitated or replaced. Building 21, which falls above the target envelope, was refurbished some time ago and has an estimated remaining service life of ten years. Building 14 has just been refurbished and based on the assumption that the current maintenance regime will be continued, has an estimated remaining service life of 30 years.

Building numbers 8, 10, 13, 15, 16, 17, 23 and 26 are all below the target envelope, which can be attributed to a number of factors, such as a too low level or quality of maintenance, quality of work execution, materials and design, and operational environment. These buildings are storage and workshop buildings and it is to be expected that the level of maintenance would be lower compared to the academic buildings. Of concern is however building numbers 15 and 23 that both showed a relatively fast rate of deterioration and although their condition is still well above the applicable condition threshold of 3.5, a detailed ‘crawl-through’ assessment by experts should be undertaken as soon as possible to establish the cause for the accelerated degradation. Building 15, which is four years old, has an estimated remaining service life of six years or a total service life of only ten years.

4.3.2 Building Set Number 2 – Student accommodation

An important source of income for Australian Universities is international students and in order to attract these students Universities need to provide good accommodation. Buildings providing accommodation for students are therefore refurbished on an annual basis and a higher condition threshold and target envelope apply to these buildings. The condition assessment was done just after these buildings have been refurbished at the beginning of the academic year before the students took occupation, which explains why the condition of building numbers 34 to 39 and 43 to 45 are above the target envelope.

REFERENCES

International Organization for Standardization, ISO 15686-1:2000, *Building and Construction Assets - Service Life Planning - Part 1: General Principles*, Geneva, Switzerland.

National Aeronautics and Space Administration, 2003, *NASA Deferred Maintenance Parametric Estimating Guide Version 2*, Facilities Engineering Division, [web page] http://www.hq.nasa.gov/office/codej/codejx/Assets/Docs/DMParametricEstimatingGuideApr03.pdf Date accessed: 07 November 2010.

McDuling, J.J., Horak, E. & Cloete, C. 2008, *Service Life Prediction Beyond the ‘Factor Method’*, Proc. of the eleventh Int. Conf. on Durability of Building Materials and Components, 11dbmc, Istanbul, Turkey, 11-14 May 2008, vol. 4, pp. 1515-1522.

Mc Duling, J.J., 2006, *Towards the Development of Transition Probability Matrices in the Markovian Model for the Predicted Service Life of Buildings*, PhD Thesis, Department of Civil and Biosystems Engineering, University of Pretoria, South Africa.

Vanier, D.J., 2000, *Advanced Asset Management: Tools and Techniques*, Innovations in Urban Infrastructure Seminar of the APWA International Public Works Congress, Louisville, U.S.A, pp. 39-56.