THE NAMIBIA BRIDGE MANAGEMENT SYSTEM: A TOOL FOR PRESERVATION OF STRUCTURES ON THE ROAD NETWORK

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Abstract

This paper describes the development and implementation of a bridge management system (BMS) for the Namibia Roads Authority (NRA). Namibia is a vast country (825 420 km^2) with a very low population density and the NRA is currently responsible for the management of 6 200 km of paved roads and 35 900 km of unpaved roads, which includes 1 430 bridges and major culverts (>3m span length) and 1 290 lesser culverts (<3 m span). In 2001, the NRA embarked on a project to upgrade their existing BMS, which was essentially an inventory database, to a fully-fledged BMS, which would be capable of utilising visual assessment data to prioritise structure maintenance and rehabilitation needs. The system selected was the locally developed STRUMAN BMS, which is used by various road authorities in South Africa, Botswana, Swaziland and Taiwan and was developed by the Built Environment division of the Council for Scientific and Industrial Research (CSIR) in Pretoria. During the first phase of the project, the inventory and inspection modules were customised to meet the needs of the NRA, which included integration of the BMS database with the Road Management System (RMS). A map module front end was also customised and integrated with the other BMS modules for graphical viewing of the structure population. The second phase of the project involved the appointment of suitably experienced structural engineers to carry out the visual assessments. These consultants were required to attend a training course (including an inspector calibration exercise) on the assessment methodology, which is based on a 4-point DERU (Degree, Extent, Relevancy and Urgency) system for rating observed defects. The Relevancy rating forces the bridge inspector to evaluate the consequences of the defect in terms of the structural integrity and serviceability. Each of these parameters is combined in the condition module to determine priority rankings of all assessed structures. A remedial work sheet is used during structure inspections to summarise the items requiring repair. A visual assessment manual was utilised to improve uniformity of the inspector rating standards. The third phase of the project involved the validation of assessments and prioritisation of structures in terms of maintenance needs. The final selection of maintenance projects will also take into account planned road maintenance projects and the relative locations of structures with similar defects.

1. INTRODUCTION

Namibia is a vast country (825 420 km^2) with a very low population density. The country has a national road network of 6 200 km of paved roads and 35 900 km of unpaved roads. The planning, design, construction and maintenance of this network are the responsibility of the Namibia Roads Authority (NRA). This network includes 1 430 bridges and major culverts (>3m span length) and 1 290 lesser culverts (<3 m span). The replacement cost of the bridges and major culverts is estimated at N$ 5.5 billion. In order to manage the maintenance and rehabilitation of this infrastructure asset class, the NRA embarked on a project in 2001 to upgrade their existing bridge management system (BMS), which was essentially an inventory database, to a fully-fledged BMS, which would be capable of utilising visual assessment data to prioritise structure maintenance and rehabilitation needs. The system selected was the locally developed STRUMAN Bridge and Structures Management System, which is used by various road authorities in South Africa, Botswana, Swaziland and Taiwan and was developed by the Built Environment division of the Council for Scientific and Industrial Research (CSIR) in Pretoria.

The BMS implemented by the NRA enables the Roads Authority to have an inventory of all structures under its control; to know what the condition of these structures are; to know what the structures' maintenance needs are; and to know if there are any structures in a critical condition as well as the consequences of failure. The BMS therefore provides a systematic approach whereby the NRA can objectively assess which structures under their control should be repaired and when.

During the first phase of the project, the inventory and inspection modules were customised to meet the needs of the NRA, which included integration of the BMS database with the Road Management System (RMS). The second phase of the project involved the visual assessments of the bridges and major culverts and the third phase involved the validation of assessments, the calculation of the condition of each inspected structure based on the visual assessment data followed by and prioritisation of structures in terms of maintenance needs. This paper focuses on Phases 2 and 3 of the project.

2. VISUAL ASSESSMENT OF STRUCTURES

During August/September 2007 the NRA, by way of a tender process, appointed two joint venture teams of consulting engineering firms to carry out principal inspections of all bridges and major culverts under the control of the NRA and to identify all large culverts.

A major culvert is defined as a culvert type structure with any single span, measured square with the walls, of 3.0 m or greater; or with a total cross-sectional opening, measured perpendicular to the walls, of 10 m^2 or more. A large culvert is defined as a culvert type structure with dimensions less than a major culvert, but with any single span, measured square with the walls, of 2.1 m or greater; or with a total cross-sectional opening, measured perpendicular to the walls, of 5 m^2 or more.

One joint venture team was appointed to assess structures in the two northern regions (Oshakati and Otjiwarongo), and the other to assess structures in the two southern regions (Keetmanshoop and Windhoek). The scope of work relating to bridges and major culverts included updating inventory data for bridges from drawings and other sources of information available in the NRA's Drawing Office; bridge inspections (visual assessments to identify and rate defects as well as verification of inventory data); culvert inspections of all major culverts (capturing of inventory data and visual assessments to identify and rate defects). The identification of large culverts involved capturing the following information:

- GPS coordinates of the large culvert;
- The km distance at which the large culvert is located;
- Description of the large culvert, e.g. 2 cells of 2m x 1.8m; and
- Two digital photographs of the elevation of the large culvert, one taken from the upstream side and the other taken from the downstream side.

Bridge inspectors from the two joint ventures attended a training workshop in October 2007. Attendance of the training workshop was compulsory for all Principal Bridge Inspectors intending to carry out visual assessments. The workshop covered various subjects including bridge management, inventory data capture, typical structural defects, assessment methodology and site inspections. The training course was also attended by NRA technical staff and technical staff from the local industry (Namibian consulting engineers, parastatals, and City of Windhoek) for the purpose of creating awareness of bridge management and for skills transfer.

At the end of the training workshop, a calibration inspection was conducted to evaluate the Principal Bridge Inspectors' understanding of the BMS visual assessment methodology. An analysis of the results of the calibration inspection indicated that uniformity of rating of the various inspectors was more than satisfactory. The ratings by two of the inspectors that did not have previous experience with the assessment methodology were slightly more conservative and it was recommended that their initial 15 to 20 inspections be verified (in the office, not on site) by one of their colleagues that had more experience with the DER rating system.

Inspections commenced in November 2007 and the last round of inspections was completed in December 2008. Final data capturing, verification and analysis were carried out during the period January to August 2009.

3. COST OF DATA COLLECTION, CAPTURING AND ANALYSIS

The total cost to collect the inventory and inspection data and to analyse and report on the data amounted to approximately N$ 8 million. Included in this amount is an amount of approximately N$ 1 million for the preparation of the tender documents, tender evaluation process, data verification, data analysis and reporting. The average cost for the various data collection and capturing activities were as follows:

Inventory data:	N$ 650/structure
Inspection: Small Bridge:	N$ 3 400/structure
Inspection: Medium Bridge:	N$ 4 250/structure
Inspection: Large Bridge:	N$ 4 650/structure
Inspection: Very Large Bridge:	N$ 5 650/structure
Inspection: Major Culvert:	N$ 3 050/structure
Identification: Large Culvert	N$ 680/structure

These unit costs must be seen in the context of the long distances that had to be travelled during the inspections. If all structures are included, the average distance between structures is approximately 15 km.

The N$ 8 million that was spent on data collection, capturing and analysis represents less than 0.2 % of the replacement cost of all the structures and approximately 5 % of the estimated maintenance and repair costs.

4. LESSONS LEARNED DURING THE DATA COLLECTION AND CAPTURING PHASE

Before commencing with bridge inspections it is most important for an authority to have an up-to-date and accurate list of all structures, including the location. The basic information that should be included on such a list is the structure number; structure type; structure class; some indication of the size of the structure; the road or route number on which the structure is located as well as the GPS coordinates taken at the centre of the structure.

If such information is not available, it is recommended that an authority intending to undertake bridge inspections first embark on a project to gather this basic information accurately. In most cases this would require someone to drive along all the roads in the authority's network and to stop at each structure to gather the basic information. Each structure should also be numbered with a unique number, which must be permanent and easy to locate on the structure. The position of culverts should be marked on the road edge or shoulder. This exercise would require a diligent person with some basic knowledge of road structures and not a bridge engineer. By undertaking such a project prior to the actual inspections, significant time and cost savings can be realised during the inspection and data capturing phases. If inspectors are appointed by way of a tender process it would also make it possible to issue tender documents with accurate information and quantities, which should result in lower tender prices due to a reduction in risk for the prospective tenderers.

Adequate quality control during the inspection phase is critical. Data should be captured into the bridge management system's database as soon as possible after the actual inspection. The ideal would be to do this immediately after the inspection of a structure has been completed and before moving on to the next structure. If this is not possible, the data should be captured at the end of each day. It is particularly important to link the structure and defect photos to the relevant structure in the database and to ensure that all the required photos were taken. This will obviate the costly exercise of revisiting specific structures to obtain missing data or photos after the completion of the field inspections.

5. GENERAL INFORMATION ON STRUCTURES

During the visual assessment phase of the project, 1 430 structures were inspected of which 483 are bridges and 947 are major culverts. In addition, 1 290 large culverts were identified. The total number of structures in the Namibia BMS database is therefore 2 720. The number of structures is summarised per structure class and maintenance region in Table 1.

Table 1. Number of structures per maintenance region

Structure Class	**Maintenance Region**				**Namibia**
	Keetmanshoop	**Oshakati**	**Otjiwarongo**	**Windhoek**	
Very Large Bridge	12	13	9	14	**48**
Large Bridge	29	31	18	31	**109**
Medium Bridge	103	31	82	101	**317**
Small Bridge	24	6	30	28	**88**
Sub-total: Bridges	**168**	**81**	**139**	**174**	**562**
Major Culvert	207	120	281	260	**869**
Large Culvert	444	113	426	307	**1 289**
Total	**819**	**314**	**846**	**741**	**2 720**

The combined length of bridges is approximately 27 km, with more than 60 % of the bridges having a total length of between 20 m and 60 m. The average bridge length is 48 m. In terms of span length, 45 % of bridges have a maximum span length of between 5 m and 10 m; 96% of bridges have a maximum span length of 20 m or less. The combined length of major culverts is approximately 9.5 km with an average length of 11 m; 95% of major culverts have a maximum span length of between 0 m and 5 m.

As shown in Figure 1, the majority of structures were constructed during the period 1960 to 1980 and the average age of bridges is 36 years, while for major culverts and large culverts the average age is 32 years.

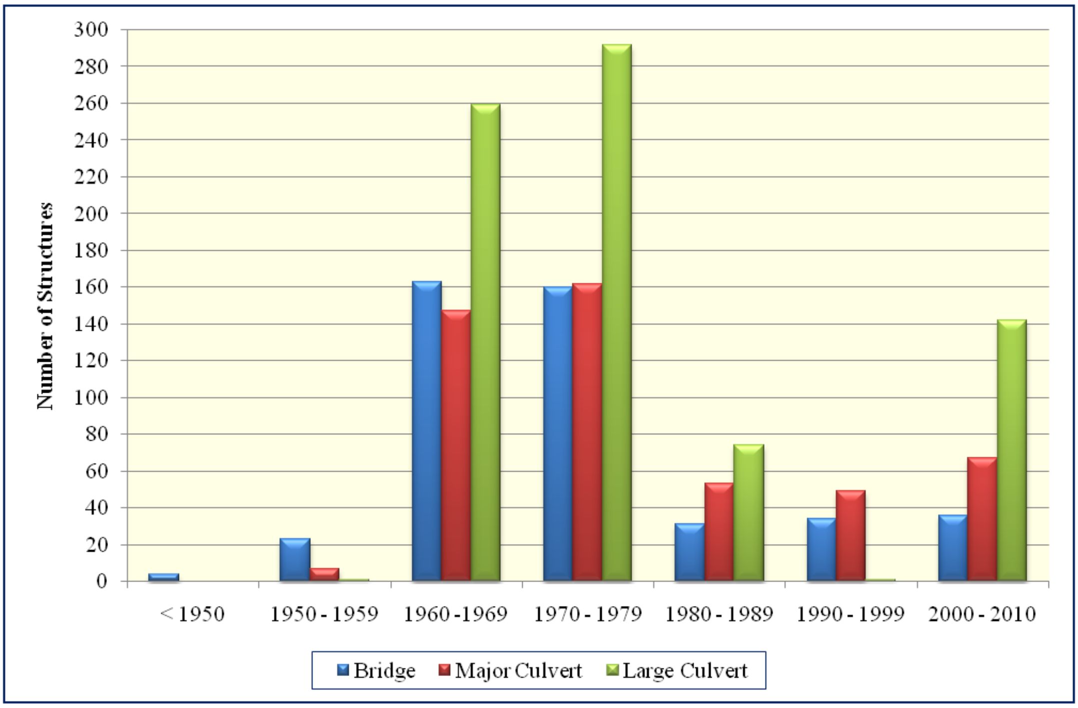

Figure 1. Distribution of year of construction of structures

The replacement value of the bridges is estimated at N$ 4.41 billion (USD 550 million) and that of major culverts at N$ 1.13 billion (USD 140 million), giving a total replacement cost of N$ 5.54 billion (USD 690 million).

6. CONDITION OF STRUCTURES

To evaluate the condition of structures, the STRUMAN BMS uses two rating systems, the condition rating system and the priority rating system. A Condition Index (CI) and a Priority Index (PI) are calculated for each structure. The CI takes the overall condition of a structure into account by averaging the ratings of all defects found on each structure, while the PI measures the ability of a structure to serve its intended functions by only considering the defects found on the *critical* elements of a structure, for example abutments, piers and deck elements on a bridge. The PI is designed to ensure that structures with the greatest need for repair/upgrading are given the highest priority. The PI value is usually higher than the CI value for the same structure, except in the case of structures with a very low PI (usually structures in a critical condition). The PI is used to develop a repair strategy for the structures, given a limited budget. Both the CI and PI ratings range from 0 to 100, with a rating of 100 indicating a structure in a perfect condition.

The CI and PI are calculated using the ratings given to defects on the various elements of the structure during the visual assessment phase. Defects are rated in terms of three aspects, namely degree (D) (how bad is the defect); extent of the defect (E) (how prevalent is the defect on the structure item being inspected); and relevancy (R) (how relevant is the defect in terms of the serviceability of the structure – structural integrity and user safety). The rating system is referred to as the DER-rating system. In addition, an urgency (U) rating is assigned to each identified defect, indicating how soon the defect should be repaired.

Each of the aspects of a defect is rated on a scale of 1 to 4 as follows:

D = Degree of severity of the defect (1 = minor; 4 = severe; 0 = no defect)
E = Extent of the defect on the structure element (1 = local; 4= general)
R = Relevancy of the defect to serviceability of the structure element (1 = minimum; 4 = critical)

Only the worst defect (highest relevancy or highest degree for the same relevancy) on each item or sub-item is rated, but all defects are recorded and assigned a remedial work activity description, repair quantity and urgency rating.

The cumulative distributions of the CI and PI ratings of all the inspected structures are presented in Figure 2, showing, for example, that 200 structures have a CI rating of less than 70 and a PI rating of less than 87.

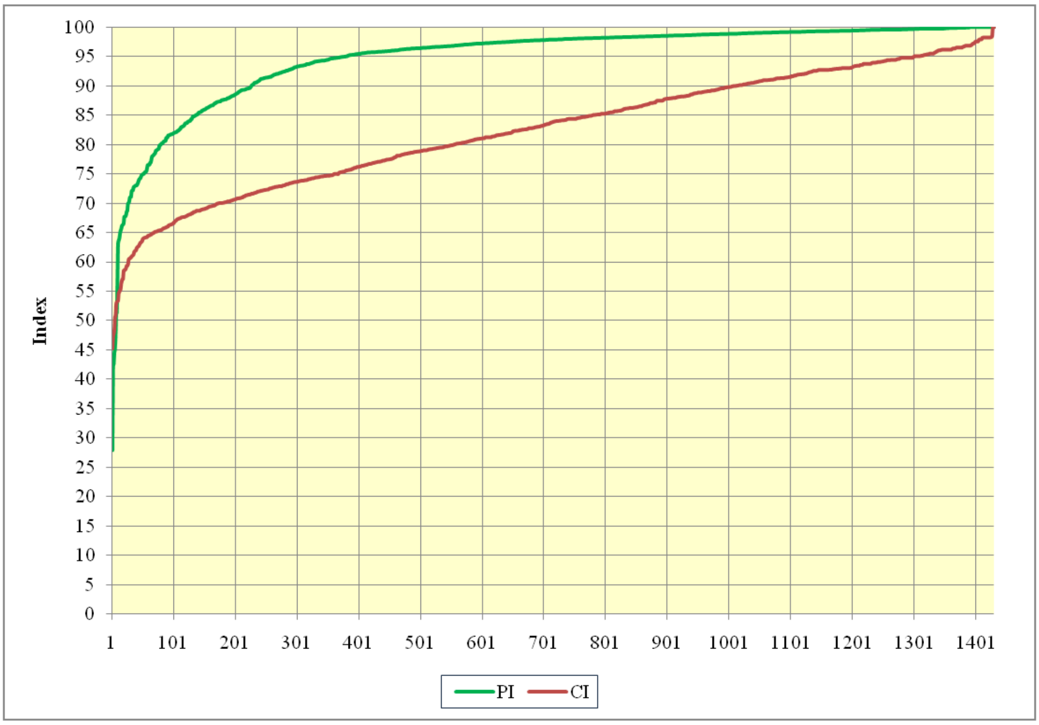

Figure 2. Condition rating of all inspected structures in terms of CI and PI

Based on the visual assessment ratings, the average CI for all bridges was 79.8 and for all major culverts, 84.3. Comparing the four maintenance regions, the structures in the Keetmanshoop and Windhoek regions (the two southern regions) are generally in a worse condition. Oshakati, the region with the lowest average age for all structures of 24 years has the highest average CI of 92.0.

Using the PI ratings to place structures in condition categories from good to warning to critical provides an indication of which structures should be repaired first. The values used to define the warning and critical levels are as follows:

Critical:	$PI < 50$
Warning:	$50 \leq PI < 75$
Good:	$PI \geq 75$

The average PI for bridges is 92.8 and for major culverts, 96.2, which are both in the Good-category. Six structures are in the critical category and 45 structures in the warning category. All the “critical” and the majority of the “warning” structures are in the Keetmanshoop and Windhoek maintenance regions. The structures per condition category per maintenance region are presented in Table 2.

Table 2. Structures per condition category per maintenance region

Condition Category	Maintenance Region				Namibia
	Keetmanshoop	**Oshakati**	**Otjiwarongo**	**Windhoek**	
Critical	3	0	0	3	6
Warning	11	1	3	30	45
Good	361	200	417	401	1 379
Total	**375**	**201**	**420**	**434**	**1 430**

In Figure 3, the distribution of the 200 worst structures across the four maintenance regions is presented, showing again that the structures in the Keetmanshoop and Windhoek regions (the two southern regions) are generally in a worse condition.

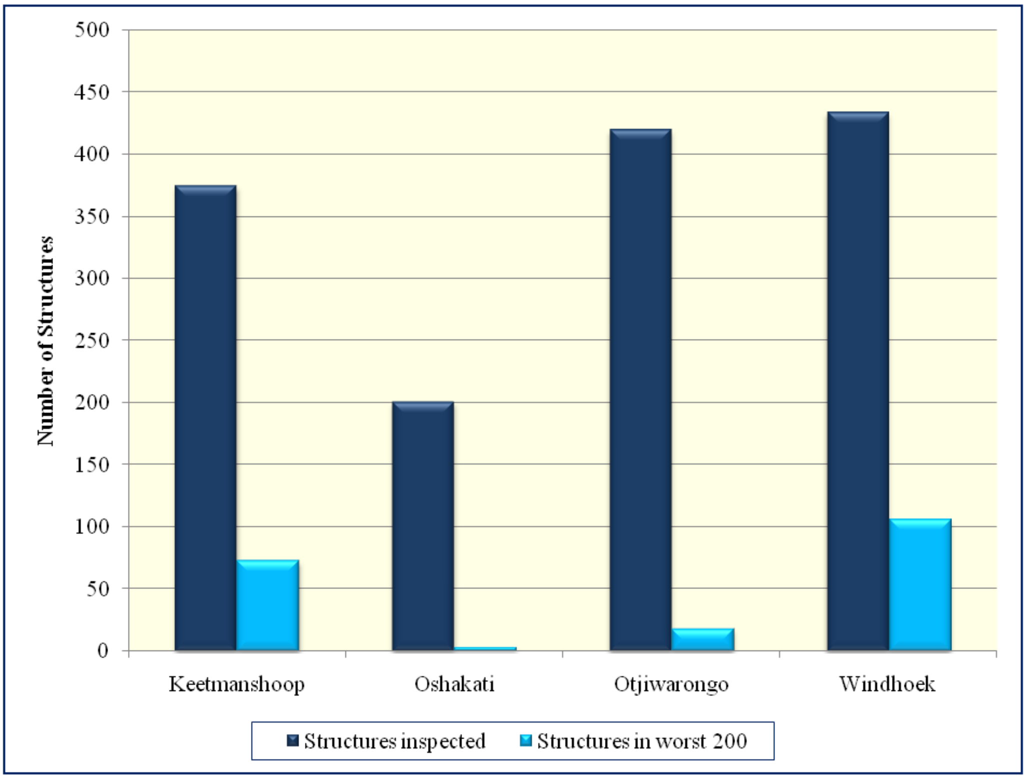

Figure 3. Distribution of 200 worst structures across the maintenance regions

Some of the defects on Bridge B0090, the Hom River Bridge, which is the bridge with the lowest PI rating (27.9), are shown in Figure 4. The critical condition of this structure is as a result of attack by aggressive water ("salts") and very poor quality concrete. The structural integrity of the bridge is at risk and could lead to the collapse of the structure. The recommendation by the Principal Bridge Inspector was that the structure be demolished and replaced with a new structure.

Figure 4. Some defects on Bridge B0090 – Hom River Bridge

7. SUMMARY OF IDENTIFIED DEFECTS

As mentioned previously, during the inspection of structures, all defects are identified and recorded. A repair item is allocated to each defect and the quantity required to repair the defect is estimated by the inspector. Considering the 21 inspection items on a bridge structure, the inspection item with the most defects for Namibia as a whole, is Item 21 - Miscellaneous Items. The majority of these defects are missing structure number plates and missing river name signs. The second most common inspection item with defects is Item 6 - Abutments. The majority of the defects on abutments are cracks and spalls. Item 2 - Guardrails is the third most common inspection item with defects. The majority of the defects on guardrails are guardrails that are not attached to end blocks, missing or damaged sections of guardrails and missing reflectors.

Considering the 14 inspection items for major culverts, the inspection item with the most defects on culverts is Item 14 - Miscellaneous Items. The majority of these defects are also missing structure number plates, river name boards and culvert markers. The second most common inspection item with defects is Item 2 - Wing/Ret/Headwalls, with Item 10 - Walls being the third most common item. The defects on Items 2 and 10 are mostly cracks and spalls.

The most common repair activities required on bridges are installation of bridge number plates, crack sealing, spall repairs, installation of river name signs and attaching guardrails to end blocks. The most common repair activities required on culverts are crack sealing, spall repairs, installation of culvert number plates, installation of culvert markers, replacing or installing guardrails and clearing siltation.

8. ESTIMATED MAINTENANCE COSTS

During the inspection of structures, the inspector identifies and rates all defects on the structure. The inspector is also required to measure and/or estimate quantities of work relating to the repair of each defect and rate the urgency of the repair. A standardised Remedial Activity List applicable to the type of structure being inspected is used for this purpose. This list contains various repair activities with a unit of measurement and unit rate per repair activity. By multiplying the measured or estimated quantities for the identified repair items by the corresponding unit rates, the estimated cost of maintenance or rehabilitation of the structures is calculated.

As mentioned previously, an urgency rating (U) is recorded for each identified remedial activity. The urgency rating is used to formulate present and future budgets. The different urgency ratings that can be recorded are as follows:

U = R	Record Only	Defects that are noted and recorded, but that do not need to be repaired;
U = 0	Monitor Only	Defects that should be monitored for a period before a decision is taken to repair them;
U = 1	Routine	Defects that can be repaired as part of routine maintenance (usually by the road authority's maintenance staff);
U = 2	< 10 years	Defects that should be repaired within the next 10 years;
U = 3	< 5 years	Defects that should be repaired within the next 5 years; and
U = 4	ASAP	Defects that need to be repaired as soon as possible

Only defects with an Urgency rating of 1, 2, 3, or 4 are included in the estimated budget calculations.

In addition, certain defects can be classified as "Make Safe". These are defects that should be repaired immediately, as they pose a threat to the safety of road users. Such defects should be reported to the road authority immediately after the inspection for action, even if only a temporary measure.

With the implementation of a maintenance plan to carry out the necessary repairs, project level investigations should be carried out on identified structures. During these project level inspections, identified defects may be found to be more extensive and/or additional defects may be identified that were not apparent during the visual assessment programme. In some cases this may result in a moderate or significant increase in the repair budgets for these structures. In some cases it may be more cost effective to demolish and replace a structure, rather than carry out the identified repairs.

The estimated cost to repair identified defects with an urgency rating of 1 to 4 on all structures is N$ 152 million (USD 9 million) of which N$ 106 million (USD 13.3 million) is for bridges and N$ 46 million (USD 5.8 million) for major culverts. The average maintenance cost per bridge is thus estimated at N$ 189 000 (USD 24 000) and for major culverts, N$ 53 000 (USD 6 600). The estimated maintenance costs per urgency category are shown in Figure 5 per maintenance region and for Namibia as a whole.

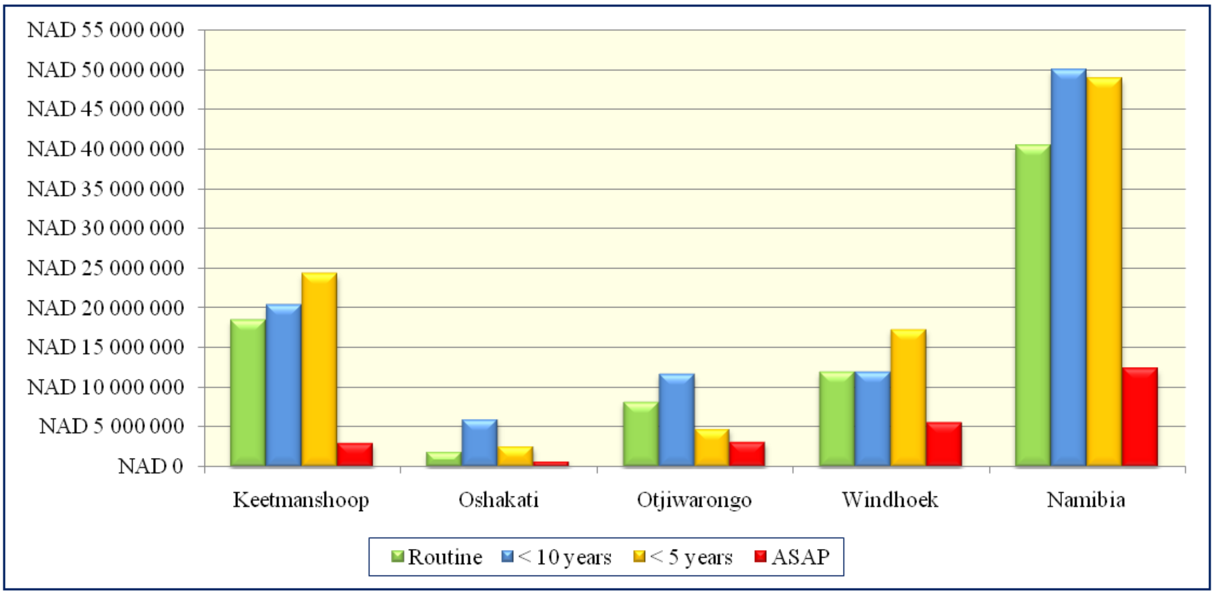

Figure 5. Estimated maintenance costs per urgency category per maintenance region

The estimated maintenance costs (rounded up to the nearest N$ 100 000) for Namibia for the following three maintenance categories are as follows:

Routine maintenance:	N$ 40 600 000 (USD 5 075 000)
Maintenance to be done within the next five years:	N$ 49 000 000 (USD 6 125 000)
Maintenance to be done as soon as possible:	N$ 12 400 000 (USD 1 550 000)

The routine maintenance should be carried out over a period of five years. The maintenance in the ASAP category should be carried out over a two year period together with the maintenance to be done within the next five years.

9. ASSET VALUE

According to the International Infrastructure Management Manual, assets should in general be valued at Fair Value. Fair value is the amount for which an asset can be exchanged between knowledgeable, willing parties (market-type valuation). Where market values cannot be established, a Discounted Cash Flow Analysis on future earnings is used as the basis for valuation. Where market-based evidence cannot be provided (market values or future earnings) the Depreciated Replacement Cost (DRC) is considered the most appropriate basis of valuation.

Bridges, culverts and other road infrastructure assets are specialised assets of a kind which are rarely, if ever, sold on the open market and their potential profitability is not a relevant valuation method. The most appropriate asset valuation method for these assets is therefore the Depreciated Replacement Cost method.

The Replacement Cost is the value of an asset that replicates the existing asset most efficiently, while providing the same level of service. This valuation is based on a reference asset, which is considered to be the closest replacement for the existing asset. The Depreciated Replacement Cost is the optimised replacement cost after deducting an allowance for wear or consumption to reflect the remaining or economic service life of the asset.

The asset value calculation methodology included in the BMS can be classified as a Depreciated Replacement Cost method. The proposed methodology involves determining the replacement cost of an asset and then adjusting (depreciating) this cost according to the age of the structure and the condition of the structure to arrive at the Asset Value (AV).

The current asset value is calculated using the following formula:

$$AV = RC \times l)\text{-}MC$$

Where: AV = *Asset Value in Rand*
RC = *Replacement Cost in Rand*
d = *Percentage Depreciation*
MC = *Maintenance Cost in Rand*

The current asset value of all bridges and major culverts is N$ 3.48 billion (USD 435 million). Overall the asset value for bridges and major culverts is 63 % of the replacement cost. For bridges only it is 62 % and for major culverts 66 %.

10. CONCLUSIONS

The development and implementation of the STRUMAN BMS for the Namibia Roads Authority has placed the NRA in a position to effectively manage the structures on the authority's road network. The first round of principal inspections assisted the NRA to compile an updated inventory of all bridges, major culverts and large culverts on the road network and to determine the condition of each structure. All structures in a critical condition have been identified and can be repaired, or if necessary, replaced. The NRA is now in a position to systematically budget for structure maintenance, repair and rehabilitation. The replacement and current asset values of all structures have been calculated and can be used as a basis to evaluate the effectiveness of future maintenance and rehabilitation actions and strategies.

11. REFERENCE

International Infrastructure Management Manual - Version 3.0, 2006.