Technical Paper

ISSN 1997-1400 Int. J. Pavement Res. Technol. 8(2):123-130

A Comprehensive Analysis for Obtaining Consistent HDM-4 Results: Case Study with a Local Council in Australia

M. U Khan[1] and P. J. Higgins[1]

Abstract: To manage a road network it is vital to have an Asset Management Plan that is consistent and gains the confidence of users and higher management. Muswellbrook Shire Council in Australia is using the Highway Development and Management (HDM-4) as its Pavement Management System (PMS) which is the basis of the Asset Management Plan. Some inconsistencies were observed earlier between HDM-4 results and field. It is essential getting consistent HDM-4 results. The current paper has tried to rectify treatment intervention levels through several HDM-4 runs, site visits and engineering judgment for obtaining sound results. It is observed that treatment decision matrix and data quality are vital HDM-4 inputs. The new and realistic compound standards with treatment intervention criteria have been proposed for urban and rural roads. As a result, the road network is maintained at 5.6 IRI (International Roughness Index, unit is m/km) with A$2 millions ($2 m) per year using 'minimise cost at target IRI' optimisation objective. It is recommended to verify HDM-4 results at site for consistency as there is a time gap between data collection and obtaining analysis results. This is a useful analysis for the asset managers, engineers and planners for obtaining justifiable asset management plan, works program and long-term strategy. Finally, it is suggested that each road authority should have set optimum maintenance standards and strategies derived using HDM-4 in managing their assets.

DOI: 10.6135/ijprt.org.tw/2015.8(2).123

***Key words**: HDM-4; Pavement management system; Treatment intervention levels.*

Introduction

A Pavement Management System (PMS) ensures efficient management of road assets. It provides cost-effective decisions on the allocation of fund for better road maintenance [1, 2]. Therefore, a PMS has been introduced in different road authorities. The system has five major components, i.e., data collection, database, decision-making tools for programming and prioritization, implementation procedures and feedback [3, 4]. It is noted that a PMS is a complete mechanism for pavement maintenance management.

One of the key components of a PMS is use of a road deterioration prediction model and economic analysis tool for obtaining sound decisions. The Highway Development and Management (HDM-4) model is a very useful economic tool for conducting life-cycle cost-benefit analysis that can also predict pavement performance [5]. The model was developed by the World Bank and some other international institutes, and is being used over hundred countries in the world. A pavement's performance (deterioration vs. time) in its life-cycle is generated through the model. Moreover, it assesses all the alternatives to select the best economic solution after reviewing several economic indicators, i.e., Net Present Value (NPV), NPV/Cost, Internal Rate of Return (IRR), etc. It can do detailed project and network level economic analysis, optimisation and prioritisation of work program.

The Muswellbrook Shire Council of New South Wales in Australia is pioneer in using HDM-4 at the local government environment in managing tertiary and access roads. The council has started using HDM-4 model as a PMS tool over the last three years. The model has been calibrated for Muswellbrook [6].

The Muswellbrook Shire council has about 625 km of road network of which about 85% are paved. It implements yearly Routine Maintenance (RM), renewal and capital works to manage its asset. However, it has been noticed that HDM-4 results are not always consistent with the treatments undertaken. Consistency of HDM-4 results is crucial for proper planning and programming, as well as ensuring appropriate investment. Therefore, a comprehensive analysis has been carried out recently to improve HDM-4 results.

The current paper has aimed to show the process in obtaining sound asset management program using HDM-4. This is useful for road asset management practitioners.

Detailed Analysis:

It is observed that consistency of HDM-4 results relate to reliable data, calibration factors and treatment intervention criteria [7, 8]. In this analysis, all these parameters and HDM-4 results were reviewed using engineering judgment and site visits. Therefore, numerous HDM-4 runs have been undertaken to obtain better results.

The overall analysis may be divided into several phases, which are discussed below.

Phase-1:

As calibration of HDM-4 was done in 2012, it seems a re-calibration may not require now. Therefore, at the beginning, calibration factors were considered acceptable. In addition, data

[1] Muswellbrook Shire Council, NSW, Australia.

[+] Corresponding Author: E-mail Misbah.Khan@muswellbrook.nsw.gov.au

Note: Submitted July 13, 2014; Revised January 19, 2015; Accepted January 20, 2015.

quality was assumed acceptable as council obtained data collected in 2012 through outsourcing. Khan observed that outsourced data quality is generally unbiased and reliable [8]. Therefore, treatment intervention criteria have been modified for initial HDM-4 runs. The analysis starts with the following 15 treatment alternatives, as practiced.

- RM:
    - pothole patching @ ≥ 10 no./km
    - Cracking sealing @ ≥ 5% wide structural cracking
    - Edge repair @ ≥ 5 m^2/km edge break
- Spray seal 7 mm @ 5 IRI
- Spray seal 7 mm @ 6 IRI
- Spray seal 7 mm @ 7 IRI
- Resealing 10 mm @ 5 IRI
- Resealing 10 mm @ 6 IRI
- Resealing 10 mm @ 7 IRI
- Resealing 14 mm @ 5 IRI
- Resealing 14 mm @ 6 IRI
- Resealing 14 mm @ 7 IRI
- Resealing 14 mm @ 8 IRI
- Overlay 40 mm @ 6 IRI
- Overlay 40 mm @ 7 IRI
- Overlay 40 mm @ 8 IRI
- Reconstruction @ 12 IRI

The different groups of road network are maintained at set standards based on roughness, which is termed here as International Roughness Index (IRI in m/km). Generally, different treatments are considered at set standards to get an optimum one.

Fifteen urban sealed roads have been chosen to assess this exercise where rehabilitation has been identified in 2014 by the Roads and Drainage Unit of the council. The roads are Market St, Victoria St, Mitchell St, Palace St, Lorne St, St. Heilers St, Francis St, Brook St, Anzac Pde, Skelletar St, Hill St, Ford St, Hunter Tce, King St and Sowerby St. It covers six road groups (totalling 83 road segments) as per the road hierarchy of council based on different traffic loading and mine affected roads.

The detailed analysis results with several HDM-4 runs are shown in the Table 1 *b*elow, which indicates an improvement of HDM-4 results after modifying treatment intervention criteria. For example, run-4 has produced a reliability of 76.1%, as 35 segments have

Table 1. Reliability of HDM-4 Results at Phase-1.

No. of HDM-4 Runs	Criteria	Planned Rehabilitation (Segment No.)	Predicted Rehabilitation (Segment No.)	Reliability of HDM-4 Results
Run-1	Base Case: Reconstruction @ 12 IRI Ideal: RM + Spray Seal 7 mm + Resealing 10 mm + Resealing 14 mm + Overlay 40 mm + Reconstruction @ 12 IRI	46	23	50.0%
Run-2	Base Case: Reconstruction @ 12 IRI Ideal: RM + Spray Seal 7 mm + Resealing 10 mm + Resealing 14 mm + Overlay 40 mm + Rehabilitation 100 mm with Mill & Replace + Reconstruction @ 12 IRI Note: • Rehabilitation 100 mm with Mill & Replace was Used @ 6 IRI and 7.5 mm Rutting. • Both Overlay 40 mm & Rehabilitation 100 mm with Mill & Replace were Considered for Rehabilitation.	46	33	71.7%
Run-3	Base Case: Reconstruction @ 12 IRI Ideal: RM + Spray Seal 7 mm + Resealing 10 mm + Resealing 14 mm + Overlay 40 mm + Rehabilitation 100 mm with Mill & Replace + Reconstruction @ 12 IRI Note: • Roughness and Total Carriageway Cracking of ≥ 10% were Used to Trigger Spray Seal 7 mm, Resealing 10 mm and Resealing 14 mm. • Both Overlay 40 mm & Rehabilitation 100 mm with Mill & Replace were Considered for Rehabilitation.	46	35	76.1%
Run-4	Base Case: Reconstruction @ 12 IRI Ideal: RM + Spray Seal 7 mm + Resealing 10 mm + Resealing 14 mm + Overlay 40 mm + Rehabilitation 100 mm with Mill & Replace + Reconstruction @ 12 IRI Note: • Roughness, Rutting, Cracking, Deflection and Structural Number (SN) Data were Checked. • Actual Deflection Data for 36 Segments were Used. • Both Overlay 40 mm & Rehabilitation 100 mm with Mill & Replace were Considered for Rehabilitation.	46	35	76.1%

Table 2. Treatment Effects for Rehabilitation 100 mm with Mill & Replace and Overlay 40 mm.

Treatment Name	Roughness		Deflection at Centre of Loading		SN to Represent Pavement Structural Strength	
	Before Treatment	After Treatment	Before Treatment	After Treatment	Before Treatment	After Treatment
Rehabilitation 100 mm with Mill & Replace	8.0 IRI	2.0 IRI	0.91 mm	0.27 mm	3.39	7.33
Overlay 40 mm	8.0 IRI	5.0 IRI	0.91 mm	0.70 mm	3.39	4.01

consistent results compared to previously planned rehabilitation finalised from field visits and engineering judgment. HDM-4 uses minimum two alternatives for an analysis, i.e., without project/base case and with project/ideal case. The ideal case covers all the above treatments-standards alternatives as a compound standard.

Phase-2:

After the above observations, it appears that investigation of treatment effects is necessary to finalise treatment intervention criteria for rehabilitation. Therefore, Hill St segment 3 and Sowerby St segments 6 and 7 were used randomly for assessing rehabilitation treatment effects', namely Rehabilitation 100 mm with Mill & Replace and Overlay 40 mm. The following results were observed which is given in Table 2.

Table 2 indicates that Rehabilitation 100 mm with Mill & Replace can significantly reduce roughness to 2.0 IRI and deflection, and can enhance strength. On the other hand, Overlay 40 mm cannot perform like Rehabilitation 100 mm with Mill & Replace. It indicates that rehabilitation is related to deflection and SN along with roughness.

Therefore, it was assessed whether these factors may be used directly along with roughness for treatment selection. HDM-4 does not have provision to select strengthening overlay with deflection and structural number. Again, structural number vs. time results obtained from HDM-4 outputs does not show a good deterioration trend. However, detailed review of the theories show that roughness and structural cracking are function of numbers; whereas, rutting is linked to deflection. It is worth noting that structural number of a pavement is derived using deflection data.

Therefore, roughness, rutting and structural cracking could be used in choosing a rehabilitation. The previous Table 1 shows that roughness and total carriageway cracking are suitable to select spray seal and resealing treatments.

Table 3. Results to Fix Rehabilitation 100 mm with Mill & Replace.

Segment Name	Planned Treatment	HDM-4 Results			
		Rehabilitation at ≥ 6 IRI and ≥ 7.5 mm Rutting	Rehabilitation at ≥ 6 IRI and ≥ 10 mm Rutting	Rehabilitation at ≥ 6 IRI; ≥ 7.5 mm Rutting and ≥ 5% Structural Cracking	Rehabilitation at ≥ 6 IRI; ≥ 7.5 mm Rutting and ≥ 10% Structural Cracking
Sowerby Street: Segment 6	Overlay 40 mm	Rehabilitation 100 mm with Mill & Replace	Overlay 40 mm	Rehabilitation 100 mm with Mill & Replace	Rehabilitation 100 mm with Mill & Replace
Sowerby Street: Segment 7	Overlay 40 mm	Overlay 40 mm	Overlay 40 mm	Overlay 40 mm	Overlay 40 mm

Table 4. Updated Treatment Intervention Criteria.

Treatment Name	Intervention Criteria
RM	• Pothole Patching at ≥ 10 no./km • Cracking Sealing at ≥ 5% Wide Structural Cracking • Edge Repair at ≥ 5 m^2/km Edge Break
Spray Seal 7 mm	• Spray Seal 7 mm at ≥ 5 IRI and ≥ 10% Total Carriageway Cracking • Spray Seal 7 mm at ≥ 6 IRI and ≥ 10% Total Carriageway Cracking • Spray Seal 7 mm at ≥ 7 IRI and ≥ 10% Total Carriageway Cracking
Resealing 10 mm	• Resealing 10 mm at ≥ 5 IRI and ≥ 10% Total Carriageway Cracking • Resealing 10 mm at ≥ 6 IRI and ≥ 10% Total Carriageway Cracking • Resealing 10 mm at ≥ 7 IRI and ≥ 10% Total Carriageway Cracking
Resealing 14 mm	• Resealing 14 mm at ≥ 5 IRI and ≥ 10% Total Carriageway Cracking • Resealing 14 mm at ≥ 6 IRI and ≥ 10% Total Carriageway Cracking • Resealing 14 mm at ≥ 7 IRI and ≥ 10% Total Carriageway Cracking • Resealing 14 mm at ≥ 8 IRI and ≥ 10% Total Carriageway Cracking
Overlay 40 mm	• Overlay 40 mm at ≥ 6 IRI • Overlay 40 mm at ≥ 7 IRI • Overlay 40 mm at ≥ 8 IRI
Rehabilitation 100 mm with Mill & Replace	• Rehabilitation 100 mm with Mill & Replace at ≥ 6 IRI and ≥ 10 mm Rutting
Reconstruction	• Reconstruction at ≥ 12 IRI

Table 5. Results for the Sealed Roads with Modified Treatment Intervention Criteria.

HDM-4 Runs	Optimisation Objective	Average Network Roughness	Required Budget to Maintain the Network with Renewal and Capital Works at the Average Roughness	
			For Year^{-1}	For Life-Cycle
Run-1	Minimise Cost at Target IRI	4.6 IRI	\$ 19.66 m	\$ 57.82 m
Run-2	Maximise NPV	5.0 IRI	\$ 8.53 m	\$ 31.58 m
Run-3	Minimise dIRI (Incremental Change in Roughness)	4.3 IRI	\$ 19.92 m	\$ 88.39 m

To finalise treatment trigger levels for Rehabilitation 100 mm with Mill & Replace, a number of HDM-4 runs were conducted with Sowerby street segments 6 and 7 by changing roughness, rutting and structural cracking criteria; which results are shown in Table 3.

The above results reveal that Rehabilitation 100 mm with Mill & Replace at ≥ 6 IRI and ≥ 10 mm rutting could produce better results – consistent to the plan. Roughness and rutting can reflect impact of deflection and SN. Therefore, this criterion is selected. As a result, the revised treatment intervention criteria for HDM-4 analysis are given in Table 4.

Phase-3:

After obtaining the treatment intervention levels for all the treatments and using updated deflection data collected in 2013,

Table 6. Key Observations After the Site Visits

Road & Segment Name	Treatment Suggested by HDM-4	Remarks on Site Visits	Consistency of the HDM-4 Results
Brook St.: segments 2 & 3	Overlay 40 mm	High structural cracks. It needs heavy patching or Overlay 40 mm.	Consistent.
Hunter Tce: segment 2	Overlay 40 mm	Overlay 40 mm is all right.	Consistent.
Hunter Tce: segment 4	Overlay 40 mm	A localised depression makes high average roughness. Wrong roughness data, and needs localised heavy patching.	Not consistent.
Ford St: segments 1 & 2	Overlay 40 mm	Overlay 40 mm is all right.	Consistent.
Ford st.: Segments 3 & 4	Overlay 40 mm	Less important Segments, and Hence Overlay is Not Needed Though Analysis is All Right. It seems that Road Hierarchy is Important in Treatment Selection; and Annual Average Daily Traffic (AADT) has to be Added as Criteria to Select Overlay.	Not Consistent (Analysis is Reasonable, But Could not Capture Road Hierarchy).
Hill st: Segment 1	Overlay 40 mm	A Localised Depression Makes High Average Roughness. Wrong Roughness data, and Needs no Treatment because of Low AADT.	Not Consistent.
Hill st.: Segment 3	Overlay 40 mm	Less Important Segment, and Hence Overlay is Not Needed Though Analysis is All Right. It Seems that Road Hierarchy is Important in Treatment Selection; and AADT has to be Added as Criteria to Select Overlay.	Not Consistent (Analysis is Reasonable, but Could not Capture Road Hierarchy).
Hill st.: Segment 5	Rehabilitation 100 mm with Mill & Replace	The Selected Treatment is OK. However, it Serves Only 1/2 Houses and AADT is very Low. In Reality, Only Routine Maintenance is Acceptable and this Segment May be Allowed to Deteriorate.	Not Consistent.
Hill st.: Segment 10	Overlay 40 mm	Localised High Roughness. Wrong Roughness Data and Needs Localised Heavy Patching.	Not Consistent.
Hill st.: Segment 12	Overlay 40 mm	Seems High Potholes and Alligator Cracking Exist. It Seems Damage Area Should be Added in Selecting Overlay or Rehabilitation. Heavy Patching May Suit Better.	Acceptable.
Sowerby st: Segments 1 & 2	Overlay 40 mm	Localised High Roughness. Wrong Roughness Data and Needs Localised Heavy Patching.	Not Consistent.
Sowerby st.: Segments 3, 4 & 6	Overlay 40 mm	Overlay 40 mm is all Right.	Consistent.

some HDM-4 runs were done for the whole sealed road network of Muswellbrook with three different optimisation objectives. Different optimisation objectives are used to manage the network at set standards, which relates to pavement performance and economic results. These objectives provide indication of network's Level of Service based on roughness at long-term with budget requirements. These are very useful information for road network planning and management. The key results are given in Table 5.

Table 5 shows that the highest budget of $88 m or about $4.5 m per year is needed to maintain the road at the best target of 4.3 IRI. At 'the minimise dIRI' objective, the first year budget required is around $20 m that covers backlog removal.

An optimisation analysis was done with $4 m and $5 m budget in year-1 which reveals that the average network roughness will increase to 5.7 IRI due to not using 100% budget. The detailed treatment results are not shown here. All these are vital information for decision-makers.

Phase-4:

It has been noted that a site visit is required to review the HDM-4 outputs after Phase-3 to check consistency. Twenty-six segments were assessed at site by two experienced engineers where 17 segments results were found reliable, which is over 65% consistent. The key observations are shown in the following Table 6.

The site visit was very useful to cross check the HDM-4 results for finalising treatment selection. The key issues for the consistent HDM-4 results observed are as follows:

- Data (any spikes to be removed & quality to be checked);
- Treatment intervention criteria (roughness, rutting, total carriageway cracking, damage area and AADT to be used for decision matrix);
- Road Hierarchy (in treatment selection);
- Road category (urban or rural in treatment selection); and
- Site visits (to finalize treatments and verify HDM-4 results).

A spike due to speed hump, etc. can increase average roughness of a segment, which effect in treatment selection. Therefore, any abnormal jump in roughness needs to be carefully reviewed and eliminated after rectifying data. Table 6 indicates that considering more criteria ensures an appropriate treatment selection. A treatment decision tree matrix may be developed for each road authority to use as input in the HDM-4 analysis. Generally, a road authority has strategy in managing roads based on road hierarchy and locations. Finally, a site visit is needed to cross verify HDM-4 results as there

Table 7. Final Treatment Intervention Criteria and Unit Prices for the Urban Roads.

Treatment Name	Intervention Criteria	Unit Price (A$ /m^2)
Routine Maintenance	▪ Pothole Patching at ≥ 10 no./km	105.00
	▪ Cracking Sealing at ≥ 5% Wide Structural Cracking	13.33
	▪ Edge Repair at ≥ 5 m^2/km Edge Break	58.33
Spray Seal 7 mm	▪ Spray Seal 7 mm at ≥ 5 IRI and ≥ 10% Total Carriageway Cracking	5.50
	▪ Spray Seal 7 mm at ≥ 6 IRI and ≥ 10% Total Carriageway Cracking	5.50
	▪ Spray Seal 7 mm at ≥ 7 IRI and ≥ 10% Total Carriageway Cracking	5.50
Resealing 10 mm	▪ Resealing 10 mm at 5-7 IRI and ≥ 10% Total Carriageway Cracking	6.50
Resealing 14 mm	▪ Resealing 14 mm at 5-8 IRI and ≥ 10% Total Carriageway Cracking	8.50
Overlay 40 mm	▪ Overlay 40 mm at ≥ 6 IRI; > 400 AADT and < 25% Damage Area	30.00
	▪ Overlay 40 mm at ≥ 7 IRI; > 400 AADT and < 25% Damage Area	30.00
	▪ Overlay 40 mm at ≥ 8 IRI; > 400 AADT and < 25% Damage Area	30.00
Overlay 40 mm	▪ Overlay 40 mm at ≥ 6 IRI; > 400 AADT and < 25% Damage Area	30.00
	▪ Overlay 40 mm at ≥ 7 IRI; > 400 AADT and < 25% Damage Area	30.00
	▪ Overlay 40 mm at ≥ 8 IRI; > 400 AADT and < 25% Damage Area	30.00
Rehabilitation 100 mm with Mill & Replace	▪ Rehabilitation 100 mm with Mill & Replace at ≥ 6 IRI; ≥ 10 mm Rutting and ≥ 25% Damage Area	100.00
Reconstruction	▪ Reconstruction at ≥ 12 IRI	125.00

Table 8. Final Treatment Intervention Criteria and Unit Prices for the Rural Roads.

Treatment Name	Intervention Criteria	Unit Price (A$ /m^2)
Routine Maintenance	• pothole Patching at ≥ 10 no./km	105.00
	• Cracking Sealing at ≥ 5% Wide Structural Cracking	13.33
	• Edge Repair at ≥ 5 m^2/km Edge Break	58.33
Spray Seal 7 mm	• Spray Seal 7 mm at ≥ 5 IRI and ≥ 10% Total Carriageway Cracking	5.50
	• Spray Seal 7 mm at ≥ 6 IRI and ≥ 10% Total Carriageway Cracking	5.50
	• Spray Seal 7 mm at ≥ 7 IRI and ≥ 10% Total Carriageway Cracking	5.50
Resealing 10 mm	• Resealing 10 mm at 5-7 IRI and ≥ 10% Total Carriageway Cracking	6.50
Resealing 14 mm	• Resealing 14 mm at 5-8 IRI and ≥ 10% Total Carriageway Cracking	8.50
Rehabilitation 100 mm with Mill & Replace	• Rehabilitation 100 mm with Mill & Replace at ≥ 6 IRI; ≥ 10 mm Rutting and ≥ 25% Damage Area	100.00
Reconstruction	• Reconstruction at ≥ 12 IRI	40.00

Table 9. Results for the Sealed Roads with Finalised Treatment Intervention Criteria.

HDM-4 Runs	Optimisation Objective	Average Network Roughness	Required Budget to Maintain the Network with Renewal and Capital Works at the Average Roughness	
			For Year^{-1}	For Life-Cycle
Run-1	Minimise Cost at Target IRI	5.6 IRI	$ 4.04 m	$ 39.58 m
Run-2	Maximise NPV	6.0 IRI	$ 3.67 m	$ 16.68 m
Run-3	Minimise dIRI	5.2 IRI	$ 3.98 m	$ 60.45 m

is a time gap between data collection and obtaining analysis results.

A considerable result has been obtained at this stage. However, the field visits has encouraged undertaking further analysis for refining the results.

The above observations indicate that roughness data may affect small length segments due to high localised roughness. In addition, road hierarchy and AADT are important in selecting appropriate treatments. Therefore, AADT and damage area are added for overlay, and damage area is included for rehabilitation. It is also noted that urban and rural roads should have separate standards. The finally selected treatment intervention criteria/compound maintenance standards for urban and rural roads are shown in Tables 7 and 8. No overlay is provided to the rural roads. It was finalised with numerous HDM-4 runs, site visits and engineering judgment.

It is believed that these new compound standards with treatment intervention criteria will provide sound HDM-4 outputs as several improvements were done along with detailed site visits. Therefore, similar to Phase 3, three HDM-4 runs were done with three different optimisation objectives which key results are given in Tables 9 and 10. Fig. 1 shows performances of the whole network at these optimisation objectives.

Table 10. Evaluation of HDM-4 Results with Site Visits.

Road & Segment Name	Treatment Suggested by HDM-4 with New Compound Standards	Remarks on Site Visits	Consistency of the HDM-4 Results
Brook St.: Segment 2	Overlay 40 mm	High Structural Cracks. It Needs Heavy Patching or Overlay 40 mm.	Consistent.
Brook St.: Segment 3	None in 2014	High Structural Cracks. It Needs Heavy Patching or Overlay 40 mm.	Not Consistent.
Hunter Tce: Segment 2	Overlay 40 mm	Overlay 40 mm is all Right.	Consistent.
Hunter Tce: Segment 4	Overlay 40 mm	A Localised Depression Makes High Average Roughness. Wrong Roughness Data, and Needs Localised Heavy Patching.	Not Consistent.
Ford st.: Segments 3 & 4	None in 2014	Less Important Segments, and Hence Overlay is not Needed Though Analysis is all Right.	Consistent.
Ford st.: Segments 1 & 2	Overlay 40 mm	Overlay 40 mm is all Right.	Consistent.
Ford st.: Segments 3 & 4	None in 2014	Less Important Segments, and Hence Overlay is not Needed Though Analysis is all Right.	Consistent.
Hill st: Segment 1	None in 2014	A localised Depression Makes High Average Roughness. Wrong Roughness Data, and needs no Treatment because of Low AADT.	Consistent.
Hill st.: Segment 3	None in 2014	Less Important Segment, and Hence Overlay is not Needed Though Analysis is all Right.	Consistent.
Hill st.: Segment 5	None in 2014	In Reality, only Routine Maintenance is Acceptable and this Segment may be Allowed to Deteriorate.	Consistent.
Hill st.: Segment 10	None in 2014	Localised High Roughness. Wrong Roughness Data and Needs Localised Heavy Patching.	Acceptable.
Hill st.: Segment 12	Overlay 40 mm	Seems High Potholes and Alligator Cracking Exist. Heavy Patching May Suit Better.	Acceptable.
Sowerby st: Segments 1 & 2	Overlay 40 mm	Localised High Roughness. Wrong Roughness Data and Needs Localised Heavy Patching.	Not Consistent.
Sowerby st.: Segments 3, 4 & 6	Overlay 40 mm	Overlay 40 mm is all Right.	Consistent.

The optimisation objective ‘minimise cost at target IRI’ provides that about $2 m is needed in each year to keep the road network at 5.6 IRI. The previous analysis results given in Table 5 reveals that about $3 m is required for keeping the network at 4.6 IRI with the same optimisation objective. The final analysis will maintain the network with relaxed standard, and hence fewer budgets are needed.

Table 6 reveals that about 53% results are acceptable after site verification. In the final analysis, new compound standards separately for urban and rural roads with treatment intervention criteria are used, which shows around 80% results are consistent. Some wrong treatment selection due to less important road and AADT has been overcome. Therefore, it appears that new treatment intervention criteria are useful. Finally, localised depression or roughness jump may be noted, and these roads’ treatments could be finalised after site visits along with the HDM-4 results.

Conclusions

Appropriate road investment can ensure efficient asset preservation. However, if a wrong treatment is given at wrong time and place, it would be costly to the community. As a result, the investment decision model like HDM-4 results must be reliable for finalizing work program of a road network. Muswellbrook Shire council has been using HDM-4 for efficient road asset management. However, some inconsistencies were found between HDM-4 results and field. Therefore, it is vital getting consistent HDM-4 results.

The current paper has tried to rectify treatment intervention levels through several HDM-4 runs, site visits and engineering judgment for obtaining sound results. The previous treatment trigger levels were simplistic in nature and mainly based on roughness and AADT. However, it seems that they do not always capture real criteria to select a treatment. The new and realistic compound standards with treatment intervention criteria have been proposed for urban and rural roads. This is a useful analysis for the asset managers, engineers and planners for obtaining justifiable asset management plan, works program and long-term strategy.

Using the improved treatment intervention criteria and engineering judgment, numerous HDM-4 runs have given reliable results, which were done in four phases. It was deemed necessary to visit sites to see the consistency of results. As a result, it reveals that AADT has to be added as a criterion for treatment selection as it links to road hierarchy. In addition, damage area is another factor that triggers for overlay and rehabilitation. Therefore, in the final Phase, the finalised compound standards with treatment intervention criteria for urban and rural roads have been used for the whole seal road network. It has provided the soundest outputs at the end.

The Phase 3 and 4 used two set of treatment intervention levels considering several factors for each treatment. The complex finalised criteria show that a treatment may not be given if all the criteria are not met. As a result, the road network is maintained at 5.6 IRI with $2 m per year using ‘minimise cost at target IRI’ optimisation objective. If no. of criteria is reduced, then a treatment will be chosen more frequently and the network can be maintained at 4.6 IRI with $3 m per year.

It is observed that any abnormal jump in roughness due to spikes needs to be carefully reviewed and eliminated after rectifying data. A treatment decision tree matrix may be developed for each road authority using pavement structural and functional criteria. Finally, a site visit is needed to cross verify HDM-4 results as there is a time gap between data collection and obtaining analysis results. In

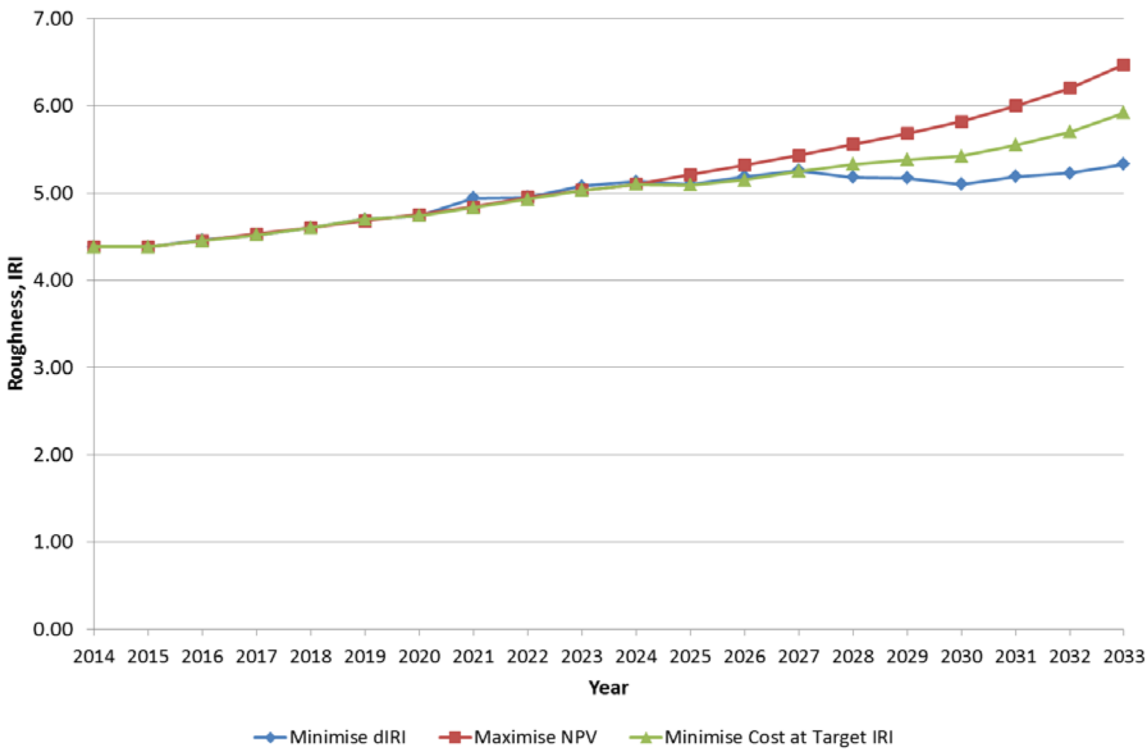

Fig. 1. Performances of the Whole Sealed Road Network with Different Optimisation Objectives.

addition, it is recommended that each road authority should have set optimum maintenance standards and strategies derived using HDM-4 in managing their assets.

Reference

1. Haas, R., Hudson, W.R., and Zaniewski, J. (1994). *Modern Pavement Management*. Krieger Publishing Co., Malabar, Fla, USA.
2. Robinson, R., Danielsson, U., and Snaith, M.S. (1998). *Road Maintenance Management: Concepts and System*. Macmillan, Basingstoke, Hampshire, UK.
3. Paterson, W.D.O. (1987). Road Deterioration and Maintenance Effects: Models for Planning and Management. *Vol. III, The Highway Design and Maintenance Standards Model (HDM-III)*, World Bank, Washington, DC, USA.
4. Battiato, G., Ame, E., and Wagner, T. (1994). Description and Implementation of RO.MA, for Urban Road and Highway Network Maintenance. *Proceedings of the 3rd International Conference on Managing Pavement*, San Antonio, Texas, USA.
5. ISOHDM (2003). *Highway Development and Management Model: Version 1.3*. World Road Association, ISOHDM, PIARC, Paris, France.
6. Rashid, M.M., Rooth, H., and Higgins, P. (2013). Pavement Management System in Australian Local Government Organisations: A Case Study of Muswellbrook Shire Council. *Proceedings of the 8th Australian Road Engineering and Maintenance Conference,* Melbourne, Australia.
7. Khan, M.U. (2007). An Analysis to Improve HDM-4 results in Bangladesh. *Road and Transport Research Journal, ARRB*, Australia, 16(2), pp. 29-49.
8. Khan, M.U. (2007). A Review of HDM-4 Outputs in Bangladesh. *Proceedings of the XXIIIrd World Road Congress*, Paris, France.