Applying a Systems Method for Setting Structure Performance Targets and Measures for a Long Term Concession

By Peter McCarten, MIPENZ, Chartered Professional Engineer, Group Technical Leader, Opus International Consultants, Napier, New Zealand

SYNPOSIS

The objectives of setting structure performance targets and measures for a long term concession are to encourage the Concessionaire to;

- Accept a high level of ownership of the asset
- Be a good custodian
- Comply with the concession requirements for network serviceability
- Limit asset consumption
- Apply innovation in technology and contracting methods.

The systems method follows the general hierarchy of asset owner needs and sets performance targets and measures at strategic, asset preservation and operational levels.

Condition Rating, Indices and States based on structure inspections are proposed as the measure for defining the intervention levels. The Concessionaire is expected to improve the reliability of the condition assessment by undertaking appropriate non-destructive testing and evaluation. The road controlling authority needs to have a Bridge Management System in place that records structure condition and the targets are based on five condition states, ranging from CS1 excellent to CS5 very poor. The indices and ratings used are those typically available within the Bridge Management System. While the Stock Condition Index sets the overall minimum condition standard the other Structure Feature targets are set to encourage the Concessionaire to implement proactive preventive maintenance strategies.

The need for the asset owner or Road Controlling Authority to be involved throughout the process to 'buy in' to the performance targets and measures and ensure the standards and practices are consistent with the wider network is emphasised.

1 INTRODUCTION

Public Private Partnerships (3P's) are a political vision for the future. The vision is based on the belief that a governments ability to meet current and future infrastructure and service obligations can be enhanced through these partnerships. In a number of countries the highway transport sector has in particular been targeted. Within these countries the various road-controlling authorities (RCA) whether national, state, district or local have proceeded with contracting out of some or all of their roadway services. As a consequence there are a range of RCA organisational structures utilising a variety of service delivery and procurement of services models and practices. These lead to a wide range of asset owner/consultant/ contractor relationships and responsibilities for construction and maintenance projects. This

paper focuses particularly on maintenance of highway structures, with an emphasis on the bridge stock and is based on the author's experience in providing technical advice to the British Columbia Ministry of Transportation (BCMoT) Canada.

Under the 3P vision there are several provinces in Canada that have entered into long term (10 – 30 year) concession arrangements. These have usually involved design/build/operate and maintain (D/B/O/M) services for new portions of the highway network and the Concessionaire has had the opportunity to impose tolls to secure his financial interest in the concession. These concessions typically involve performance-based specifications. The assets under these concessions are of similar age and are usually subject to similar traffic loadings and environmental conditions. Recent experience with these arrangements has resulted in varying degrees of success. While there are a number of reasons for the resulting outcomes it has been found the design/build/operate services of the concessions typically meet asset owner and road user expectations but the maintenance services are not achieving the outcomes expected by the RCA, particularly for the highway structures. Over recent years there has been significant advancement in specifying performance measures and targets for pavement maintenance and general road corridor activities and this has allowed the private contracting industry to better understand the expectations for that work but for bridges, culverts, tunnels and other roadside structures the progress has been very limited.

As BCMoT have programmed a number of 3P initiatives for the near future there was a need to develop a method for setting Performance Measures and Targets for structures under a concession agreement. The concession term could exceed that typically adopted for D/B/O/M concessions with a period of up to 55 years likely should highway "leasing" concessions be pursued. These leasing concessions would use sections of the network where the structure ages, traffic volumes and environmental conditions are similar. In these concessions the concessionaire has full responsibility for funding, work prioritisation, maintenance and operation management and is required to provide the full range of engineering services, inspections, investigation, design, maintenance/construction physical works (including supervision of these activities) and operations/maintenance management. In the very long term leasing concessions the RCA needs to decide whether it is appropriate to include structure replacement in the Concession or those activities remain the responsibility of the RCA.

This paper outlines the considerations and process that was followed to determine the measures and develop the targets for a Concessionaire to meet good asset management practices for the structures on a portion of road network in a long-term concession. To achieve the reliability expected a proactive preventive maintenance approach has been adopted and to ensure standards and practices are consistent with the wider network asset owner involvement is emphasised.

2 BRIDGE MANAGEMENT

Before setting targets and measures for structure condition it is important the Concessionaire have in place the personnel and management structure to undertake the structures asset management. It is suggested the Concessionaires set up should reflect the RCA structure asset management set up.

In its basic form the structure asset management cycle consists of:

- Inspection at the specified interval
- Rating the condition of the structure and elements
- Inventory updating

- Programming correction of deficiency
- Undertaking remedial works, and
- Reporting achievements

Fundamental to the structures' asset management cycle is Structures Inspection management. It is from inspections that asset condition is monitored, defects are identified and maintenance programming and strategies evolve. Structure inspections would be undertaken at a frequency and standard appropriate to the structure and be managed by a suitably qualified Bridge Structural Engineer. It is important the Bridge Structural Engineer be:

- Experienced in supervising structure construction, structure design, inspection and maintenance
- Responsible for programming and technical supervision of the bridge inspection and maintenance programme
- Responsible for the technical competence of all personnel
- Responsible for the structural safety of all structures, and
- Responsible for consulting with specialist staff when necessary

While the inspector is to be experienced in either structure design, or construction or maintenance his/her principal responsibility is to identify defects. The inspector will need to know where and what to look for, and report the significance or otherwise of the defect. The Bridge Structural Engineer is ultimately responsible for interpreting the observations and developing the appropriate investigations and analysis or maintenance strategy to meet the target performance levels.

As with any inspection and maintenance management activities a significant quantity of data will be generated and needs to be managed. At the end of the Concession the RCA will require the Concessionaire to 'hand – over' inspection, maintenance and any new construction as built records. Rather than the Concessionaire developing his own Bridge Management System (BMS) it is suggested the Concessionaire make use of the RCA's own BMS. The RCA will need to determine what information is to be provided by the Concessionaire and the format and interface lines of communication for providing the information. It is important the RCA have a comprehensive BMS in operation.

A comprehensive BMS is one that in addition to managing and storing basic inventory information, inspection programmes, maintenance schedules and maintenance cost records, is able to store and manage structure condition records. It is desirable but not necessary for the BMS to have the following functions:

- Tracking levels of service
- Life cycle engineering
- Managing preventive maintenance strategies
- Tracking structure reliability
- Maintenance optimisation techniques

In view of the importance of bridge management to the structures asset management cycle performance targets are set using a Structure Management Index that reflects the following:

- Number of inspections completed vs those programmed each year
- Number of defects addressed vs the number identified

- Number of structures for which maintenance or rehabilitation has been undertaken vs the number identified for those treatments
- BMS updating is completed promptly and accurately

3 BRIDGE MAINTENANCE

Understanding material deterioration and bridge maintenance strategies is important for setting targets and measures for structure condition.

Historically bridge maintenance repair, rehabilitation and replacement activities were performed on an as-needed basis. These employed best existing practice that usually involved reactive strategies to address potential bridge safety issues, Frangopol [(1)] .

Frangopol [(1)] has highlighted the need to consider bridge components separately from the overall bridge system as their effect on the structure reliability can be significantly different. When setting performance targets consideration must also be given to the different maintenance strategies and repair methods currently available and anticipate future advances in technology. It is a fundamental aim of performance-based specifications to encourage innovation and new technology and the targets and measures must reflect this.

With the current understanding of material deterioration and the investigative techniques available the bridge management personnel can be proactive and identify preventive maintenance strategies. There is now wide recognition of the cost effectiveness of preventive maintenance strategies and these are encouraged in the Concession. The difference in these maintenance strategies is highlighted in the following example, Figure 1.

For a particular bridge defect Figure 1 shows the comparison in bridge performance (reliability) progression under both reactive and fully preventive maintenance strategies. The critical intervention decision for the reactive strategy is whether rehabilitation or replacement should be adopted when the Target Level is reached. Traditionally the Target Level has been poor condition and relatively little investigation or analysis was required to determine when the maintenance was required.

The critical decisions for a fully preventive maintenance strategy are the intervention timing and what maintenance technique should be utilised. For this strategy to be applied the bridge management personnel need to understand the rate of change in condition in order to be able to predict development of deterioration and assess the effects of that deterioration, as the Bridge Structural Engineer can then make an informed decision on the maintenance strategy and repair methods. Lifetime reliability and whole of life costing techniques can be applied to optimise the bridge maintenance strategy. For the bridge defect assumed for Figure 1 the expected ‘straight line’ approximation of the performance level for the optimised maintenance strategy has also been shown on Figure 1.

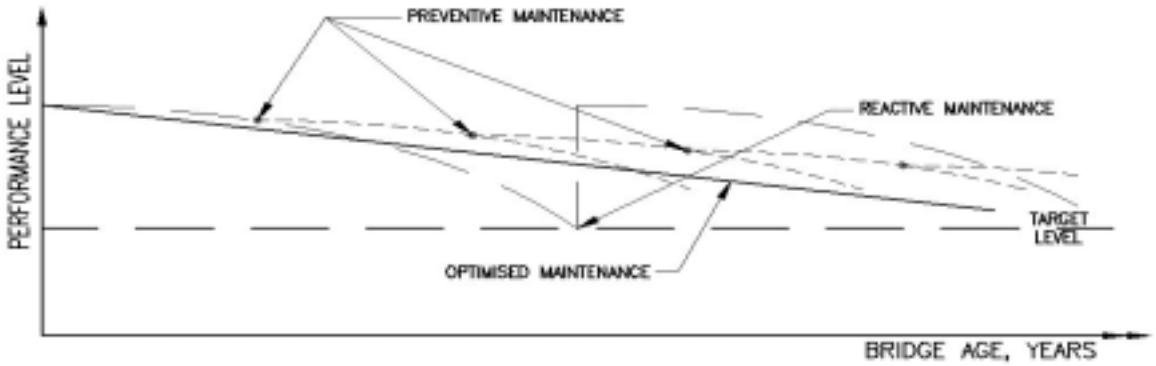

Figure 1: Whole of life Bridge Performance Profiles As affected by Reactive, Preventive and Optimised Maintenance Strategies

When setting overall performance targets for a long-term concession the "ideal" is to achieve this Optimised Maintenance Performance level for each and every bridge. In reality each bridge under a particular Concession will have different inherent defects, exhibit different rates of deterioration and suffer damage that is unique to it, requiring each bridge to have its own maintenance strategy. The Concession will involve the agglomeration of the individual bridge maintenance strategies. In a manner similar to the statistical "theorem of large populations" it is argued that the bridge management for a Concession involving many structures should approximate the Optimised Maintenance Performance Level of the typical bridge and that this Optimised Maintenance Performance Level would form the basis for setting overall bridge stock targets.

As it is fundamental the Concessionaire manage the bridge stock under the Concession to the same criteria used in the wider network a review of the RCA's current practices must be made. A statistical review of the particular RCA bridge management practices for the adopted measure(s) will allow the 'actual" Maintenance Performance Level to be determined. For consistency across the wider network the 'actual' Maintenance Performance Level must form the basis of the Concession targets. It is however recognised that some adjustment of the 'actual' Maintenance Performance Level may be required to remove extraordinary bridge maintenance influences.

At the structure level maintenance performance levels need to be set to ensure proactive preventive maintenance strategies are considered before reaching a serviceability target.

At the component or element level Maintenance Performance Levels also need to be set to ensure the reliability of the bridge system as a whole is not compromised.

4 CONDITION INDICES

Throughout the above discussion reference has been made to Performance Level and Structure Condition but how do we measure this. Frangopol [(1)] recognises that most BMS currently in use require elements/components/bridges to be characterised by discrete condition states describing the type and severity of deterioration in visual terms. To ensure consistency in defect identification and severity reporting national or regional Bridge Inspection standards are set or an inspector certification/ accreditation system is implemented. Catbas et al [(2)] have noted the relationship between visible signs of defects/damage and the

corresponding “condition” and “structure reliability” is often difficult to establish. In the proposed Concession it is the responsibility of the Bridge Structural Engineer to establish this relationship for every defect/damage reported by the Bridge Inspector. In making this determination the Bridge Structural Engineer will need to recognise that with time visual Condition States will change even if the Inspector does not. Figure 2 shows a typical reinforced concrete beam material and the deterioration stages, and indicates the expected correlation to the visual Condition States.

The figure highlights two important effects:

- Visual inspection will typically identify durability defects before serviceability or structure reliability is compromised
- Post Maintenance visual Condition States are expected to track down with element deterioration

The Bridge Structural Engineer can use the first effect to his advantage with preventive maintenance and must be aware of the second effect.

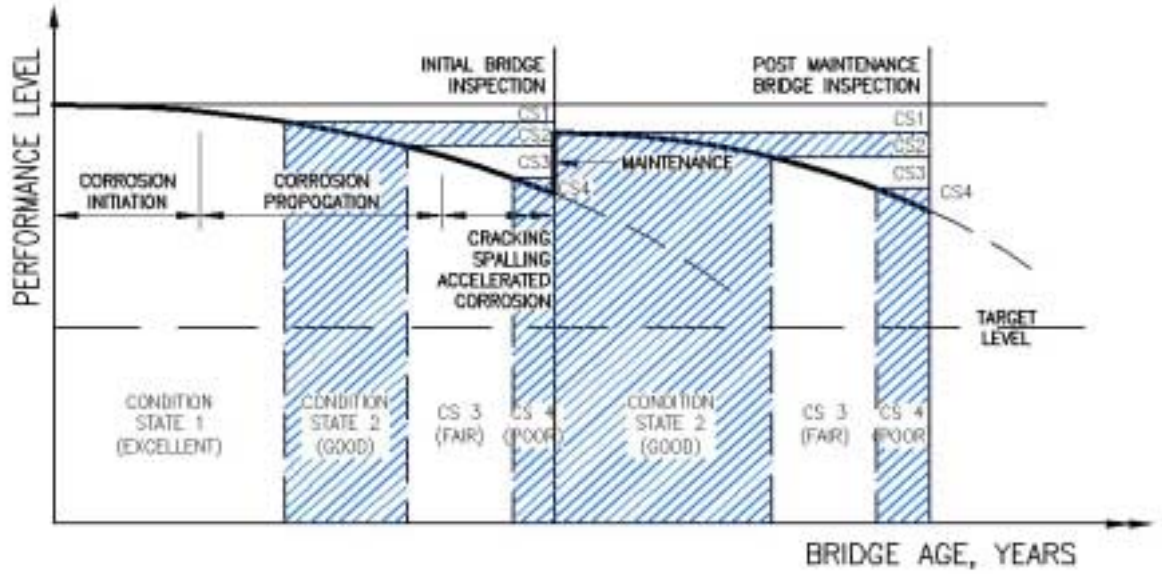

Figure 2: Typical reinforced concrete beam deterioration and correlation with Bridge Inspection Condition States

Catabas et al [(2)] provides a good treatise on Condition and Damage Indices and shows the importance of integrating various experimental approaches and related technologies. It is recognised that ‘structure response’ health monitoring techniques do have some application to “constructed” engineering systems. At this point in time current health monitoring techniques are focussed on the overall bridge condition rather than components or elements and significant analysis and interpretation is required before determining appropriate maintenance strategies. While the assessment of structure condition within a concession could be based on an experimental approach and targets and measures set using that information, it is considered the techniques are expensive and not sufficiently advanced to be able to use them with confidence at this time for monitoring Concessionaire performance. A Concessionaire could use these experimental techniques to raise confidence with visual condition assessments.

Sanford et al [(3)] show the importance for the Bridge Management personnel to consider both qualitative and quantitative data when determining condition states. These integrated

condition states take into account the mechanisms and causes for the deterioration and raise confidence with Condition State reporting. Non Destructive Evaluation (e.g. carbonation tests, chloride ion tests, reinforcing section loss measurement) techniques are to be used by the Concessionaire to supplement the inspection programme.

At this time it is proposed the Condition States (CS) be based on an auditable bridge inspection programme and that five CS's be adopted, being:

CS1	-	Excellent Condition (Highest CS): as-built condition, no observed defects
CS2	-	Good Condition: normal wear and deterioration
CS3	-	Fair Condition: minor loss in Condition or minor observed defects
CS4	-	Poor Condition: advanced loss in condition or significant defects
CS5	-	Very Poor condition (Lowest CS): serious loss in condition or serious defects

Figure 3 shows how the 5CS's would relate to a bridge Primary Component (concrete beam) and a Secondary Component (deck joint) for the whole of life performance profile.

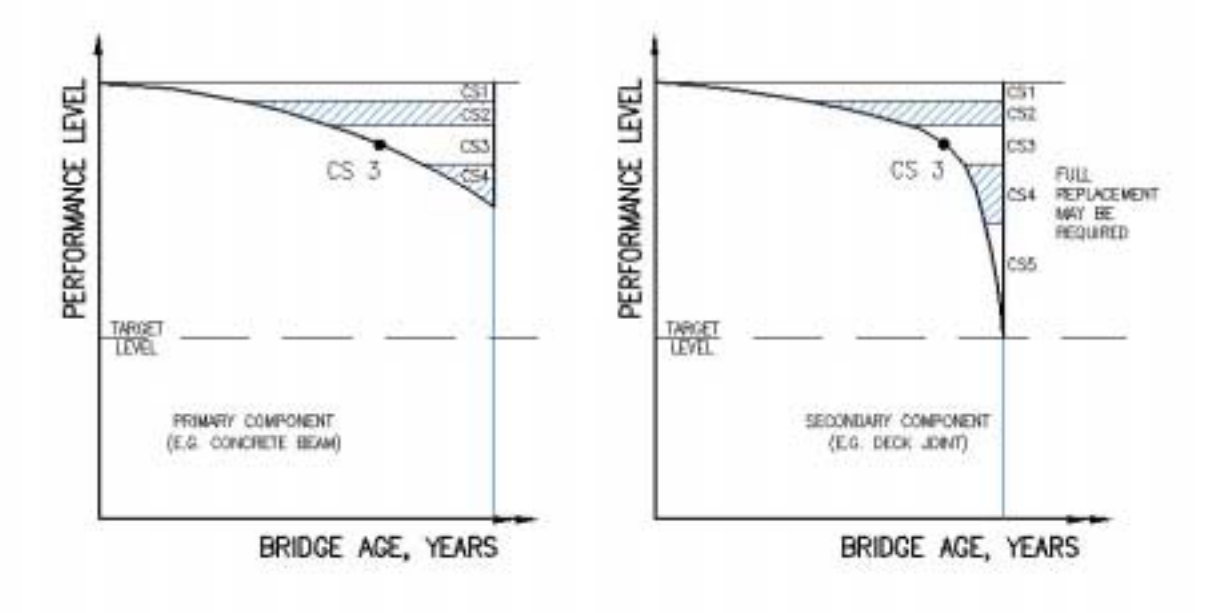

Figure 3: Whole of Life Component Performance Profiles (Primary vs Secondary) and Correlation to Condition States

Figure 3 highlights four effects that must be taken into account when setting performance targets:

- Condition State 3 is the indicator for the rate of deterioration increase in the progression profile, hence is the appropriate target for limiting asset consumption (i.e. initiating preventive maintenance strategies)
- Condition State 4 is the indicator for limiting loss of component serviceability
- Condition State 5 is the indicator for limiting component structural failure (i.e. initiating reactive maintenance strategies)

- Primary and Secondary Components have significantly different Performance Profiles and hence it is appropriate they are subject to different Performance Targets at the Operational Level

The raw Condition State data from the inspections is input into the RCA's BMS. The data is usually input for each component with the condition being a rating based on the percentage of each element with each exhibiting a particular Condition State. The Component Condition Rating is therefore a weighted average of the element Condition States. It is also usual practice for the BMS to use the Component Condition Rating data to determine an overall summary condition indicator for the bridge or structure. The specific combination (weighting factors, importance, etc) is dependent upon the purpose of the bridge indicator e.g. for decisions on intervention, treatment or as a measure of management effectiveness, hence RCA's often will have several condition indicators. In setting targets a decision needs to be made on the most appropriate indicator for the Concession, this is the Bridge or Structure Condition Index. The Concession terminology should follow that used in the RCA BMS.

5 PERFORMANCE MEASURES

Performance based specifications used for the Concession give the Concessionaire full freedom for managing cost, time and quality to meet the specified performance targets.

With the Concessionaire having full management freedom it is difficult to set measures and targets based on the process/practices applied to fulfil the obligations under the concession. The RCA prime requirements are satisfactory asset condition throughout the term of the concession with a particular concern being the condition of the asset at 'hand-back' at the termination of the concession.

To ensure the outcomes are met the Concessionaire is required to implement their own compliance monitoring system to ensure both Contract Standards and Response Times are met. This compliance monitoring will need to be sufficient to demonstrate compliance and be robust enough to withstand external review or audit.

A hierarchy of performance measures is proposed that will allow overall Strategic Performance Targets to be met. For bridges and structures the Strategic Performance Targets would typically include:

- Structure condition and function – ensure design levels are maintained to avoid compromising passage by legal heavy commercial vehicles, and ensure the structure remains safe and functional at all times for the travelling public
- Side protection – guards and barriers have adequate strength and are appropriately positioned to provide safe access over bridges throughout the concession term
- Structure risk – likelihood and consequences of failure or damage throughout the concession is appropriately managed
- Physical environment – waterway and other environmental features as existing or set by permit or consent are managed throughout the concession
- Management – inspections, condition reporting and Bridge Management System updating is appropriately programmed and completed accurately.

The Performance Measures to achieve the above targets are set at two levels, being:

- Asset Preservation Performance Levels – typically define the minimum condition for bridge assets or their components during the concession term and at 'hand back'. Bridge assets typically have a design life greater than the concession period and hence some loss in average condition is expected, refer to Figure 1, and that needs to be allowed for when setting targets
- Operational Performance Levels – typically define the minimum condition for elements of the bridge assets. These reflect the highway users expectations for the day-to-day serviceability of the structures and the Concessionaire must comply with standards and response time targets.

The targets and measures for these performance levels are illustrated in Section 6.

6 PERFORMANCE TARGETS AND MEASURES SUMMARY

The above discussion introduces the concepts to be considered in setting the performance measures and targets and these can be summarised as below.

The Asset Preservation Performance Level Targets and Measures that should be considered for any long term Concession have been summarised in Table 1, these follow the hierarchy of structure feature. The criteria for intervention is based on the Condition Rating or Index specified.

Structure Sub-Category	Structure Feature	Performance Measure (intervention level)	BMS Condition Rating or as specified Index Used
Bridges, Major Retaining Walls, Major Culverts, Tunnels and Major Sign Structures	Component	Limit Asset Consumption	Any Component Condition Rating between 3.0 and 3.5
		Serviceability	Any Component Condition Rating between 3.5 and 4.0
		Reactive	Any Component Condition Rating of 4.0 or greater
	Structure	Limit Asset Consumption	Any Structure Condition Index between 3.0 and 3.5
		Serviceability	Any Structure Condition Index of 3.5 or greater
	Stock	Serviceability	Stock Condition Index set for each year of the Concession, with this reflecting asset consumption of the bridge stock
	Management	Structure Management Index	Structure Management Index range to be limited

Table 1: Asset Preservation Performance Level Targets and Measures

The targets for the Asset Preservation Performance Level are specifically set for each RCA and Concession, they depend upon the number of bridges/structures in the Concession, bridge materials and the environmental factors influencing structure durability. A response time is to

be set that reflects the remedial action to be applied. For this performance level and the Limit Asset Consumption Measure there is a focus on identifying and reporting maintenance strategies and asset management planning for Components and the Structure. The Concessionaire will have the option of undertaking physical works, to remedy the defect, deterioration or damage, or implement a monitoring programme to manage the risks. At the Serviceability and Reactive Measures the urgency for physical works is increased. The Stock measure is an overall indicator of Concessionaires management of structure condition.

The Operational Performance Level Targets and Measures that should be considered for any long term Concession are summarised in Table 2.

The targets for the Operational Performance Level are specifically set for the Concession and should reflect those of the wider network. A response time must be set and this should relate to the remedial action to be applied. The operational standards and actions would be prescribed and implied by the RCA Structure Maintenance Specifications and the objectives or outcomes defined. At the Operational Performance Level the Limit Asset Consumption Measure is to ensure bridge management personnel consider preventive maintenance strategies for the defective, deteriorated or damaged elements.

Structure Sub-Category	Structure Feature	Performance Measure (intervention level)	Element Condition State Target
Bridges, Major Retaining Walls, Major Culverts, Tunnels and Major Sign Structures	Element of a Primary Component	Limit Asset Consumption	Target Proportion of Asset with Condition State 2 or higher
		Serviceability	Target Proportion of Asset with Condition State 3 or higher
	Element of a Secondary Component	Limit Asset Consumption	Target Proportion of Asset with Condition State 3 or higher
		Serviceability	Target Proportion of Asset with Condition State 4 or higher
		Reactive	Limit the Proportion of Asset with Condition State 5

Table 2: Operational Performance Level Targets and Measures

7 CONCLUSIONS

The main objective of this paper is to outline a systematic method for setting structure performance targets and measures for a long term concession. A brief review of bridge management, material deterioration and bridge maintenance strategies has been made to outline the considerations required for setting the performance targets and measures. Condition Rating, Indices and States based primarily on inspections are proposed as the measure for defining the intervention levels. It is recognised that on going non destructive testing and evaluation of the structures will allow bridge management personnel improved understanding of the material state and likely rates of deterioration raising confidence with condition state reporting. Performance targets and measures have been considered at the Asset Preservation and Operational levels. The systems method for intervention is based on structure features and imposes intervention over a range of possible maintenance strategies, with proactive preventive maintenance being encouraged. Using the Road Controlling

Authority Bridge Management System and with limits set specifically for the RCA will ensure the standards and practices are consistent with the wider RCA network.

8 ACKNOWLEDGEMENTS

The contributions of British Columbia Ministry of Transportation staff are acknowledged. For providing data and advice on current practice the contributions from Gary Farnden are particularly appreciated.

9 REFERENCES

1. Frangopol D.M., Kong J.S., and Gharaibeh E.S. "Reliability – Based Life-Cycle Management of Highway Bridges". *Journal of Computing in Civil Engineering,* ASCE, Vol. 15, January 2001, p 27-34.
2. Catbas F.N., and Aktan A.E. – "Condition and Damage Assessment: Issues and some Promising Indices". *Journal of Structural Engineering*, ASCE, Vol. 128, No 8, August 2002, p 1026 – 1036.
3. Sanford K.L., Herabat P., and McNeil S. – "Bridge Management and Inspection Data : Leveridging the Data and Identifying the Gaps". *Transportation Research Circular 498,* Transportation Research Board, 2000.

10 DEFINITIONS

The following terms used in the paper are defined as below:

- Element: individual component, example a single deck joint or beam
- Component: a group of elements of similar type, for example the deck joint component will consist of large movement and small movement pier or abutment joints
- Primary Component: Deck, beam, substructure and foundation
- Secondary Component: Barrier, deck joint, bearing and waterway
- Bridge: a bridge will consist of a group of components and different bridge types will consist of different types of components e.g. suspension bridge vs beam/slab bridge.
- Stock: will consist of a group of bridges (Stock Condition Index is the numerical average of the Bridge Condition Index for the group of bridges determined after each inspection cycle)