CALCULATION OF CONDITION INDICES FOR ROAD STRUCTURES USING A DEDUCT POINTS METHOD

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ABSTRACT

The DER-rating method has been adopted as the national standard for the rating of road structures. This method is defects-based and involves the rating of defects on the various inspections items of road structures in terms of degree (D), extent (E) and relevancy (R) rating. The DER-rating method has been included in the Draft TMH19 Manual for the Visual Assessment of Road Structures. The D, E, and R ratings are used to calculate condition indices for road structures. The method used is a deduct-points approach, similar to what is recommended in the Draft TMH22 Road Asset Management Systems Manual for calculating different condition and need indices for road pavements.

This paper describes the procedure to arrive at a Priority Condition Index (PCI) that identifies those structures with critical defects that should receive urgent attention, using the D, E and R ratings allocated to defects during the visual assessment of the structure.

For road structures, defects are identified per inspection sub-item and the worst defect on a sub-item is rated, which then becomes the rating for that inspection sub-item. The sub-item DER ratings are used as input to calculate deduct points for the sub-item. These sub-item deduct points are then used as input to calculate a PCI for the sub-item. The worst sub-item PCI value determines the condition index for an inspection item. Finally, the condition indices of the inspection items are used to calculate the PCI for the whole structure. The PCI value ranges from 0 (worst condition) to 100 (best condition). The structure's PCI determines what condition category the structure falls in. Five condition categories, namely "Critical"; "Poor", "Fair", "Good"; or "Very Good", are used.

1 INTRODUCTION

The problems associated with rating systems that use weighted ratings for different defects in road management systems have been recognised for many years. The major problem being that weighting of defects can never overcome the problem of averaging good and poor conditions and ending up with an average result. In addition, minor, but critical defects are often overwhelmed by otherwise generally

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good conditions and reflect a better result that what is required to raise the priority of the structure in the management system.

It is believed that this problem was initially addressed for concrete pavements by Michael I Darter in Illinois and culminated in the publication of the NCHRP Report 277 referenced below. The problem was further addressed by Van Zyl et al in 2012 for road pavements in the Western Cape and led to a substantial revision of the ratings used in the Western Cape Province with results that better represented engineering judgement than the older weighting systems.

This was recognised during the development of the Draft TMH22 Road Asset Management Systems Manual (COTO, 2013) where the Deduct Points Method (DPM) is the recommended method for calculating condition indices for road pavements in South Africa.

The above problems associated with weighting methods also occur when rating structures such as bridges, culverts, retaining walls and tunnels (referred to as road structures) and this paper describes an updated DPM method for calculating the Priority Condition Index of a structure using the visual ratings allocated to the various defects that are observed.

2 RATING OF DEFECTS ON ROAD STRUCTURES USING THE DER RATING METHODOLOGY

Road structures are rated using a defects-based system as described in TMH19 Visual Assessment of Road Structures. This defects based system has been in use for more than 20 years, but only became the standard rating method for road structures in 2012. Structures are visually rated by structural engineers, with design experience in the type of structure being rated, using DER ratings of 1 to 4 as follows:

D = **D**egree of defect:	How bad or severe is the defect.
E = **E**xtent of defect:	How widespread is the defect on the inspection item being inspected.
R = **R** relevancy of defect:	The consequence of the defect with regards the structural/functional integrity of the inspection item or the safety of the user of the structure.

For inspection purposes, each type of structure is divided into inspection items, which are individual elements of the structure, such as deck slabs, deck expansion joints, abutments, piers and foundations, and items associated with the structure type, such as waterways. These inspection items are subdivided into sub-items where appropriate, such as North and South abutment or Pier 1, 2 and 3 for a bridge with 3 piers.

These ratings are done at an inspection item, or sub-item level where applicable, and only the worst defect on the item is rated. If a defect is present, the rating values allocated for D, E and R are 1; 2; 3; or 4. If no defect is present, D is allocated a value of 0 and E and R are not rated.

The permissible DER rating values are defined in Table 1.

Table 1: Permissible D/E/R rating values

Rating	D (Degree)	E (Extent)	R (Relevancy)	
X	Not applicable			
U	Unable to inspect			
0	No visible defects			
1	Minor	Local	Minimum	No structural integrity or safety issues
2	Moderate	More than local	Moderate	Some possible structural integrity or safety issues
3	Warning	Less than general	Major	Structural integrity or safety compromised
4	Severe	General	Critical	Potentially a serious impact on structural integrity and/or user safety

A restriction is placed on the R-rating in that it cannot be more than one point higher than the D-rating. Certain D & R combinations are therefore not valid, as indicated in Table 2.

Table 2: Valid Degree and Relevancy Combinations

D&R	R=1	R=2	R=3	R=4
D=1	1;1	1;2	Not valid	Not valid
D=2	2;1	2;2	2;3	Not valid
D=3	3;1	3;2	3;3	3;4
D=4	4;1	4;2	4;3	4;4

3 DEDUCT-POINTS METHOD FOR ROAD STRUCTURES

3.1 Introduction

The deduct method used in road pavements is relatively simple and involves computing deduct points for each type of distress and deducting a combination of these points for the 6 most significant distress manifestations from the maximum condition of 100. A set of deduct points is computed for each rated distress depending on the influence that, that distress is adjudged to have on the overall condition of the pavement asset. Different deduct values are allocated to each type of distress to include the relative weight of that type of distress on the overall condition of the pavement. For example, in a road pavement crocodile cracks are typically more significant with respect to structural condition than large block cracks and have more deduct points for the same rating of degree and extent. This is shown in Table 3 where the maximum deduct points for crocodile cracks at a rating of 5;5 are 80 while for block cracks it is only 65. The spread of deduct points across the

range of values of degree and extent can also differ and reflect the significance of the distress at various levels of condition.

Table 3: Example of deduct points for crocodile and block cracks in road pavements

	Crocodile Cracks				
	Few		<-- Extent -->		Many
Degree	**1**	**2**	**3**	**4**	**5**
1	4	12	16	21	28
2	12	18	24	30	35
3	15	30	40	50	58
4	21	50	60	67	75
5	25	55	70	75	80

	Block Cracks				
	Few		<-- Extent -->		Many
Degree	1	2	3	4	5
1	6	12	14	18	25
2	9	21	25	29	35
3	15	30	35	40	45
4	18	35	50	55	60
5	21	40	55	60	65

The distress manifestations are ranked in order of highest to lowest deduct points and a combination of the top 6 is deducted from the maximum condition index of 100. In this way a minor amount of significant distress, with the highest number of deduct points, can reflect its true effect on the Condition Index and not be ameliorated by being averaged with very little distress elsewhere.

With structures, the situation is somewhat different as structures have many items and sub-items that need to be inspected (inspection items), each with their own unique manifestations of distress and influence on the overall condition of the structure. Structures with critical defects that should receive urgent attention need to be identified. The items and sub-items of the structure are inspected and the defects identified on each item or sub-item and the effect of these defects on the structural integrity and/or safety of road users needs to be reflected by the overall condition index. For example, a bridge with a crack with a DER rating of 4;4;4 in the bridge deck must have a higher priority for attention than a bridge with a 4;4;4 crack in a wing wall and should therefore have a lower condition index.

Therefore, it was decided to use a single set of deduct values for each item/sub-item depending on its DER rating and to subsequently weigh the deduct points in accordance with the significance of that item on the structure's priority for repairs or rehabilitation. The deduct points for the 5 worst items are then combined as described below and subtracted from 100 to determine the Priority Condition Index (PCI) of the structure. The PCI calculated using the Structure Deduct Points Method (SDPM) is used to identify structures with critical defects that should receive urgent attention.

Prior to adopting the deduct method, the PCI for structures was calculated by combining the condition indices calculated at item/sub-item level through a process involving forced, ignored and normal items and bands of index values. This method did give PCI values that could be used to identify structures with critical defects that should receive urgent attention, but in some cases led to the averaging good and poor conditions and ending up with an average result. This was especially the case where the forced items (such as deck items; piers, and abutments) had very few defects. The PCI values also tended to be on the high side, but with experience it

was known that any structure with a PCI value of less than 70 had to be considered for maintenance or rehabilitation work. This caused problems when presenting results to non-engineering stakeholders, as a structure with a condition of 70% would be considered to be in a fair to good condition by the average person.

3.2 General Description of the Deduct-points Method for Road Structures

The first step in the calculation of the PCI is to determine the deduct points at an inspection sub-item level, for example, for each of 3 piers. The deduct points for the sub-item that is in the worst condition (highest deduct points), is selected to reflect the deduct points for that item. In the above example, the worst pier with the highest deduct points is representative of all the piers supporting the bridge.

Secondly, the deduct points for all the items are weighted to reflect their relative effect on the overall structure's condition.

Finally, the PCI for the whole structure is calculated, in the same way as for pavements, by subtracting the 5 highest weighted deduct points from 100. The resulting PCI ranges from 0 (worst condition) to 100 (best condition). Based on the PCI value, the structure is allocated to one of the five condition categories described in Table 3.

Table 4: Condition and functional categories (as defined in Table E1 in the Draft TMH22)

Condition Category	Index Range	Condition Category Description	Functional Category Description	Colour Code
Very Good	85 - 100	Asset is still like new and no problems are expected.	Good service levels at all times	Blue
Good	70 – 85	Asset is still in a condition that only requires routine maintenance to retain its condition.	Mostly good service levels with isolated problems occurring at certain times.	Green
Fair	50 – 70	Some clearly evident deterioration and would benefit from preventative maintenance or requires renewal of isolated areas.	Reasonable service but with intermittent poor service.	Orange
Poor	30 – 50	Asset needs significant renewal or rehabilitation to improve its structural integrity	Generally poor service levels with occasional very poor service being provided.	Red
Critical	0 - 30	Asset is in imminent danger of structural failure and requires substantial renewal or upgrading with less than 10% of EUL remaining.	Very poor service levels at most times.	Purple

3.3 Calculation of Deduct Points for an Inspection Sub-item (dpij)

Equation 1 is used to calculate the deduct points at inspection sub-item level, using the DER rating of the worst defect on that inspection sub-item.

$$dp_{ij} = DP_{max} \times \frac{(k_d \times D + k_e \times E) \times R^a}{b_p}$$ **Equation 1**

where:

dp_{ij}	=	*calculated deduct points for inspection sub-item j of item i;*	
DP_{max}	=	*maximum deduct points per inspection sub-item*	
	=	*75 (agreed value)*	
D	=	*degree rating for inspection sub-item j of item i;*	
E	=	*extent rating for inspection sub-item j of item i;*	
R	=	*relevancy rating for inspection sub-item j of item i;*	
k_d	=	*degree factor*	*= 1**
k_e	=	*extent factor*	*= 0.25**
a	=	*relevancy exponent*	*= 1.5**
b_p	=	$(k_d \times D_{max} + k_e \times E_{max}) \times R_{max}^a$	
	=	$(k_d \times 4 + k_e \times 4) \times 4^a$	
	=	$(1 \times 4 + 0.25 \times 4) \times 4^{1.5}$	
	=	*40 (using agreed values for k_d, k_e and a*	

Note * The three factor values k_d, k_e and a have been assigned based on studies that were carried out to correlate structure conditions as expressed by the PCI with engineering judgement.

Equation 1 is a slight modification of the equation that has been used previously to calculate the condition index at sub-item level. The original equation was refined based on studies that were carried out to correlate sub-item conditions as calculated with engineering judgement. The original equation has been in use for more than 20 years.

The values calculated for dp_{ij} can range from 75 for DER = 4;4;4, i.e. the worst condition, to 100 for D = 0 (no defect), i.e. the best condition.

The deduct points for the various combinations of DER, calculated using Equation 1, are presented in Table 5. With the requirement that R cannot be more than one point higher than D, certain DER combinations are not possible and these have been left blank in Table 4. Using the five condition categories defined in Table 3 the deduct-points in Table 4 have been highlighted to show what condition category they represent.

Table 5: Deduct points per R rating for valid DER rating combinations

D	E	R				D	E	R			
		1	2	3	4			1	2	3	4
1	1	2	7			2	1	4	12	22	
	2	3	8				2	5	13	24	
	3	3	9				3	5	15	27	
	4	4	11				4	6	16	29	
3	1	6	17	32	49	4	1	8	23	41	64
	2	7	19	34	53		2	8	24	44	68
	3	7	20	37	56		3	9	25	46	71
	4	8	21	39	60		4	9	27	49	75

3.4 Calculation of Weighted Deduct Points for an Item (DPi)

To calculate the deduct points for an item, the deduct points for the sub-item with the highest value only is used. This value is then weighted to reflect this item's importance relative to all the other items that make up the structure, on a scale of 0 to 5. The agreed item weights for the various road structures are included in the Draft TMH22 and an example of the weights for the 21 items that are inspected on a typical bridge are presented in Table 6.

Table 6: Inspection Item Weights for a Bridge (General)

Inspection Item		Weight
No.	Description	
01	Approach Embankment	2
02	Guardrail	0
03	Waterway	2
04	Approach Embankment Protection Works	2
05	Abutment Foundations	5
06	Abutments	5
07	Wing/ Retaining Walls	4
08	Surfacing	1
09	Super-structure Drainage	1
10	Kerbs / Sidewalks	1
11	Parapet	3
12	Pier Protection Works	1
13	Pier Foundations	5
14	Piers & Columns	5
15	Bearings	3
16	Support Drainage	1
17	Expansion Joints	2
18	Longitudinal Members	5

Inspection Item		Weight
No.	Description	
19	Transverse Members	3
20	Decks & Slabs	5
21	Miscellaneous Items	0

The overall weighted deduct points for each item, that reflects its contribution to the PCI of the structure, are calculated using Equation 2.

$$DP_i = \frac{w_i}{w_{max}} \times dp_{imax} \qquad \textbf{Equation 2}$$

where:

DP_i = *The weighted deduct points for inspection item i;*

w_i = *weight for inspection item i;*

w_{max} = *highest weight for the inspection items making up the structure type – typically 5;*

dp_{imax} = *deduct points for the inspection item i; in the case of multiple sub-items this is set equal to the maximum deduct points to reflect the sub-item in the worst condition.*

As illustration of the use of Equation 2, the possible deduct points for the various combinations of DER have been calculated for the various inspection item weights and these results are presented in Table 7.

Table 7: Deduct Points for Valid DER Combinations per Item Weight

D	E	R	Item Weight (w_i)					
			0	1	2	3	4	5
			Weighted Item Deduct Points (DPi)					
1	1	1	0	0	1	1	2	2
1	2	1	0	1	1	2	2	3
1	3	1	0	1	1	2	3	3
1	4	1	0	1	2	2	3	4
2	1	1	0	1	2	3	3	4
2	2	1	0	1	2	3	4	5
2	3	1	0	1	2	3	4	5
2	4	1	0	1	2	3	5	6
3	1	1	0	1	2	4	5	6
3	2	1	0	1	3	4	5	7
3	3	1	0	1	3	4	6	7
3	4	1	0	2	3	5	6	8
4	1	1	0	2	3	5	6	8
4	2	1	0	2	3	5	7	8
4	3	1	0	2	4	5	7	9
4	4	1	0	2	4	6	8	9
1	1	2	0	1	3	4	5	7
1	2	2	0	2	3	5	6	8
1	3	2	0	2	4	6	7	9
1	4	2	0	2	4	6	8	11

D	E	R	Item Weight (w_i)					
			0	1	2	3	4	5
			Weighted Item Deduct Points (DPi)					
2	1	2	0	2	5	7	10	12
2	2	2	0	3	5	8	11	13
2	3	2	0	3	6	9	12	15
2	4	2	0	3	6	10	13	16
3	1	2	0	3	7	10	14	17
3	2	2	0	4	7	11	15	19
3	3	2	0	4	8	12	16	20
3	4	2	0	4	8	13	17	21
4	1	2	0	5	9	14	18	23
4	2	2	0	5	10	14	19	24
4	3	2	0	5	10	15	20	25
4	4	2	0	5	11	16	21	27
2	1	3	0	4	9	13	18	22
2	2	3	0	5	10	15	19	24
2	3	3	0	5	11	16	21	27
2	4	3	0	6	12	18	23	29
3	1	3	0	6	13	19	25	32
3	2	3	0	7	14	20	27	34
3	3	3	0	7	15	22	29	37
3	4	3	0	8	16	23	31	39
4	1	3	0	8	17	25	33	41
4	2	3	0	9	18	26	35	44
4	3	3	0	9	19	28	37	46
4	4	3	0	10	19	29	39	49
3	1	4	0	10	20	29	39	49
3	2	4	0	11	21	32	42	53
3	3	4	0	11	23	34	45	56
3	4	4	0	12	24	36	48	60
4	1	4	0	13	26	38	51	64
4	2	4	0	14	27	41	54	68
4	3	4	0	14	29	43	57	71
4	4	4	0	15	30	45	60	75

3.5 Calculation of Deduct Points for a Structure (DPS) and the Priority Condition Index of the Structure (PCI)

To calculate the deduct points for the structure, the five inspection items with the highest deduct points are used and DP_S is calculated using Equation 3:

$$DP_S = DP_{i1} + a \times DP_{i2} + b \times DP_{i3} + c \times DP_{i4} + c \times DP_{i5}$$ **Equation 3**

where:

DP_S = *total deduct points for the structure;*

DP_{i1} = *deduct points for the inspection item with the highest value (primary inspection item);*

DP_{i2} = *deduct points for the inspection item with the 2nd highest value (secondary inspection item);*

DP_{i3} = *deduct points for the inspection item with the 3rd highest value (tertiary inspection item);*

DP_{i4} = *deduct points for the inspection item with the 4th highest value (first other inspection item);*

DP_{i5} = *deduct points for the inspection item with the 5th highest value (second other inspection item);*

a = *factor for the contribution of the secondary inspection item*

b = *factor for the contribution of the tertiary inspection item*

c = *factor for the contribution of the other inspection items*

Experience in the use of the deduct method in the pavement management field has shown that the contribution of the primary inspection item (highest deduct points) should be taken as the full value (100%); the contribution of the secondary defect should be in the order of 20% to 30% of the its deduct points; the contribution of the tertiary defect should be in the order of 10% of its deduct points; and the contribution of additional defects should not be more than 5% (Van Zyl et al., 2012).

Based on this, the values for the contribution factors for road structures have been chosen as follows:

a = 30%
b = 10%
c = 5%

The PCI for the structure is calculated using Equation 4:

$$PCI = 100 - DP_S$$ **Equation 4**

where:

PCI = *Priority Condition Index of the structure*

DP_S = *total deduct points for the structure;*

The value of PCI ranges from 100 (structure with no defects) to 0 (worst condition).
The theoretical maximum deduct points (DP_S) for a bridge structure would be achieved if five of the inspection items with the highest item weight of 5 all have at

least one inspection sub-item with a defect with a DER rating of 4;4;4. From Table 5, the deduct points (DP_i) for each of these five items would be 75.

Using Equation 3, the deduct points for this structure (DP_S) would be:

$$DP_S = 75 + 0.3 \times 75 + 0.1 \times 75 + 0.05 \times 75 + 0.05 \times 75 = 112.5$$

Using Equation 4, the PCI for this structure would then be:

$$PCI = 100 - 112.5 = -12.5$$

DP_S are however limited to a maximum of 100 points in order not to obtain negative values for PCI.

4 SUMMARY

This paper describes the procedure used to calculate a Priority Condition Index (PCI) that identifies those structures with critical defects that should receive urgent attention. The D, E and R ratings allocated to defects during the visual assessment of the sub-items and items of the structure are combined using a deduct points system similar to what is recommended in the Draft TMH22 Road Asset Management Systems Manual for calculating different condition and need indices for road pavements.

The PCI calculated using the deduct points system has been tested on a number of road authorities' bridge and major culvert inspection data and appears to provide a better and more consistent indication of priority than the earlier methods used. The deduct points system for the calculation of the PCI for road structures described in this paper will be included in the next version of the Draft TMH22 Road Asset Management Systems Manual.

5 REFERENCES

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