Predictive Modeling of Bridges

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pitt&sherry

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FINANCIAL REVIEW
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Synopsis

Bridge and culvert asset management has been evolving across Australia over a period of time. Currently most asset owners understand what structures they own, where they are and what condition they are in. What is less understood is what condition those structures will be in the future and what maintenance work will be required other than the reactive type maintenance determined from level 2 inspections.

Understanding the importance of planning for the future and the need for long term asset management plans, **pitt&sherry** has developed a methodology for the prediction of bridge and culvert asset deterioration. The modelling technique takes into account the various types of components, environments and deterioration rates and life of bridge and culvert components.

Understanding that bridge owners have limited funding and therefore have some of the highest needs for good forward planning **pitt&sherry** has implemented the predictive modelling into a low cost asset management system that bridge owners can now use to understand when certain treatments will be required, the cost effectiveness of the treatments as well as the design life and value of their structures.

Authors Biography

Andrew Sonnenberg has over 15 years' experience in the design of road and bridge projects in Australia. His work in both the public and private sectors has provided a sound understanding of the complexities of asset management and the skills to successfully project manage multidisciplinary projects through to completion.

As national Bridge Engineering Manager at **pitt&sherry**, Andrew oversees the company's bridge engineering network across Australia, and has a deep understanding of the country's best practices when it comes to bridge design assessment and management. His practical experience is reinforced by a strong theoretical background, which includes a Master of Business Administration and a PhD obtained from the study of the shear strength assessment of reinforced bridge beams.

1. Background

pitt&sherry is an Australian consultancy with offices in Queensland, New South Wales, Victoria and Tasmanian. The company's experience has been obtained from providing asset management and design services to a broad range of asset owners across Australia. These works includes, bridge inspection, heavy vehicle route assessment, bridge design, tender assessment, superintendent representatives works and development of structure management plans.

By undertaking works covering the full spectrum of bridge asset management **pitt&sherry** has gained the necessary understanding to develop an asset management system, Asset*Asyst*® which includes a comprehensive bridge management system with the required functions for good bridge asset management. The system also handles assets such a road, railways, buildings and other community infrastructure.

2. Challenges of Bridge and Culvert Asset Management

Bridge and culvert asset management has been evolving across Australia over a period of time. Currently most asset owners understand what structures they own, where they are and what condition they are in. What is less understood is what condition those structures will be in the future and what maintenance work will be required other than the reactive type maintenance determined from the level 2 inspections.

There is a lack of understanding and appropriate systems to support the complexity of good asset management. This had lead to asset owners making compromises over the management of their assets. Readily available systems often have major limitations and flaws such as:

- Separating a structure into a very limited number of components (less than five but more often one) for the purpose of assessing a structures future life instead of reflecting the structures true physical components, which for a bridge typically exceeds 10 components. An example of a limited approach is assuming the life for a structure can be represented by separating a structure into two components, superstructure and substructure. This leads to false sense of accuracy often little better than assuming the life for the whole structure
- No capability to record the financial value of each of the components of a structure which in turn makes it impossible to accurately assess the effect of deterioration on the asset value
- A lack of ability to record the intervention level for components
- Lack of ability to record repair history
- Typically have a one size fits all approach
- Although the data is collected in inspections there is a lack of use of the exposure class of components
- The use of GIS systems and other Bridge information systems that have no bridge management capability

Apart from limitations with software there are also limitations with current processes' that impact on the ability to create accurate predictions about structure condition includes:

- Bridge inspection manuals using non condition related parameters in assessing "condition" for some components. For example barrier post spacing is a controlling factor for the condition state of approach barriers and bridge barriers in VicRoads Road Structures inspection manual. A post spacing of 2.5m or more implies condition state three in VicRoads system for off structures barriers, while the same post spacing for on structure barriers implies condition state 2. Such condition state descriptions do not reflect condition and, arguably, are inconsistent.
- Condition inspections under the level 2 process of the various road authorities has been visually based (excluding timber drilling) and as such may not be the best method of identifying some systemic causes of deterioration, such as carbonation, chloride ingress and other environmental contaminants
- Condition state may be affected by structural overload, impact, flood and other types of deterioration not related to a gradual process of decay due to environmental exposure
- The limited levels to which inspection data is recorded effects the accuracy of estimates. In the VicRoads Road Structure inspection manual only the beams overall are rated rather than each beam, such that if a beam has been replaced overtime there isn't the ability to track it
- Current practice is to use deterministic models relying on past inspections to predict future inspection outcomes rather than the fundamental drivers for deterioration and knowledge from comprehensive deterioration studies of materials

- A lack of understanding of the effect of maintenance and repairs and what will be the new condition rating of a component following a repair

To tackle some of the above problems **pitt&sherry** has combined it bridge engineering group's expertise with its Information Technology team to develop a predictive modelling tool for bridge and culvert structures. The tool currently interfaces with Asset*Asyst*® but the principles could be used in other systems or the data exported from other systems for processing in the tool.

3. AssetAsyst® and Asset Man*agemen*t Systems

Asset*Asyst*® is a roads, pathways, buildings and bridges asset management software package that has been specifically designed for infrastructure asset owners. It is currently used by authorities throughout Australia. Typically Asset*Asyst*® is used by clients that have:

- a broad network of aging road and or rail, bridge and culvert assets
- low budgets to implement obligations of road management legislation
- few dedicated asset management resources and no specific data managers
- a need to optimise risk exposure as maintenance and capital budgets are small

The AssetAsyst® platform provides core services to integrated modules. It features:

- Spatial asset organisation and navigation via a GPS mapping interface that imports and links existing GIS layers, and support real time GPS tracking
- A sophisticated query framework capable of developing custom, ad-hoc queries across all asset types
- User defined fields and reporting
- Queries may be saved, recalled, and used to filter the user interface to provide 'drill-down' data exploration
- Tablet data collection capabilities
- A generic reporting foundation that processes result sets from the query framework to produce specific views of asset data, or export data to Excel spreadsheets for further analysis
- Permission based security and auditing tools
- Attachment functions for external files
- Financial management including depreciation

4. Predictive modelling

With the benefit of a good asset management system with predictive modelling as the following questions can be answered:

- What is the ideal level of expenditure?
- What is the cost to do nothing?
- When will the structure reach an undesirable condition?
- When will the structure need to be closed if works are not undertaken?
- What is the cost of undertaking repairs and when will they be required?
- What is the cost of replacement?

Good asset management software draws information from a range of sources including generic, condition, financial and works information (as depicted in the

Figure 1).

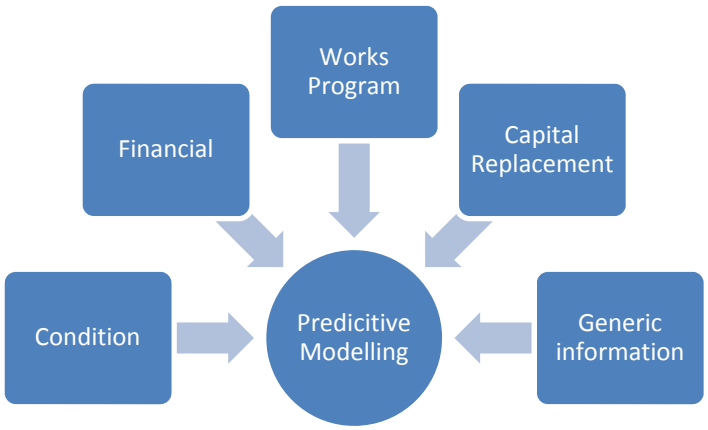

Figure 1 Predictive model inputs

In order to undertake predictive modelling access to the following information is required from the Bridge Management System.

Generic information

- The various structure types an asset owner may have such as bridges, culverts, boardwalks, retaining walls and signs.
- The length and width of structures and their widening and lengthening etc.
- Year of construction of the structure and the individual components.
- Type of components as defined by the user of those in use by the major state road authorities.
- Estimate life of components
- Calculated, Preconfigured or user defined Deterioration curves.

Condition data

Component condition information typically using a one to four condition rating scale. The exposure classification for each component is also recorded. If defects are identified during field inspection then a recommended repair, timeframe and cost needs to be identified.

Works information

Each defect indentified during inspection needs to be able to be assigned to a works order and the condition post treatment estimated prior to the works occurring. Defects may be assigned to a general works order for rectification or placed against a routine maintenance work order.

Example of routine works may be the clearing of siltation in blocked culverts due to a poor initial design leading to regular culvert siltation that is known require clearing. Other routine works could include the painting of girders every 20 years prior to paint system failure.

Defects must also be able to be closed out and the actual cost of repair recorded.

Financial data

The system needs to record the programmed replacement year and cost of a structure. The cost may be based on a replacement type of structure for easy index and modification if an Asset owner wishes to apply a rates based procedure. However, to apply the predictive model it is necessary to determine the original value for each component.

5. The predictive modelling process

pitt&sherry has developed a deterministic predictive modelling process utilising the comprehensive data held within a bridge management system. Through detailed deterioration modelling a condition based value of each component in a structure can be determined and future condition of components can be predicted. This information is then used to optimise the selection and timing of maintenance and rehabilitation treatments.

Deterministic models are based on statistical analysis of historic data to obtain a best fit data. Asset*Asyst*® supports user defined curves including deterministic curves. As deterministic models are based on historic data it is important to have reliable data. The reliability of the data is affected by an understanding of past works, clarity in inspection manuals, appropriate assessment criteria and degree of errors during inspection. Given the possibility of unreliable data it is important to review and apply engineering judgement to the data which is to be used in the modelling.

To manage the fact that condition states noted in the State Road authority manuals are based on a discrete scale of 1 to 4 and mostly a visual qualitative assessment means that varying the condition of an individual component can be expected to have stepwise deterioration over its life. Assuming a component moves from condition state 1 (as new) to condition state 4 (failed) and based on a linear degradation implies that a component found in condition state 1 could be either newly built or up to 25 years old (refer to

Figure 2). Moreover a component found in condition state 4 would be expected to be anywhere from 75 plus years old.

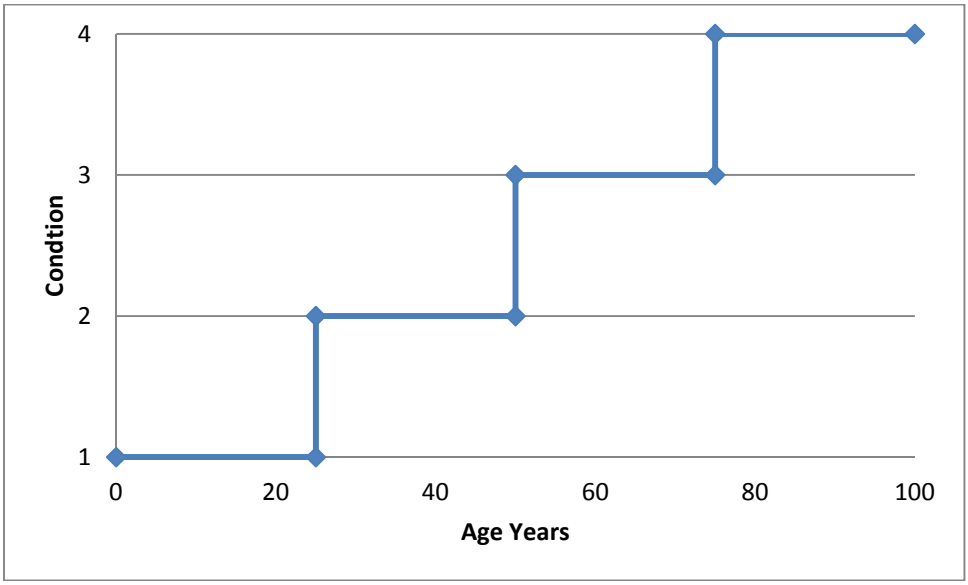

Figure 2 Linear deterioration

Most condition data collected from level 2 inspections tends to follow a non linear stepped curve. For a component in condition one, its life could be anywhere between 0 and 60 years old. If an estimate is to be made of the remaining useful life then it is unlikely a sensible estimate will be made without some understanding of the components age. Visual observations are relatively poor at estimating remaining life in the early stages of a components life as there is often little change in physical appearance. To understand changes earlier in a structures life where age isn't known some form of quantitative assessment is required.

pitt&sherry has implemented a process that uses a components life in the predictive model. For example, assuming the mock deterioration curve in Figure 3 was utilised then a component found to be in condition state 1 and known to be 18 years old will be assumed to have a condition based age of 18 years. If the age of the component is known to be 70 years old then it would be assumed to be soon to transfer to condition state 2 and have a condition based age of 60 years. Where the age of the component is not known the model assumes the component is in the mid life of the observed condition state. For example, a component in condition state one and again using Figure 3 an age of 30 years would be assumed.

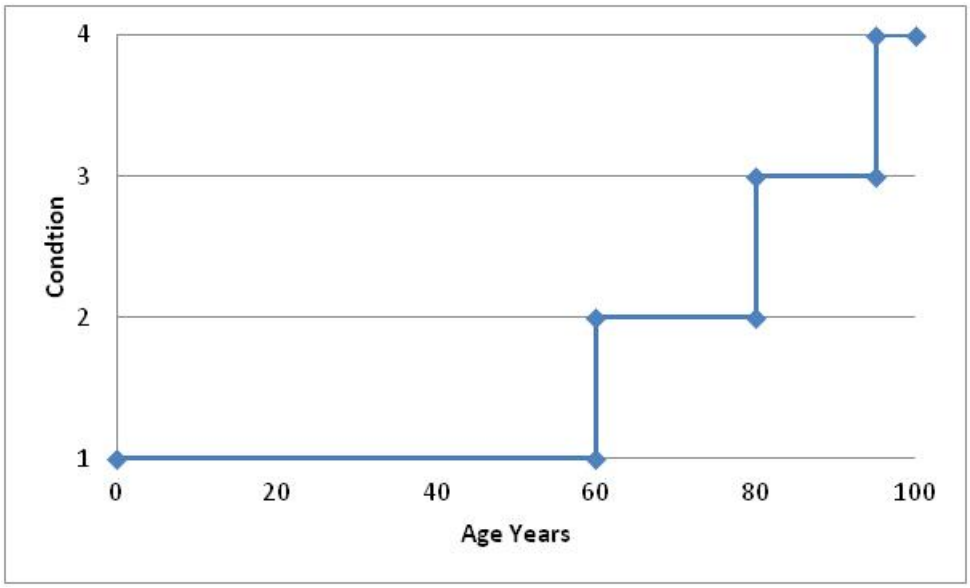

Figure 3 Non-linear deterioration

Due to variability within components a component will be represented by a range of condition states but mainly in state 1 to 2 and then some in state 3 or 4. To account for these situations a weighted average of the condition of the components can be used to represent the condition as a number between 1 and 4. For example a component 95% in condition state one and 5% in condition state two can be said to be in condition state 1.05.

The deterioration modelling process is quite complex and as such a brief outline of the methodology is provided below:

1. Enter asset generic data, including; asset number, asset name, asset owner, asset class, year of construction, construction cost, and replacement value for each asset.
2. Compile and enter all component data for each asset, this includes a list of each component and its most recent condition rating from a Level 2 inspection.
3. Determine a life span for each component based on component type, material and exposure classification.
4. Determine an original value for each component based on component type and material. The sum of the original values for each component is set to equal to the original cost of the bridge.
5. Calculate a “Condition Based Value” for each bridge component, by modifying the original cost of the component utilising a condition curve.
6. Summarise the “Condition Based Value” of each component to determine the “Condition Value” for each asset.

7. Model the deterioration of each component over a set duration utilising a deterioration curve model.
8. When repair/renewal works have been scheduled, the effect on a components condition is recorded.
9. Identify the condition and Condition Based Value of each component at the end of the modelling period for two conditions:
    a. No work condition - condition and value of components and asset assuming no works are undertaken
    b. Work condition - condition and value of components and asset assuming all programmed works are undertaken.
10. Identify the year a component will reach a "Component Condition Intervention Level" based on the deterioration model.
11. Identify the year a component will reach the "end of its life".
12. A "condition index" is then calculated for the structure with and without any proposed works.

Given the amount of information required to be processed and the changing and ongoing nature of the process (as represented by the figure below) a bridge management system is required to keep track of the history of these changes.

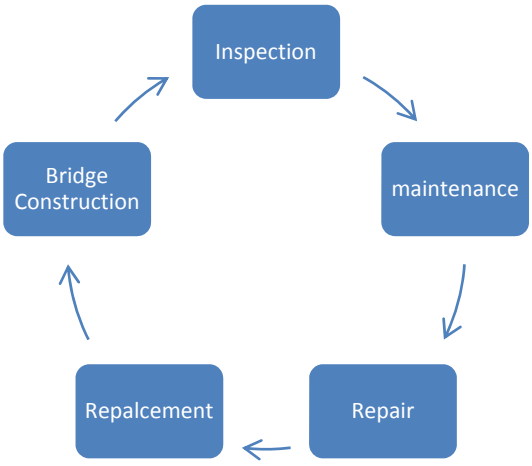

Figure 4 Changing nature of assets

6. Apply the predictive modelling process to solve common problems

The following section outlines a range of common problems where predictive modelling can be of assistance. The following examples have been simplified to illustrate the benefits of the process and do not include factors such as the time value of money or indirect costs and benefits.

6.1 What form of construction is of the most benefit?

Often asset owners prepare tender documents for design and construct contracts for bridges and depending on the specification requirements, client budgets and their understanding of design requirements a range of types of structures are often designed and built. There are examples of long life structures (100 years) as well as short lived structures (20 years).

Using a basic example of the choice between a timber deck footbridge and a concrete deck footbridge we can make the following assumptions and estimates in Table 1. Based on the outcome of the assessment the Concrete deck is more cost effective if the asset is to remain in service for a long time. If however the required life is only 20 years then it is more cost effective to have timber.

Table 1 Decking options

Deck type	Estimated life (years)	Cost $ /m^2	Running cost per year $/m^2	Years to intervention
Timber	20	50	2.5	20
Concrete	100	75	0.75	75

6.2 Is it better to repair or replace?

Using the example of a steel trussed foot bridge (refer to Table 2) with a footprint of 20 m^2 we can explore the question of whether it is better to repair or replace.

Table 2 Repair costs for 20 year life extension

Component	Estimated life from new (years)	Original Cost $	Repair Costs $	Current Estimated Remaining life (years)
Timber deck	20	1,000	1,500	0
Concrete abutment	100	5,000	N/A	80
Steel truss and railings	60	20,000	N/A	40

If the timber deck is at the end of its life and we replace it like for like for at a cost of $1,500 then the additional life gained is 20 years. Given there is significant value in the other components it is better to repair than replace with a new structure.

If we find the steel truss to be at the end of its useful life (refer to Table 3) after having replaced the timber deck a number of times it is predicated that it is better to replace the structure than repair. The

repair of the steel truss and railing would extend the life of the structure by 10 years until the timber deck required replacement and then if that was replaced an additional 40 years of life until the abutments needed replacing. The running cost would be $775 per year for repair and $583 per year for replacement including writing off any residual value of the structure.

Table 3 Repair costs for 40 year life extension – steel truss and railings

Component	Estimated life from new (years)	Original Cost $	Repair Costs $	Current Estimated Remaining life (years)
Timber deck	20	1,000	1,500	10
Concrete abutment	100	5,000	N/A	40
Steel truss and railings	60	20,000	25,000	0

6.3 Is there benefit of preventative maintenance?

The benefit of preventative maintenance can be observed through reviewing the cost of this maintenance and estimating the life extension it provides for the component that is under maintenance. For example shown in Figure 5 is the idealised deterioration for painted and unpainted steel beams. The effect of the paint treatment in this instance is a life extension of 20 years. In the deterioration model the paint system and other components are modelled to understand the benefit of the life extension. It may be that all other components have a shorter life within a structure and there may be no benefit in using paint protection to extend the life of the steel beams.

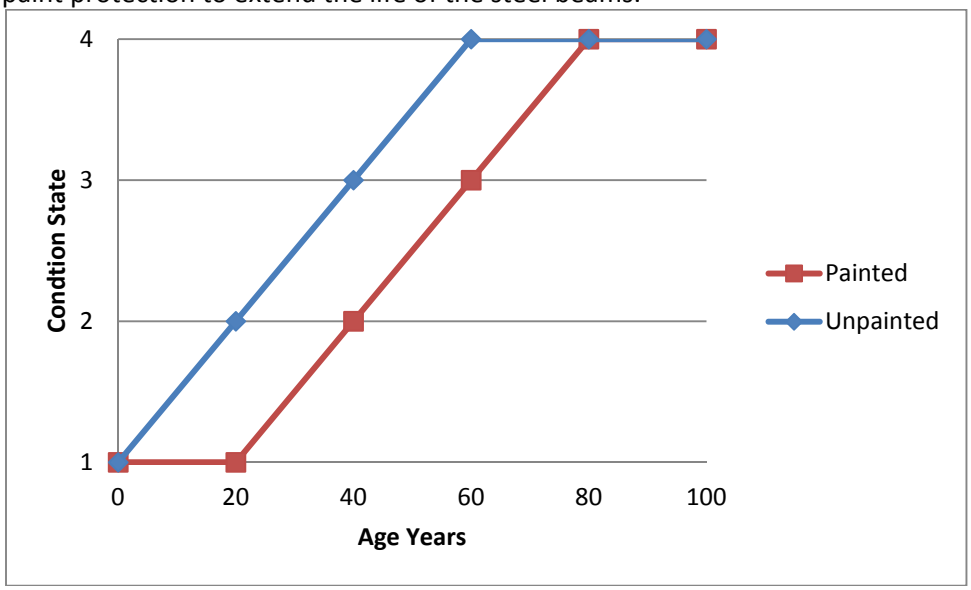

Figure 5 Idealised deterioration for Painted and Unpainted steel beams

6.4 When will works be required

Table 4 shows some sample output from predictive modelling in AssetAsyst®. The output indicates that the bridge approaches and approach barriers are expected to require intervention in four to ten years. After that time it is expected that if works are not done the structure will need to be closed. Provided works are undertaken to the approaches and barriers we expected that the structure will be able to remain in service for another 34 years.

Table 4 Predictive model results from AssetAsyst®

Structure Components											
			Condition (%)								
Comp	Component Name	Exp. Class	1	2	3	4	Remaining Life	Functional Limit	Years To Intervention	Orig Const. Cost	Condition Based Value
50C	Bridge kerb/Footways: Concrete	1	0	95	5	0	58	37	12	$9,782	$6,358
51S	Bridge Railings/Barriers: Steel	2	0	100	0	0	54	34	11	$9,782	$6,521
52O	Bridge Approaches: Other	1	0	100	0	0	12	9	4	$4,891	$3,261
54O	Waterway: Other	1	100	0	0	0	341	101	101	$0	$0
55S	Bridge approach barrier: Steel	1	0	100	0	0	15	10	4	$4,891	$3,261
62C	Arch Culverts: Concrete	2	0	100	0	0	54	34	11	$58,691	$39,127
63C	Endswall/Wingwalls: Concrete	2	0	100	0	0	54	34	11	$19,564	$13,042

7. Conclusions

pitt&sherry has developed a methodology for the prediction of bridge and culvert asset deterioration. The modelling technique allows for deterioration estimates based on deterministic means but also engineering knowledge. Although deterministic curves are useful for making predictions they are limited by the quality of the data they are derived from. The data is affected by a range of factors including the inspection manuals definitions of condition which include factors that are unrelated to condition.

Using engineering knowledge and the observations from inspections, not only condition, but defect information it is possible to make informed decisions regarding the ongoing management of these structures. These decisions include determining if it better to repair or replace, what form of repair or replacement structure is the most cost effective, when will works be required and when will the structure be at the end of its life.

As predictive modelling requires a large amount of data from a range of inputs which change over time the process of the modelling is best undertaken in a bridge management system like Asset*Asyst*® that links condition, works and valuation information together.

Appendix A

Definitions

Remaining life – is a numerical value in years from the reporting date at which time a component in a structure is considered to be fully deteriorated e.g. estimated to be at the end of condition state 4.

Functional life – is a numerical value in years from the reporting date until it is forecast that a particular component or structure will reach a condition whereby the component or structure is no longer in a serviceable state e.g. works must be undertaken to ensure the safety and continued use of the structure.

Year to intervention – this represents a numerical value in years from the reporting date until it is forecast that a particular component or structure will reach a condition state where it will be evident that defects of a sufficient nature to require remediation could be scheduled to maintain the life of structure in a serviceable condition.

Original cost of structure – The sum of the dollar value assigned to each component of a structure when it was constructed. This includes any original, wandering's or lengthening portions of the structure and modified as required for the time value of money.

Condition index – is a percentage determined by dividing the structures condition based valuation in dollars by the structures original cost in dollar with dollar values modified as required for the time value of money. A condition index of 100% represents a structure in "as new" condition. A condition index of 0% represents a structure in a totally failed state. In practice the condition index only reaches 0% sometime after it being removed from service.

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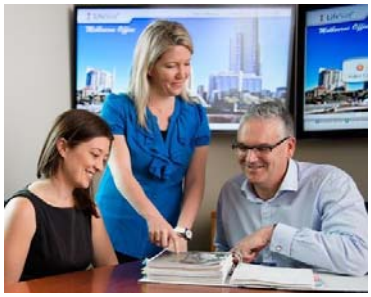

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